ENERGY DEVELOPMENT AND ECONOMIC GROWTH IN INDIA

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ABSTRACT

A dynamic simulation model of the Indian economy has been developed which captures the important linkages between economic growth and the development of various forms of energy. Non-commercial forms of energy which supplied the bulk of total energy requirements of the economy so far have clearly reached their saturation limits. Capital costs for coal and petroleum increase with resource depletion. The cost of hydroelectricity increases as the cheaper and more accessible resources are exhausted. The costs of renewable energy sources such as solar, wind and biomass decrease with cumulative production due to technical progress. Such sources of energy become more important sources in the future though their current share of the total energy production is negligible.

The thesis examines the dynamics of the transition to the new era as well as responses of the economy to energy shocks such as steep increases in international oil prices. It investigates the possibility of an interim crisis if the domestic energy industry is slow to develop or if the response of energy demand to rising energy prices is sluggish. Such a difficult transition may be marked by persistent import dependence, high energy prices and high outlays in the energy sectors that reduce the resources available to the non-energy sectors for consumption and growth.

An aggregate production function utilizing capital, labour and energy as factor inputs has been utilised for the economy along with a neo-classical formulation for consumption and savings in the economy. The model generates the energy demand of the economy endogenously and incorporates the adaptation of energy intensity to rising real energy prices through more efficient new capital equipment as well as retrofits of inefficient equipment.

The model has been calibrated using Indian data. Where parameters or assumptions are based on uncertain facts, sensitivity tests have been carried out. The effect of government policies such as taxation of energy or emphasis on conservation have been investigated.

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1.0 INTRODUCTION

In this paper we describe a model which is intended to examine the links between economic growth and energy development. We consider various forms of energy and the impact of exogenous changes in international oil prices and technology on the various forms. The model uses Indian data, but the features represented have general relevance for many developing countries which are undergoing rapid modernization and transition from non-commercial to commercial forms of energy.

Most previous studies of the energy problem in developing countries have focussed on energy supply and energy demand issues in isolation (19,25). However, the interactions between supply and demand are very important in determining the reaction of the system to exogenous shocks.

The model developed is a highly endogenous model. It considers issues of capital investment, and the effect on energy consumption of the type of capital invested in. The model also allows for modification of existing capital equipment for more energy efficient operation through retrofitting. The rate of investment is constrained by the availability of savings to meet investment needs.

The model is intended to examine shifts in the relative shares of different forms of energy, depletion of fossil fuels and the change in renewable fuel costs. To accomplish this the model has four commercial energy production sectors, representing the production of coal, oil, hydroelectricity and renewables. In addition to commercial energy production the model takes into account the abundant sources of non-commercial energy currently represent a major proportion of energy consumption in developing countries.

The emphasis of the study is on understanding the impact of structural features such as delays in the perception and reaction to events, physical delays such as long construction times for coal and hydroelectric projects and to identify forces that may oppose or dilute policy measures.

The macroeconomic effects of the increase in the real price of imported oil in the 1970's have been examined. The low share of energy in the national output implies that the long-run effect of even significant increases in the real price of energy on GNP will be small. Such crises may take the form of excessive high cost oil imports as well as stagnating of investment flows into non-energy sectors due to high outlays in the energy sectors.

The model has been utilized to explore the impact of taxes and subsidies on the development of various forms of energy. Taxes on an energy source reduce its attractiveness to consumers and hence its share of total energy demand. This ultimately reduces production of that form of energy.

It is seen that conservation policies such as information campaigns and energy audits have a beneficial impact in the short run in reducing the energy demand during the difficult transition, but in the long run, the economy would have made the required adjustments even in the absence of such policies.

The model ignores certain potentially significant concepts such as economic cycles, nominal prices and wages and foreign exchange constraints on imports of energy in the short run. The model also ignores some long-term constraints on growth such as environmental pollution and scarcity of non-energy resources. Such excluded issues are important, but are outside the scope of this study.

2.0 MODEL OVERVIEW

There are five production sectors portrayed in the model, a main production sector and four energy sectors representing coal, petroleum, hydroelectricity and renewables. The main production sector generates the energy demand of the economy which is allocated among the four domestic energy sectors and imports. Actual energy consumption equals energy demand with any gap between energy demand and domestic production being met through imports. The output of the main production sector is allocated among investment in the five production sectors, exports and domestic consumption. The consumption (household) sector generates the savings in the economy which are invested in the form of capital in the five production sectors. Figure 1 shows the key flows among the sectors.

2.1 Exogenous variables: International oil prices are treated as exogenous in the model. Because of the small role that developing countries play in determining world demand domestic developments would have any significant influence on international oil prices. The model also treats as exogenous the labour force in the economy. While energy prices

and availability could influence the employment potential in the economy, this influence is weak in a labour-surplus economy. Technical progress is also exogenous. Sensitivity analysis has been carried out on a plausible range of possible future values of all these exogenous variables.

2.2 Excluded variables: The model deliberately excludes the following concepts and issues to make the task of model building manageable. Since the purpose was to create a simple model to investigate the links between economic growth and energy development, their exclusion was considered justified.

2.2.1 Cycles: The focus of the project is on long-term fundamental linkages between energy development and economic growth. Short run (4-7 year) business cycles, and long waves (40-60 year cycles) (12) have been ignored. Short-lived inventories which have been shown to play a role in business cycles (15) have also been excluded.

2.2.2 Prices and Wages: All prices and costs in the model are expressed in constant 1970-71 prices. Strong government control over the price and wage setting processes in the key sectors of the economy tend to make prices and costs adjust to real changes in exogenous variables such as international oil prices or technical progress.

2.2.3 International Trade: The model assumes trade balance at all times with the economy exporting enough goods and services to pay for the imports of oil. That the economy can and will import all the energy that it needs is certainly a strong assumption. In the short run, foreign exchange constraints may develop as a result of the inability of the economy to divert output from dangerously low consumption levels to exports or to develop an export market in pace with its energy needs. In the long run, the needed adjustments would take place.

2.2.4 Non-energy Constraints: Limits to growth may be imposed on the economy by environmental pollution or by shortages of non-energy resources such as fresh water. Pollution in particular may be closely linked to the rate of energy development and hence could conceivably be important in the long run. Because the work is intened to deal with energy ecoconomy interactions these variables have not been included.

3.0 PRODUCTION SECTOR

3.1 Production Function

Production in this sector constitutes the national output The production function for this sector is hence a key determinant of overall behavior. This sector uses capital, labour and energy as factor inputs. The production function portrays the combination of these factors to produce the output of the economy. While labour is specified exogenously, capital and energy are endogenously determined in the model. The model uses a two-level nested CES production function (see Figure 2) for the long-run potential production: (1)

$$PP_t = RP*(ELF_t/RL)^{LEXP}(EK_t/IC)^{CEXP}$$

$$EK_t = IC*\left[(1-RVSEC)(C_t/IC)^{-ESP} + RVSEC(ERC\ /REC)^{-ESP}\right]^{(-1/ESP)}$$

$$ESP = (1-ESE)/ESE$$

where
- PP -- Potential Production
- RP -- Reference Production
- ELF -- Effective Labour Force
- RL -- Reference Labour
- EK -- Effective Capital
- IC -- Initial Capital
- LEXP -- Share of Labour in Output
- CEXP -- Share of Capital in Output
- RVSEC-- Share of Energy in Output
- ESE -- Elasticity of Substitution between Energy and Capita
- ERC -- Energy Requirements of Capital
- REC -- Reference Energy Consumption
- C -- Capital

A Cobb-Douglas formulation implying unit elasticity of substitution between effective capital and effective labour is used in the equation for potential production (PP). Empirical investigations have tended to support near-unit elasticities between these inputs. (7) There is however considerable uncertainty with regard to the elasticity of substitution between capital and energy (ESE), one of the most important parameters in modelling energy-economy interactions. (8) A CES formulation has hence been chosen in the equation for effective capital (EK) so that the sensitivity of results to the elasticity can be tested.

3.2 Capacity utilization in production.

$$PR_{it} = PP_{it} * CU_{it}$$

$$CU_{it} = f(DP_{it}/PP_{it}) \quad \text{(see Figure 3)}$$

where
- PR -- Production in sector
- PP -- Potential Production in sector
- DP -- Desired Production in sector

Since it takes time to change potential production, the model allows for variable utilization of existing capacity in all production sectors. Capacity utilization is determined by comparing desired production with potential production. When desired production (DP) exceeds potential production (PP), capacity utilization increases due to use of overtime and extra shifts, but at a diminishing rate because of constraints on such increases in capacity utilization. Similarly when DP drops below PP, capacity utilization is reduced, but less than proportionately, reflecting a desire for stability of output.

3.3 Investment Function

$$CAPITAL_t = CAPITAL_0 + \int_0^t (KAR_t - KDR_t)\, dt$$

$$KDR_t = CAPITAL\ /\ ALK$$

where
- ALK -- Average Life of Capital

The investment function seeks to capture the pressures, constraints and decision rules that lead firms in the five production sectors to adjust capital stocks towards percieved optimal levels. Figure 4 depicts the formulation for the investment function (23) used in the model. Capital stock in the sector (CAPITAL) is increased through acquisitons (KAR) and reduced through discards (KDR).

A third order exponential delay is assume for construction with a total construction period of KCT years. Capital construction initiation rate (KCIR) is given by the ratio of the backlog of orders of capital(UOK) to the delivery delay in the economy (DDG).

Backlog (UOK) is increased by capital order rate (KKOR) and reduced by KCIR.

KAR_t = DELAY3P(KCIR ,KCT)

$KCIR_t = UOK_t/DDG_t$

$UOK_t = UOK_0 + \int_0^t (KKOR_t - KCIR_t)\,dt$

Capital Order rate (KKOR) equals the discard rate of capital (KDR) corrected for the following factors:

a)correction for growth (XGK)

b)correction for the stock under construction (XKUC)

c)correction for the backlog of orders in the supply line (XBK)

d)correction for desired capital (XK).

$KKOR_t = KDR_t * f\ (TXK_t)$

$TXK_t = (XGK_t + XKUC_t + XBK_t + XK_t)/KD_t$

KKOR is however constrained to be positive regardless of how negative the pressure to adjust production (TXK) becomes.

The managers obtain their signals to increase or decrease capital intensity by comparing the marginal revenue product of capital with its marginal cost. Information on marginal productivity can, however, be gained only through experimentation and comparison of operating results with different factor proportions.

$RPC = MPC/MCC = (\partial(PP)/\partial C)/(IR + (1/ALC))$

where

- RPC -- Relative Productivity of Capital
- MPC -- Marginal Productivity of Capital
- MCC -- Marginal Cost of Capital
- PP -- Potential Production
- IR -- Real Interest Rate
- ALC -- Average Life of Capital

The effect of relative productivity on desired capital as well as desired energy intensity is specified as a non-linear function (NTERPI).

4.0 ENERGY DEMAND

4.1 Desired Energy Consumption

The energy consumption of the economy is tied to the existing capital stock. The model includes a mechanism for retrofits that permits partial

366 upgrading of the energy efficiency of existing capital equipment to the level of efficiency of new equipment.

$DEC_t = ERC_t * SCU_t$

$ERC_t = ERC_0 + \int_0^t (IERC_t + RERC_t - DERC_t)\,dt$

$DERC_t = EIC_t * CDR_t$

$PEIR_t = RPFE * EINI_t + (1-RPFE)\ NEIC_t$

$NEIC_t = NERC_t / C_t$

$NERC_t = NERC_0 + \int_0^t (IERC_t - NEIC_t * CDR_t)\,dt$

$IERC_t = EICUC_t * CAR_t$

$EICUC_t = ERCUC_t / CUC_t$

$ERCUC_t = ERCUC_0 + \int_0^t (EINI_t * CCIR_t - IERC_t)\,dt$

$EINI_t$ = SMOOTH ($DEIC_t$,NTAEII)

$DEIC_t = EIC_t * ERPE_t$

where

- EIC -- Energy Intensity of Capital
- PEIR -- Potential Energy Intensity Through Retrofit
- EICUC -- Energy Intensity of Capital Under Construction
- ERCUC -- Energy Requirements of Capital Under Construction
- CCIR -- Capital Construction Initiation Rate
- CAR -- Capital Acquisition Rate
- CDR -- Capital Discard Rate
- NTAEII -- Manufacturers' Time to Adjust Energy Intensit of New Equipment

Desired energy consumption in the economy (DEC) is determined by the capital equipment in use in the economy (C) and increases with capacity utilization (SCU). The energy requirements of capital (ERC) increase with new investment (IERC) and are reduced through capital discards (DERC) as well as retrofits (RERC).

It is assumed that existing equipment cannot be upgraded economically to match the energy intensity of new equipment. The Retrofit Potential RPFE (set to 0.25 in the base case) represents the fraction of the gap between the energy intensity of new investment (EINI) and the original intensity of existing equipment (NEIC) that can be economically realised through retrofits. RPFE determines the ex-post flexibility for changing the energy intensity of existing capital. If the retrofit potential is zero, energy intensity can be changed only through capital turnover (a putty-clay approach). If the retrofit potential is one, existing capital offers no constraint to retrofits (a putty-putty approach) though the necessary adjustments through retrofits is with a delay. To keep track of NEIC , the original energy requirement of capital (NERC) are also computed. Figure 5 shows the formulation for energy requirements of capital used in the model.

4.2 Energy Prices

$$UP_{it} = RS_{it}/PP_i$$

$$RS_{it} = (1+FT_{it})(C_{it}*IR + CUC_{it}*IR + CDR_{it})$$

where

- UP -- Price Per Unit of Energy
- RS -- Required Revenues from Sales
- PP -- Potential Production
- FT -- Fractional Advalorem Tax
- C -- Capital employed in the sector
- CUC -- Capital Under Construction
- IR -- Real Interest Rate
- CDR -- CAPITAL DISCARD RATE

The model endogenously generates the costs and prices per unit of energy endogenously. The price of imported energy (PIE) is however specified exogenously.

Capital (C) is the sole factor input in the energy sector and thus the major determinant of peoductionenergy costs. Energy prices are regulated by the government on the basis of average costs.

The government can influence the market's reaction to the various forms of energy through taxes or subsidies. Since the energy sectors are under government control, the model treats the difference between market prices and the cost of capital as an effective tax or subsidy.

$$DPE_T = (RS_{IT} + PIE_T*IMP_T) / DEC_T \quad \text{IF IMP>0}$$

$$= (RS_{IT})/(DPR_T+NCEP_T) \quad \text{IF IMP<0}$$

Where

- PIE -- Price of Imported Energy
- IMP -- Quantity of Imports
- DEC -- Desired Energy Consumption
- DPR -- Domestic Production of Energy
- NCEP -- Production of Non-Commercial Energy
- RS -- Revenues from Sales

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The Domestic Price of Energy (DPE) is the marginal cost of energy faced by the main production sector. It determines the productivity of energy and hence is crucial for the factor balancing mechanism. The formulation adopted reflects the current government policy of pooling domestic costs and international prices to obtain an average price of energy (10). If the economy were to become self-sufficient however, the domestic price of energy would become the weighted average cost of total domestic production.

4.3 Noncommercial Energy Production

Noncommercial sources of energy such as firewood, agricultural waste and animal dung have in the past been the dominant sources of energy in India.

Table 1:Production of commercial & non-commercial Energy
(in million tons of coal equivalent)

Year	Commercial	Noncommercial	Share of noncommercial.
1953-54	41.30	133.63	0.76
1960-61	64.60	155.18	0.71
1965-66	85.60	170.28	0.67
1970-71	99.60	183.70	0.65
1975-76	134.90	207.44	0.61

(derived from Tables 2.5 & 11.3 of the Report of Working Group)

From Table 1, it is however seen that while commercial energy grew at 5.4% p.a., non-commercial energy grew only at 2% p.a.Total energy consumption grew at the rate of about 3% p.a. The total energy-GDP elasticity is thus just 0.82 which compares favourably with comparable data for developed nations. (18,19) This provides a logical explanation for the high commercial energy-GDP elasticity observed in developing countries in a period of transition from non-commercial to commercial forms of energy. Production of non-commercial forms of energy is specified exogenously in the model.

5.0 PRODUCTION IN THE ENERGY SECTOR

Potential production in the energy sectors is determined by the capital stock of each sector and the productivity of that stock.

5.1 Coal and Petroleum

The resource bases of coal and oil are represented by the same structures with different parameters. Reserves (RES) in these sectors in the model are the ultimate geological recoverable reserves. They include not only proven reserves but also reserves expected to be estabilished in future with furthur exploration. (27) Accordingly capital in these sectors include investments in exploration and development as well as production.

$$PP_{it} = NPEK_{i0} * RPC_{it} * C_{it}$$

$$RES_{it} = RES_{i0} - \int_0^t PR_{it} dt$$

$$RPC_{it} = f\,(RES_{it})$$

where

- PP_{it} -- Potential Production of i (coal/petroleum)
- RPC -- Relative Productivity of Capital
- RES -- Reserves
- PR -- Production
- NPEK -- Productivity of Energy Capital (27)
- f -- a functional relationship, which is linear in this sector

The linear functional relationship above implies that as reserves are depleted marginal cost of production rises gently at first and then at an increasing rate as the industry is forced to exploit the costlier deposits.

5.2 Hydroelectric Production

$$HPP_t = HPP_0 + \int_0^t HPAR_t \, dt$$

$$HPAR_t = (HCAR_t - HCDR_t) * HRPC_t * HNPEK_0$$

where

- HPP -- Hydroelectric Potential Production
- HPAR -- Hydroelectric Potential Acquisition Rate
- HRPC -- Hydroelectric Relative Productivity of Capital
- HCAR -- Hydroelectric Capital Acquisition Rate
- HCDR -- Hydroelectric Capital Discard Rate
- HNPEK-- Normal productivity of Hydroelectric Investment (27)

As the more economical sites are exploited, the cost of hydroelectricity will increase. One can conceive of a theoretical potential for hydroelectric generation based on the runoff over all heads without taking into consideration the economic viability of the projects.

5.3 Production of Renewable Energy

$$RPP_t = RPP_0 + \int_0^t (RPAR_t - RPLR_t)\, dt$$

$$RPAR_t = RCAR_t * RNPEK_0 * RRPC_t$$

$$RRPC_t = (RCUMP_t / RCUMP_0)^{PEXP}$$

$$RCUMP_t = RCUMP_0 + \int_0^t RPR_t \, dt$$

$$RPLR_t = RCDR_t * RPP_t / RC_t$$

where

- RPP -- Renewable Potential Production
- RPAR -- Renewable Potential Acquisition Rate
- RPLR -- Renewable Potential Losing Rate
- RCAR -- Renewable Capital Acquisition Rate
- RNPEK-- Productivity of Energy Capital in starting year
- RRPC -- Renewable Relative Productivity of Capital
- RCUMP-- Renewable Cumulative Production
- RPR -- Renewable Production Rate
- RCDR -- Renewable Capital Discard Rate
- RC -- Capital in Renewables Sector
- PEXP -- Progress Elasticity Coefficient

Though Renewable sources of energy such as solar, wind and biomass currently supply a negligible share of the energy demand of the economy, they could conceivably become important in the future as the costs of depleting resources such as coal and petroleum rise and as costs for Renewable technologies decrease with time due to the learning effect. The Productivity of capital in this sector is expected to increase with cumulative production due to economies of scale in development and manufacture and rapid diffusion of innovations. A progress function is used to capture this effect in the model similar to Hirsch's Progress function for labour (11).

6.0 CONSUMPTION OF OUTPUT

6.1 Domestic Consumption and Savings

$$DINC_t = PR_t - NEXP_t$$

$$CONS_t = SINC_t - SAV_t$$

$$SINC_t = SMOOTH(DINC_t, TAI)\,(1 + PGI_t * TAI)$$

$$SAV_t = TDR_t + PGI_t * TC_t + (((DSC * SINC) - TC_t)/TAS)$$

$$AG_t = CONS_t + NEXP_t$$

$$OG_t = AG_t + PGI_t * UOG_t + ((DDD*AG_t) - UOG_t)/TAG$$

$$UOG_t = UOG_0 + \int_0^t (OG_t - AG_t)\, dt$$

where
- TAI -- Time to Average Income
- DSC -- Desired Savings Coverage (years)
- TAS -- Time to Adjust Saving

Consumption of output in the model is based on standard macro-economic theory. The formulation includes the formation of income expectations, as in the permanent income hypothesis, as well as the influence of wealth in the determination of consumption, as suggested by the life-cycle consumption theory. Output in the economy (PR) is partially spent abroad (NEXP) to pay for imports of oil. The balance constitutes disposable income (DINC). Consumers spend a portion of their income (CONS) and save the rest (SAV). Normal savings cover depreciation of all capital equipment (TDR) as well as new investment needed to maintain growth of capital at the perceived growth rate in income. (PGI)

The total capital stock in the five production sectors constitutes the wealth of the economy (TC). Correction for any deviation of actual savings from desired wealth is hence assumed to be made over a period TAS (assumed to be 25 years) through additional savings. During growth, orders for goods (OG) placed by the domestic consumers as well as external importers are higher than the actual consumption and exports by an amount needed to sustain the backlog of orders (UOG) at its optimal value so that the delivery delay of goods (DDG) is at its desired level (DDG). In a period of growth, the backlog will have to rise at the growth rate to maintain delivery delay at normal value.

7.0 CALIBRATION OF THE MODEL

7.1 Key Parameters

The model has been calibrated using Indian data. The model is initialised so as to start in equilibrium in the year 1900. It takes a few years for the model to reach steady-state growth conditions. Calibration seeks to make important model variables such as Production (PR), Desired Energy Consumption (DEC) and production of Coal (CPR), Petroleum (PPR) and

Hydroelectricity (HPR) close to their actual values in recent years. Tables 3 and 4 in Appendix 1 provide values of the parameters used in the base run of the model along with sources and references.

7.2 Analysis of the Base Run

Figure 6 and Table 2 show the results of simulation using base case parameters till the year 2050. The base case provides the standard against which changes in parameters and key policies are investigated.

Economic Growth in the model is generated by growth of the labour force (2.5% per annum) and labour augumenting technical progress (2% per annum). The resulting growth in the national output (PR) is approximately 4.5% per annum in the absence of changes in energy prices. The real cost of capital is constant in the model while the average cost of energy increases. The cost of oil and coal rise due to depletion and the cost of hydroelectricity rises due to the increasing scale of operations. Though the real cost of renewable energy falls due to technical progress, the share of renewable energy in total energy production is small. The decline in the productivity of energy due to the increase in average costs causes the mix of capital, labor and energy to be rebalanced, slowing the rate of economic growth as capital and labour are substituted for energy. As production of non-commercial energy is assumed to be constant beyond 1980, growth in commercial energy demand and domestic energy production will however be higher than growth in total energy demand.

The level of imports over the years as shown in Table 2 is interesting and illustrates some of the important mechanisms within the model. The steep five-fold increase in the price of oil in the 1970's leads to a drop in the level of imports to near-zero levels during the 1980's. After some subsequent fluctuations, imports eventually grow faster than coal, petroleum and hydroelectricity (see Figure 6). The increase in the price of imported oil in the 1970's reduces the attractiveness of imported oil and causes an increase in demand for the domestic energy sources. However, long construction times and perception delays prevent an immediate increase in domestic production. Imports which are the residual source of energy in the model hence continue at a high level for nearly a decade before domestic production increases sufficiently to reduce imports Excessive high-cost imports in the interim period reduces the productivity of energy. Substitution and conservation now reduce the growth in total energy demand (see Figure 7). After 1985, energy demand grows again as conservation opportunities are exhausted.

The base case assumes zero growth in the real price of imported oil beyond 1980. The costs of coal, domestic petroleum and hydroelectricity, however, increase with time due to depletion and scale effects. Imports are forced to grow faster than domestic sources, and becomes a significant source of energy once again beyond 1990.

Figure 8 shows that the oil price increases do not have any perceptible effect on national output or consumption. In response to the increase in average cost of energy in the 1970's, (see Figure 9), the energy efficiency of the economy (measured by the ratio of energy consumption to national output) improves through retrofits as well as replacement of capital stock by more efficient equipment. This compensates partially for the increase in the cost of energy. The higher cost of energy also leads to substitution of energy by capital. Beyond 1980, increase in the production of the lower cost domestic energy leads to a decrease in the average cost of energy. By 1985, imports have been adequately reduced and the average cost of energy increases slowly thereafter due to coal and oil depletion and the increase in the cost of hydroelectricity. The overall impact on national output and consumption of the steep increase in oil prices during the 1970's is hence negligible.

The high import oil prices however lead to high investments in the domestic energy sectors. As shown in Figure 10, during the transition, energy investments become a significant fraction of the total investment in the economy. Diversion of capital from the non-energy sectors of the economy reduces potential growth in the economy.

This example illustrates how the model captures some of the important mechanisms that are at work in the economy and the utility of the model in tracing the major transmission channels. It also illustrates an important issue regarding energy price shocks. Since the share of energy in the national output is small, the effect of an increase in the real price of energy will be small in equilibrium. However, during the

transition, the economy may need significant adjustments in sectoral shares and factor balances. Such issues can be explored fully only in a disequilibrium framework such as has been used in this model.

Table 2: Base Run Simulation Results

TIME E+00	PR E+09	CONS E+09	C E+09	LF E+06	DEC E+15	EOR E+15	IMP E+15	DPR E+15	DGDP E+03	ACE E-06
1950	163	139	533	141	4.46	.90	.25	.65	27.5	.43
1960	215	172	582	188	4.35	1.26	.44	.82	20.3	.67
1970	329	256	835	212	6.12	2.14	.85	1.29	18.6	.83
1980	482	368	1428	236	7.66	3.83	1.29	2.54	15.9	2.68
1990	739	560	2222	303	8.54	4.54	.50	4.04	11.6	1.68
2000	1173	872	3593	389	11.09	7.09	.59	6.49	9.5	2.01
2010	1876	1370	5975	500	16.04	12.04	1.87	10.17	8.5	2.86
2020	2979	2157	9920	642	21.94	17.94	2.12	15.81	7.4	2.94
2030	4711	3372	16131	824	30.69	26.69	4.41	22.28	6.5	3.73
2040	7399	5261	25752	1058	41.39	37.39	8.34	29.05	5.6	4.71
2050	11569	8189	40572	1358	54.12	50.12	14.24	35.88	4.7	6.04

PR -- Production (in billion rupees)
CONS -- Consumption (in billion rupees)
C -- Capital (in billion rupees)
LF -- Labour Force (in millions)
DEC -- Desired Energy Consumption/Energy Demand (in quads)
EOR -- Commercial Energy Demand (in quads)
IMP -- Imports (in quads)
DPR -- Domestic Production of Energy (in quads)
EGDP -- Energy-Net National Product Ratio ('000 BTUs/rupee)
ACE -- Average Cost of Energy (rupees/million BTU)

8.0 POLICY ANALYSIS AND CONCLUSIONS

Policy making in a complex environment is characterised by restricted room for manoeuvre given various system constraints and feedbacks. The long term consequences of policy intervention may well conflict with the direct consequences initially anticipated. For example, it may appear paradoxical that an increase in the production of non-commercial energy in the future will not have a significant impact on the demand for commercial forms of energy. Though the share of non-commercial energy does indeed go up, the associated reduction in the average cost of energy increases the total energy demand within the economy sufficiently high to offset the direct impact. (In real life, such compensation will be partial because the model does not incorporate the costs associated with the production of non-commercial energy.) While similar and generally more complex compensating mechanisms are typical for most policy interventions, some policies have higher leverage than others.

The effects of taxes and subsidies as well as emphasis on conservation have been assessed with the use of the model.

8.1 Taxes and Subsidies

Taxes on an energy source reduce its attractiveness to the consumers thereby reducing its share of total energy demand. This ultimately reduces production of that form of energy. By increasing the average cost of energy and hence reducing the relative productivity of energy, a tax also reduces total energy demand. Figure 11 shows the effect of a 50% advalorem tax on petroleum coupled with a 50% subsidy on renewable energy. As expected, petroleum development is slowed and renewable energy develops faster than in the base case.

In the initial stages when the share of petroleum is high compared to production of renewables, such a policy creates a net inflow into the government treasury. However when renewable energy production becomes large enough, continuation of this policy will be constrained by the government budget. A more realistic representation would involve a gradual reduction of subsidies for renewable energy over a period of time, eg. subsidy of renewable energy linked to tax revenues from petroleum. Policies such as these could easily be investigated if taxes and subsidies are treated as variables in the model.

Figure 12 (see section 8.2) shows the effect of the above policy on the average cost of energy (ACE) and the energy-NNP ratio (ratio of energy demand to net national product at factor cost). The average cost of energy tends to reduce due to the direct effect of subsidies on renewable energy as well as due to reduction in unit costs associated with the accelerated technical progress in this sector. This is compensated fully until about year 2020 by the increase in the cost of petroleum due to the taxes. The greater production of renewables in later years compared to the production of petroleum leads to a reduction of average energy costs compared to the base case.

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8.2 Emphasis on Conservation

A natural response of the Government to energy price shocks as in the 1970's is to emphasise conservation and substitution. High energy prices provide a natural incentive to the economy to reduce energy demand. Governments could attempt to accelerate this effect through taxes which would, however, have undesirable political consequences. In fact, the usual response is to reduce taxes and increase subsidies. In this context, emphsis on conservation is seen as a desirable alternative to control energy demand.

The model has been used to investigate conservation policies that increase the speed of response of the economy to energy price increases. The time to adjust energy intensity of new investment (NTAEII) equals two years in the base case. The time to adjust Retrofit Potential (RATE) equals four years. Information campaigns that accelerate consumer demand for more efficient equipment would put pressure on manufacturers to improve energy efficiency of new equipment at a faster pace and reduce NTAEII. Energy audits, information campaigns and tax credits on conservation investments would reduce RATE, though there are clearly limits to the extent to which the reaction times could be reduced.

Figure 13 shows the effect of reducing NTAEII an RATE to 1 year as also increasing them to 4 years and 5 years respectively. The response to the oil price increase of the 70's is compared with the base case for both scenarios. It is seen that conservation policies have a beneficial impact in the short run in reducing energy demand during the difficult energy transition. The effects vanish beyond 1990 unless the cost of energy rises again leading to additional opportunities for improvement in energy efficiency.

8.3 Conclusion

1) The model in its current stage of development can shed light on the response of the economy to energy shocks such as steep price increases. In particular, it can identify the transmission channels that are responsible for the overall effects.

2) The decline in the rate of growth of non-commercial energy accounts completely for the high energy-elasticity coefficient observed in India compared to developed countries.

3) The impact of energy shocks such as oil price increases is seen to be essentially a medium term phenomenon. The transition in response to such a major shock as for the five fold real increase in prices in the 1970's may last 20-25 years. The long-term impact of such shocks will however be relatively small as the economy adjusts to the new prices through appropriate factor balancing and conservation investments.

4) Taxes can have a significant impact in reducing the development of any form of energy. Subsidies accelerate such development but are limited by government budget constraints.

5) Conservation policies can be very effective within limited bounds during the difficult transition period following an energy price shock in modulating energy demand. Their impact in the long-run is however small unless there are further major increases in the cost of energy.

Development of the model in the following directions is likely to be useful for policy makers and analysts:

1) Taxes and subsidies should be treated as variables in the model to enable exploration of policies such as subsidies on renewable energy linked to tax revenues on petroleum.

2) Future research to determine values of elasticity of the substitution of energy and technical progress in Renewable energy would be useful. While the principal model results do not depend on their specific values, precision would be necessary to evaluate the numerical impacts of different policies.

3) The model is not currently designed to explore issue such as the impacts of foreign exchange shortages, economic cycles, and long-term constraints such as environmental pollution and scarcity of non-energy resources on energy development. All these are fruitful areas for furthur development of the model.

In its current stage of development, however, the model incorporates widely held assumptions with regard to the key relationships among energy and macroeconomic variables (derived largely from Working Group, November 1979). It provides a framework to test the impact of key policy issues such as emphasis on conservation, influences of fossil fuel resources on future energy costs, and the role of taxes and subsidies in regulating energy development along desired lines.

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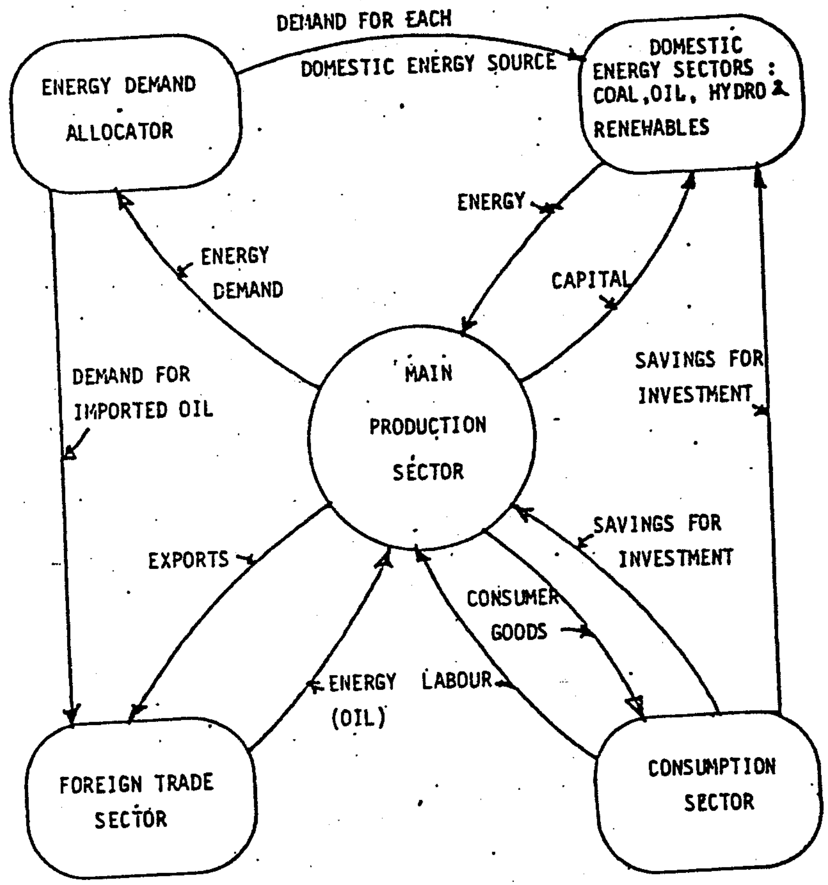
Figure 1 : Key Flows between Sectors



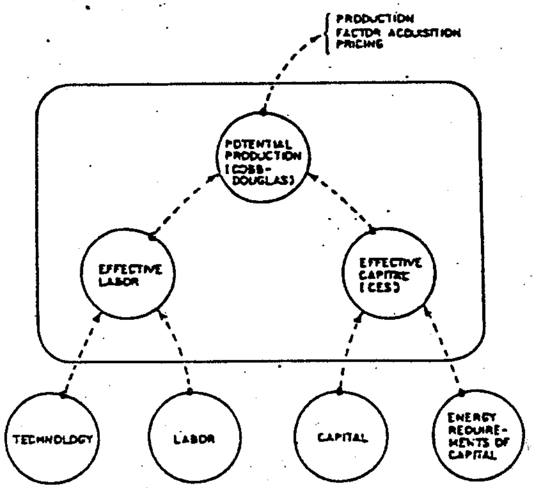


Figure 2 : Potential Production
(adapted with permission from Sterman 1981)

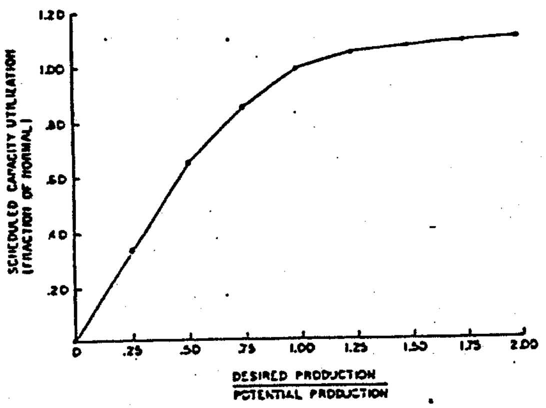


Figure 3: Scheduled Capacity Utilization
(adapted with permission from Sterman 1981)

Figure 4 : Capital and Investment Function
(adapted with permission from Sterman 1981)

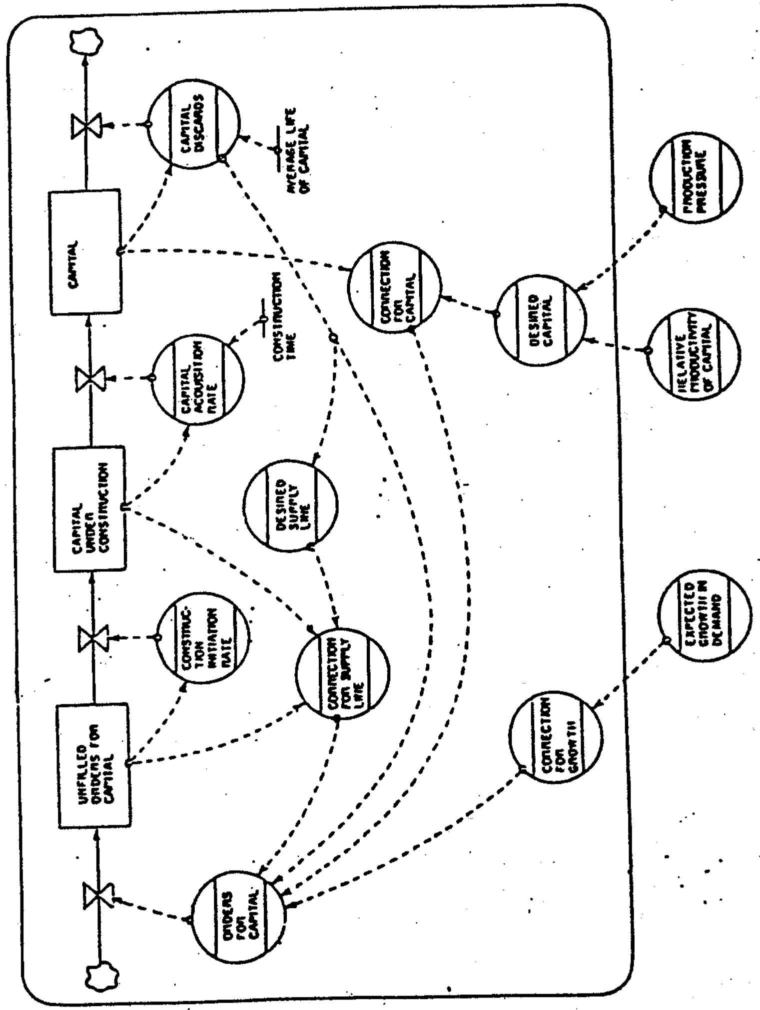
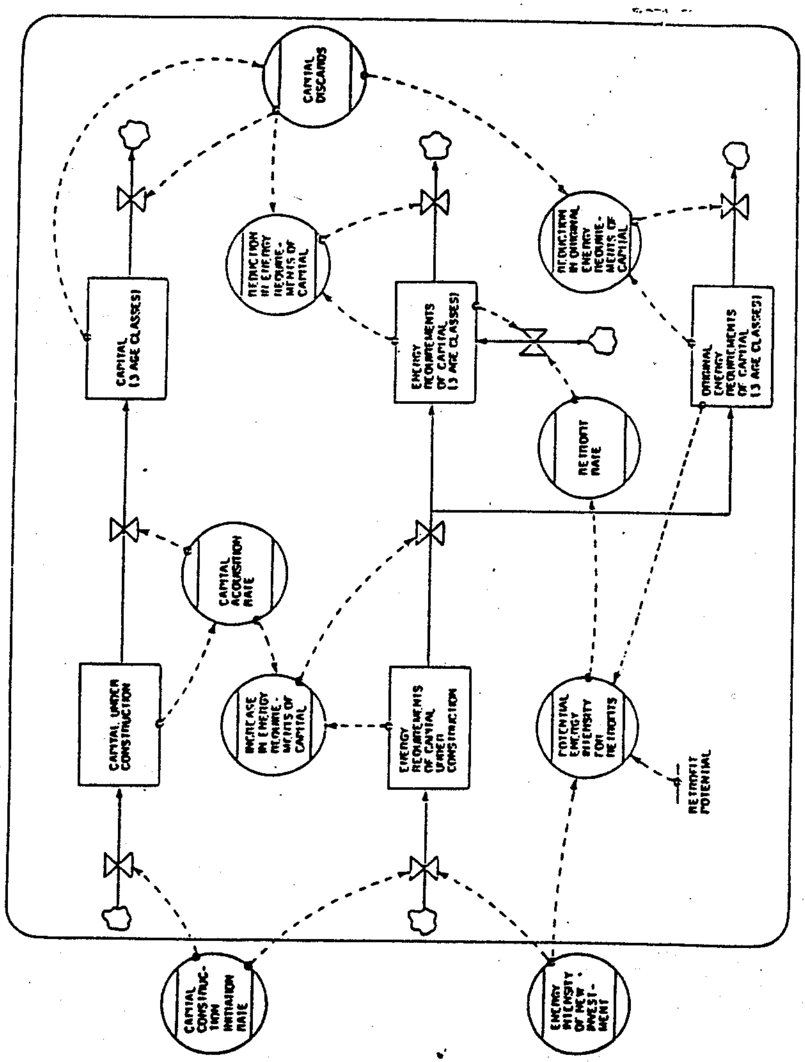


Figure 5 : Energy Requirements of Capital
(adapted with permission from Sterman 1981)



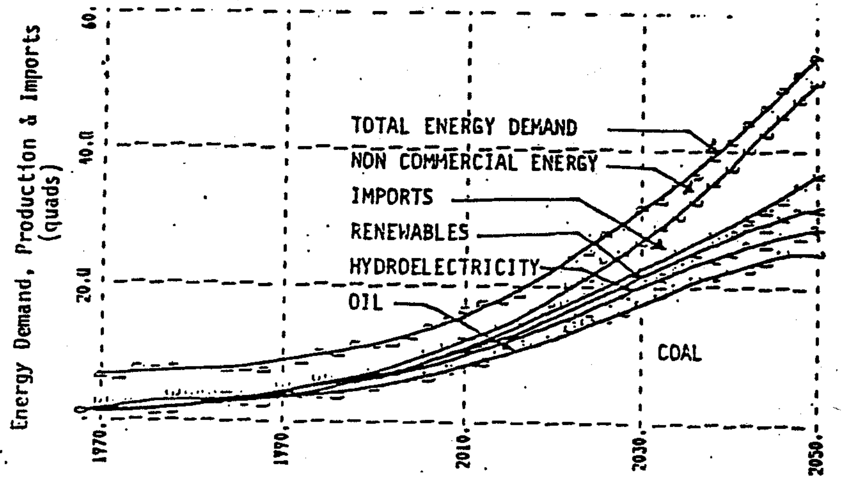


Figure 6 : Energy Shares in the base run

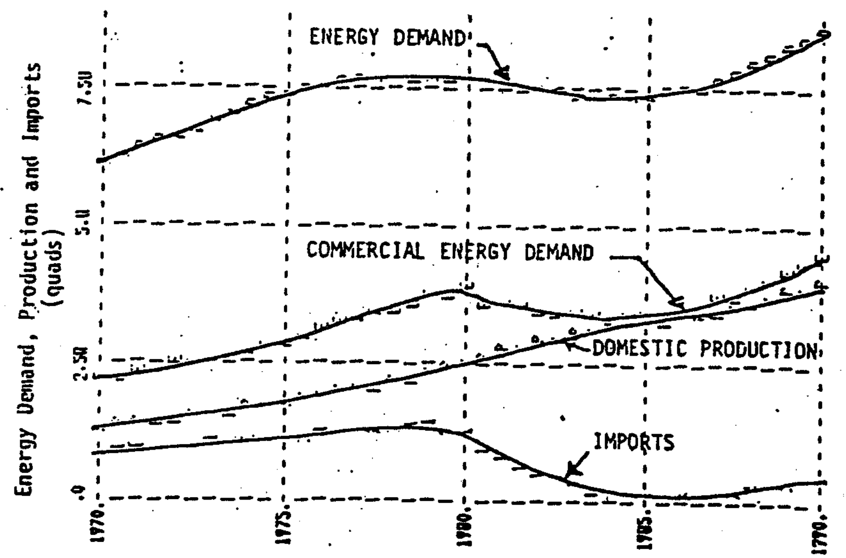


Figure 7 : Effect of the oil price shock
of the 1970's

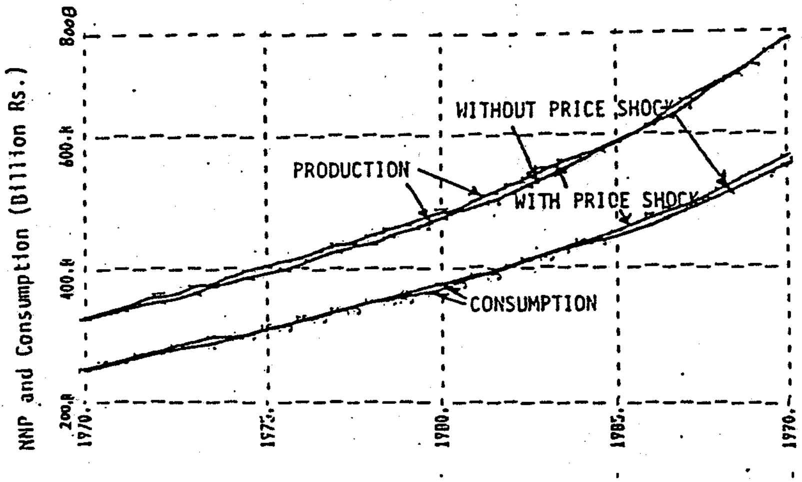


Figure 8 : Net National Product and Consumption

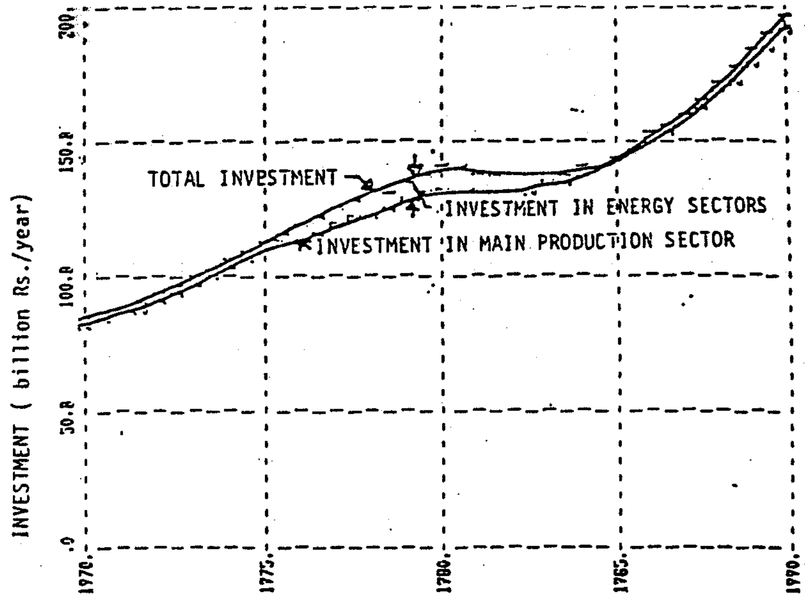


Figure 10 : Investment in Energy and Main production

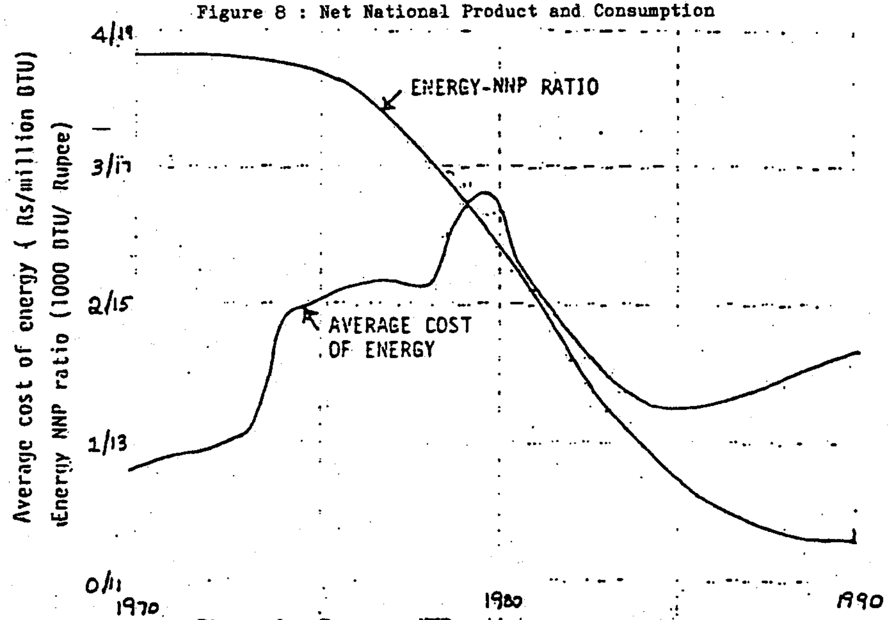


Figure 9 : Energy - NNP ratio

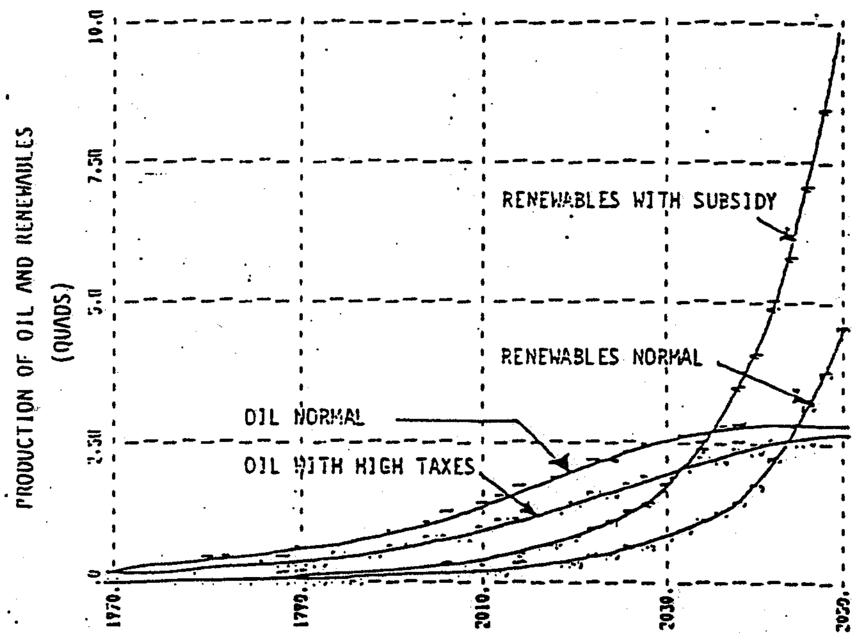


Figure 11 : Effect of 50% tax and on oil and 50%
subsity for renewable energy

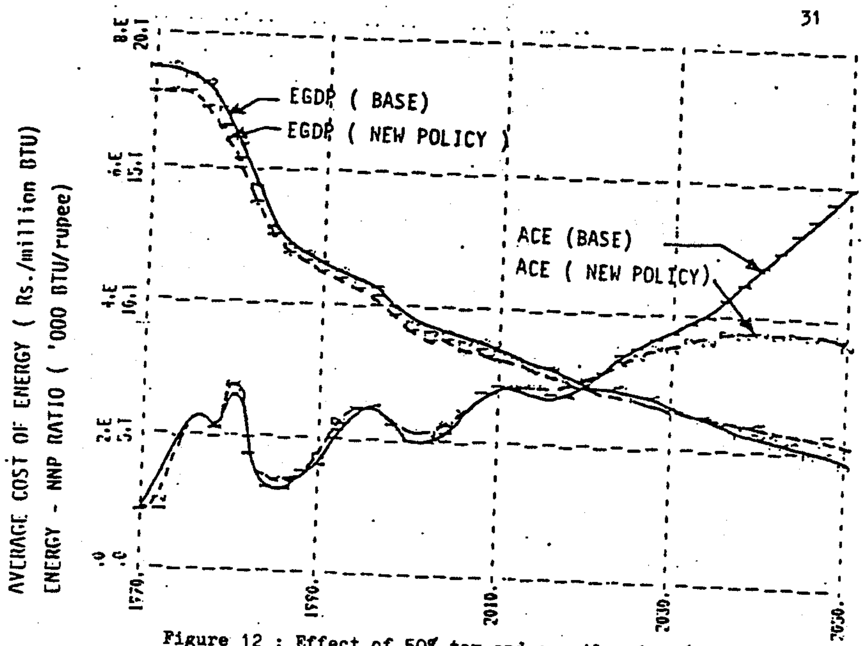


Figure 12 : Effect of 50% tax and on oil and 50% subsity for renewable energy

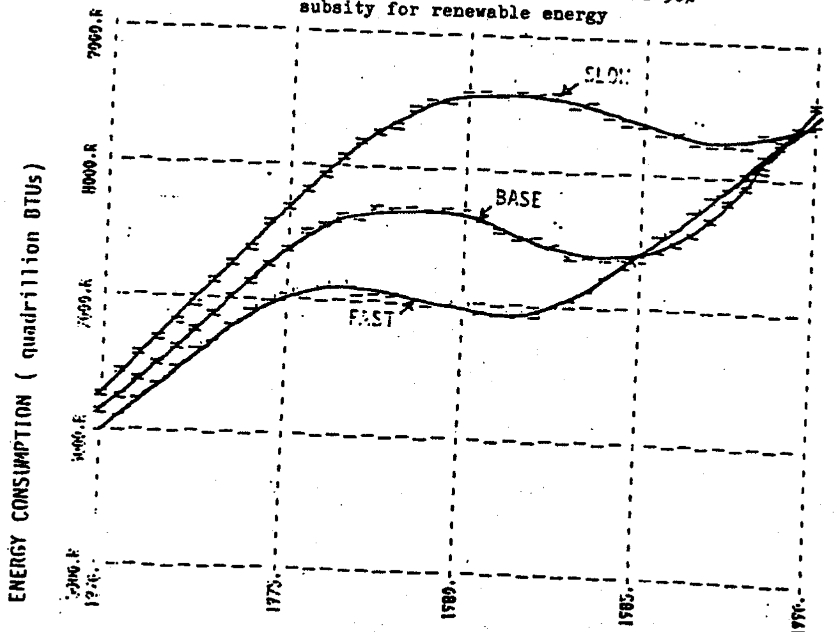


Figure 13 : Conservation Policies

Appendix 1.

Table 3 : National Parameters

Reference Production (NNP at factor cost)	: Rs.130 Billion
Future Technical Progress	: 2% per annum
Reference Labour (13)	: 110 million
Future growth in Labour Force (13)	: 2.5 % p.a.
Reference Value Share of Capital	: 0.3
Reference Value Share of Labour	: 0.7
Reference Value Share of Energy (28)	: 0.04
Elasticity of Substitution of Energy	: 0.75
Real Interest Rate	: 5% p.a
Time to Perceive Relative Productivity (sec 3.1)	: 2 year
Time to Adjust Goods	: 4 years
Time to Average Income (9)	: 2.5 years
Time to Adjust Savings (16)	: 25 years
Average Life of Capital (24)	: 30 years
Capital Construction Time	: 1 year
Time to Adjust Capital (23)	: 4 years
Time to Adjust Backlog	: 1 year
Normal Delivery Delay	: 1 year
Time to average orders (23)	: 1.5 years

Table 4 : Key Energy Parameters

	COAL	OIL	HYDRO	RENEWABLES
Initial Reserves (quads)(27)	2200	260	-	-
Normal Productivity of (27) Capital (BTU/Rupee)	160000	34500	8000	6000
Life of capital (years)	15	15	50	1
Construction Time(years)(27,28)	5	2	5	0.5
Convenience Factor	0.3	1.0	2.5	1.5
Fractional Taxation (18)	0.073	0.15	0.127	0

Time to adjust Energy Intensity of new equipment (NTAEII)	: 2 years
Retrofit Potential Fraction	: 0.25
Retrofit Adjustment Time	: 3 year
Import Convenience Factor(ICF)	: 1
Allocation Weight Factor (AWF)	: -2
Reference Capital in Hydroelectricity (27)	: Rs.1 Trillion
Time to Adjust Shares (TASHARE)	: 10 years
Renewable Cumulative Production in 1900 (section 5.3)	: 3 quads
Renewable Progress Elasticity (PEXP)	: 0.35
Future Growth in non-commercial energy (27,28)	: 0
Future growth in international oil prices (section 4.2)	: 0