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REPORT ON GLOBAL WARMING AND ASSOCIATED IMPACTS

(PHASE V)

TATA ENERGY RESEARCH INSTITUTE
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REPORT ON GLOBAL WARMING AND ASSOCIATED IMPACTS

(PHASE V)

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Examining the Replacement of coal by natural gas in utility and industrial application

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Incremental Costs of GHGs Abatement Programs : A first cut at a definition.

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Introduction

Negotiations for a Framework Convention on Climate Change have been completed, and the convention will be adopted at Rio de Janeiro in June 1992. The proposed convention involves provisions for transfers of technology and financial resources from industrialised countries (ICs) to developing countries (DCs) to enable the latter to fulfil their (differentiated) responsibilities under the convention. Transfers of finances are for meeting the "agreed full incremental costs" of measures which may lead to reductions in future growth rates of GHGs emissions.

This paper addresses the question of defining such incremental costs. It develops definitions and a Linear Programming (LP) model to arrive at a concept of "minimal incremental costs", i.e., a notion of economic costs involved in meeting Global Warming responsibilities which policy makers could agree upon as the *least* that would be involved in such programs. The model assumes two alternative formulations of Global Warming responsibilities under a future protocol. The first specifies a time path of GHGs *emissions* in the economy as a whole. The second, supposes that such a protocol would specify a time path of GHGs *intensity* in the economy (which may be a vector disaggregated by sector).

The "costs" considered in this paper are economic, not financial. The principal difference is that financial costs, as typically determined by an accountant, involve only actual financial expenses (on capital, labour, materials, taxes, depreciation). Economic costs, on the other hand, are "opportunity costs", i.e., the benefits foregone by not utilizing a given resource in the best alternative use. Consider for example, an owner who manages her own retail store and pays herself no salary. Since no monetary transaction occurs, an accountant would not recognise any costs. On the other hand, for the economist there exists an opportunity cost equalling the highest salary that the owner could have earned by working elsewhere.

Further, economic costs exclude transfer payments such as taxes and subsidies, since these do not represent any direct claims on the resources of the economy. They merely represent a transfer of control over the resources from one agent to another within the economy. For example, when a firm pays taxes to the government these do not form a part of the economic costs since all that occurs is a transfer of purchasing power from the firm to the government. However, if the government were to use the funds so obtained to, say, construct a dam, then these expenditures would constitute economic costs.

Economic costs also correct for market failures -- for e.g., by including externality costs, which are costs passed onto third parties not involved as producers or consumers of the good/service in question. In the case of environmental externalities experienced by the society in question, it is assumed that these externality costs refer to local, not global impacts. In other words, it is assumed that the protocol either ensures that the global emissions profile is such that no Global Warming impacts are perceptible, or that all costs of adaptation or damage would be met under other regulatory arrangements or provisions.

Techniques for computation of the elements of economic costs (and benefits) are detailed in several standard texts on cost-benefit analysis, and will not be repeated in this paper. What we attempt in this paper, assuming that individual elements of costs & benefits (including of local environmental impacts on amenities) can be computed, is the following :

First, we furnish a definition of "minimal incremental costs" of an abatement alternative, which policy makers would generally agree on as representing the least economic costs involved. Second, we develop the specification of a general Linear Programming (LP) model to compute the cost thus defined, over a national abatement program for a specified time-period under alternative regulatory assumptions.

2. Possible regulatory protocols:

A multilateral regulatory framework (protocol) may, in our judgement, take one of two forms. One, it may specify for each country (or category of countries) a path of future aggregate GHGs emissions over time. Alternatively, it may specify (perhaps for each defined sector, say steel making, in given categories of countries or each country) a time path of GHGs intensities of output (i.e., tonnes of GHGs emitted per tonne of steel produced). These are illustrated in Figures 1 & 2 overleaf:-

Fig 1: Timepath of GHGs emissions in an economy

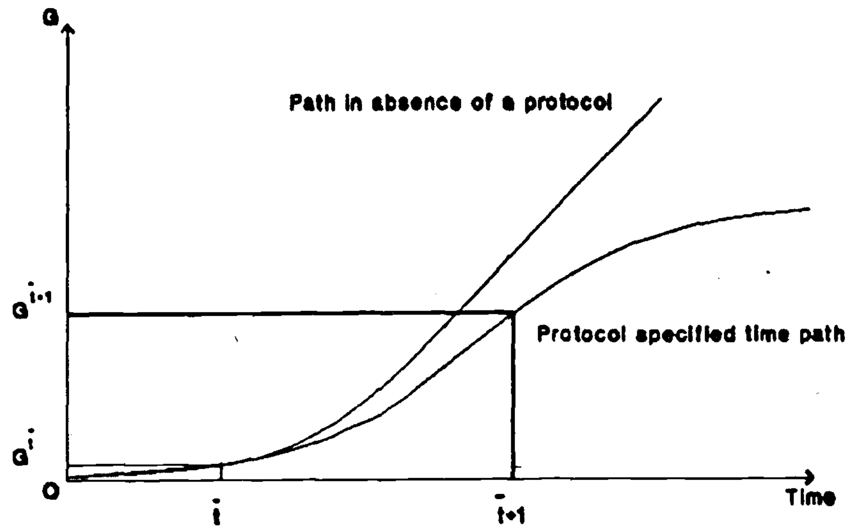
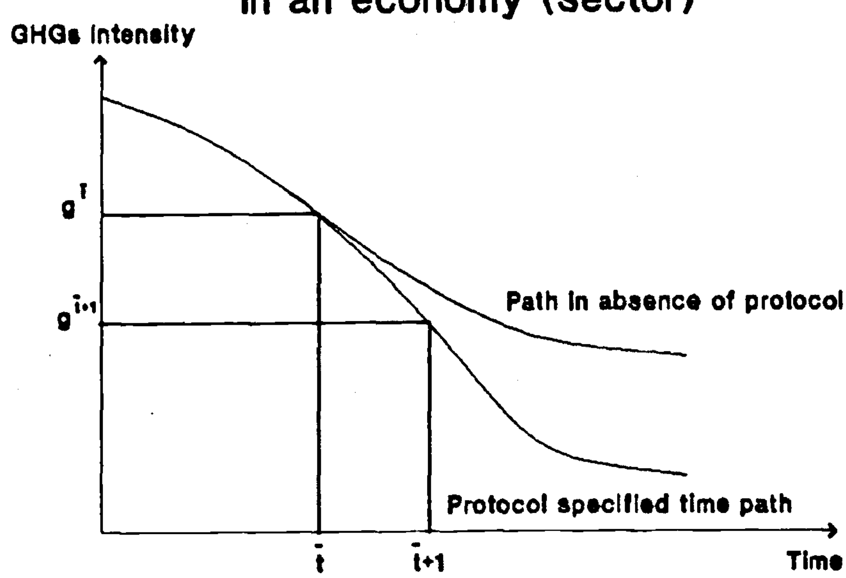


Fig 2: Time path of GHGs intensity in an economy (sector)



The shapes of the time paths depicted in each case may be explained as follows:

In the case of DCs, it is unlikely that any protocol in the foreseeable future would provide for actual reductions in GHGs emissions. However, the adoption of benign technologies would, over time, tend to reduce the growth rates of GHGs emissions, and at some time in the future, the aggregate GHGs emissions may stabilize. On the other hand, in the absence of a protocol, GHGs emissions growth rates may be unchanged, or increase, as the economy grows and undergoes structural change biased towards energy intensive sectors. Figure 1 is thus explained.

Further, increasing use of benign technologies in the economy generally, and in particular in energy intensive sectors, would reduce the GHGs intensity over time. In the absence of a regulatory protocol, GHGs intensity may also be expected to fall with time, because of autonomous technological change, which may induce energy efficiency. These considerations help explain Figure 2.

3. Costs and Benefits of a Given Project

In this section we briefly review how net economic benefits of a given project are computed.

Figure 3 depicts a typical project profile of costs and benefits. Each project is associated with a stream of benefits and costs over time. However, these values are not strictly comparable since agents (individual, firm, society) typically have a (positive) time preference, i.e., they prefer to reap benefits earlier and pay costs later. Discounting reduces these values to a common denominator ie., the present value of a stream of benefits (costs) over time. The discount rate used is the social (rather than the private) discount rate since we are considering the problem from the viewpoint of the policy analyst)[1]. The perspective is deterministic, i.e., no uncertainty attaches to any element of costs or benefits associated with the known (set of) technologies. Net economic

[1]Note that the social discount rate represents a societal choice, i.e., the respective weights attached to identical benefits (costs) occurring at different times. Techniques for computing social discount rates are also elaborated in the cost-benefit literature. They are some what controversial, but we do not go into these aspects in the present paper.

benefits or net present value (NPV)[2] is computed as the sum of each year's benefits less costs, discounted by the discount factor. Mathematically.

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+S)^t} \qquad (1)$$

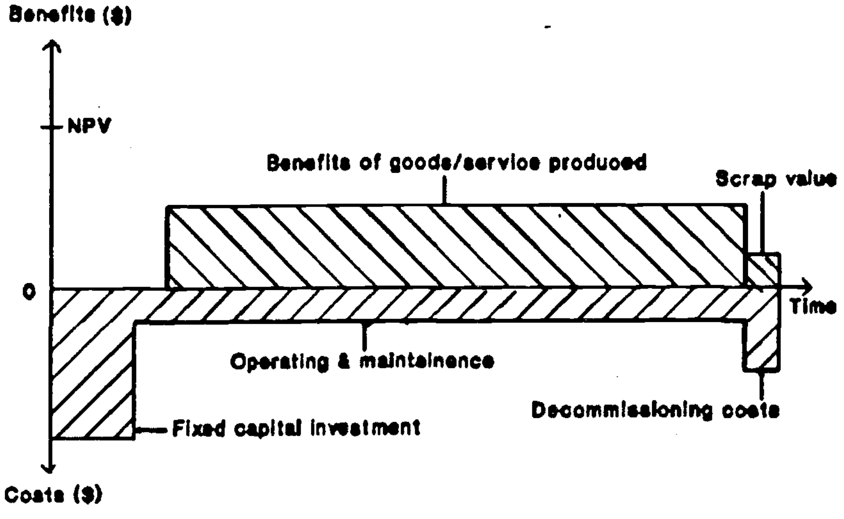
where:

B_t : Benefits at time t

C_t : Costs at time t

S : Social discount rate.

Fig 3: Typical profile of costs and benefits of a project

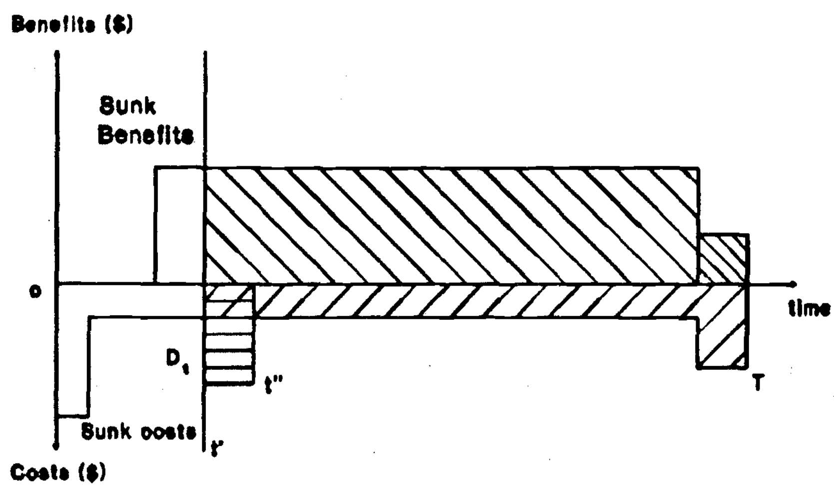


[2]The NPV is the criteria of ranking alternative projects on the basis of the respective gains in economic efficiency that they yield.

4. **Costs & benefits of an "interrupted" project:**

An abatement program may involve the interruption of an existing plant before its "normal"[3] economic life is over, and its replacement by another plant embodying a (more) GHGs benign technique. We explain below how the net benefits over the remaining normal economic life of the existing project are to be computed. Figure 4 graphically depicts the costs & benefits of project interruption.

Fig 4: Computing foregone costs & benefits of project interruption



The project commenced at t = 0, and its lifetime (without interruption) would be till t = T. However, it is interrupted at t = t' and decommissioned, over the period t = t' to t".

All "past" benefits and costs of the project (i.e., in the period t = 0 to t') are considered "sunk", and the foregone costs and benefits are reckoned over the period t' to T. The "net foregone benefits" (NFB) at t' is accordingly the discounted value of all costs and benefits foregone by the interruption, less the net costs of the

[3]"Normal" in the sense of in the absence of a GHGs abatement program.

decommissioning operation, where all streams are discounted to the point of decommissioning. Mathematically:

$$NFB^{t'} = \sum_{t=t'}^{t=T} \frac{(B^t - C^t)}{(1+S)^{(t-t')}} - \sum_{t=t'}^{t=t''} \frac{D_t}{(1+S)^{(t-t')}} \qquad (2)$$

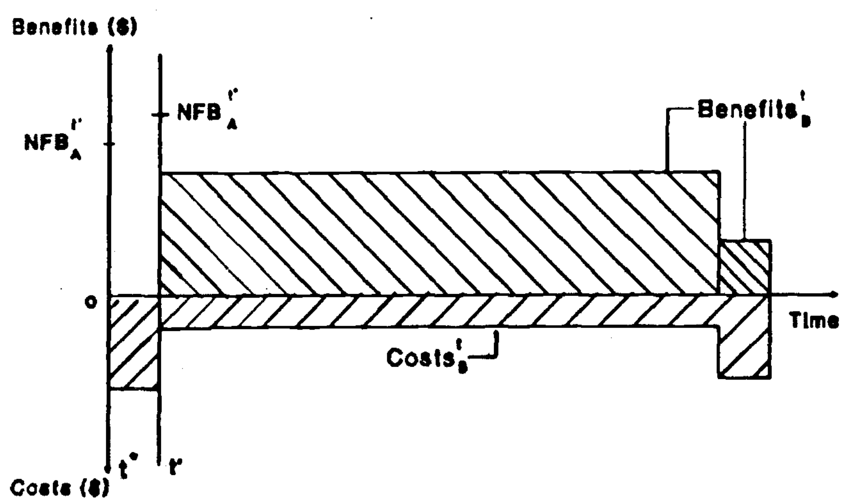
where D_t is the net costs of decommissioning (i.e., inclusive of any scrap value).

5. **Definition of "minimal incremental cost of an abatement option"**:

We now employ the concepts developed above to define the minimal incremental costs (MIC) of an abatement option involving the interruption of an existing plant and its replacement by another (GHGs benign) technique. The situation is depicted in Figure 5 (where the phasing of costs and benefits of the replacement plant are illustrated, not those of the existing plant).

The existing plant is termed A, and the replacement plant B. Both plants are assumed in this definition to yield the same level of service (e.g., MW of electricity).

Fig 5: Costs & benefits of a replacement project



The NFB of the existing project A, which is interrupted at t = t' when the replacement project B goes on stream, so that there is no interruption of service, is $NFB_A^{t'}$ computed as explained in the previous section. Discounting this value to t^*, the point of time when investments in the replacement project B commence, we arrive at the NFB of project A at time t^* as:

$$NFB_A^{t^*} = \frac{NFB_A^{t'}}{(1+S)^{(t'-t^*)}} \qquad (3)$$

The NPV of project B at t = t^* may be computed as described above (by using equation (1)). We now define the "minimal incremental cost of switching from A to B at time t^*" as the difference between the net foregone benefits of the existing project A and the net present value of the replacement project B, both reckoned at the time when investment in the replacement project commences. That is:

$$MIC_{AB}^{t^*} = [NFB_A^{t^*} - NPV_B^{t^*}] \qquad (4)$$

6. **From project level to program minimal incremental costs:**

An abatement program in response to a regulatory protocol will, in the case of a diversified economy, involve a large number of options. While one may work out the MICs of particular abatement options, an important policy question is how to choose a least cost set of abatement options over a planning period, given two types of constraints. First, the economy should adhere, in each period, to the GHGs (emissions or intensities) path specified in the regulatory protocol. Second, that capacity in each sector of the economy at the following period is known or determined exogenously in the current period.

A detailed Linear Programming (LP) model is set out in the Appendix to both define, and determine, the minimal incremental costs of such a program. The main features of the model are briefly explained below.

The policy objective is assumed to be the minimization of the total economic costs of adhering to the abatement path at each planning period[4]. This is in keeping with the provisions of the convention that any abatement measures undertaken by the DCs are contingent upon the transfer of finances (and technology) from the ICs.

The planning horizon is one period, since it is assumed that future capacities in each sector are known only up to one period in advance. Additionally, the set of available techniques is fixed only for one period in the future. The economy adheres to the protocol specification (of GHGs emissions or intensities) at the beginning and end of the period. There is a (large) discrete set of techniques, which may be embodied in current and future plans. An abatement option consists of a switch from an existing plant to another employing a (more) GHGs benign technique. However, the set of pairs of such technique switches are restricted to those in the same sector. For example, an electric thermal power plant may be replaced by another electric power plant employing a more GHGs benign technique, but not by say, an aluminium smelter.

Apart from switches in technique involving the same levels of service, the economy may make fresh investments (retirements) in each technique, in keeping with its growth/economic structure objectives, detailed in the set of sectoral capacities at the next period.

Minimal incremental costs are involved in each abatement technique, and there are net benefits (net foregone benefits) in each case of fresh investment (retirement). Expressed as costs (i.e. net benefits are negative costs), these are aggregated into the total costs of the abatement program.[5] A LP model is then specified, minimizing these total costs, subject to the sectoral capacities and the GHGs emissions (intensities) stipulated in the protocol, in the next period in each case.

A numerical solution of this LP model may be obtained by standard algorithms (e.g., the Simplex or Karmarkar methods). The solution will furnish the "optimal" levels

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[4]One may suppose as an alternative, that the policy objective could be to minimize the sum of the minimal incremental costs of individual options. As a planning objective for DCs this is implausible because it would not ensure that the total costs of remaining on the specified abatement path, given the society's growth objectives, are also minimized.

[5]Where negative costs (net benefits) are involved in a particular abatement option these are excluded from reckoning of total costs on the assumption that these options may be adopted anyway, i.e., even in the absence of a protocol ("no regrets" strategies).

of switches of pairs of techniques, as well as the set of fresh investments (retirement) in each technique for each period. These elements of the solution may be employed to determine the "minimal"[6] incremental cost of the abatement program in each period.

7. Concluding comment:

The present exercise is a very limited one. The definitions of "minimal incremental costs" at both the project and program levels are rather restrictive, and are aimed at locating a datum of incremental costs which, perhaps, all analysts may agree upon as representing the minimum direct economic costs involved.

Any actual abatement option or program will doubtless involve other direct and indirect costs. These may be in the nature of transactions costs in planning and implementation, including domestic regulation, as well as costs of dissemination of abatement techniques. Major costs may also be involved in remedying social impacts, e.g., the retrenchment, retraining and rehabilitation of coal mining communities. Macroeconomic effects of any significant abatement program may involve costs by way of changes in relative price levels and welfare levels of different classes, due to general equilibrium effects. Such macroeconomic effects may be difficult to apportion between the abatement and growth/structural change components of the overall program. A major research challenge for the near future is to develop appropriate notions of incremental costs which take account of these elements.

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[6] "Minimal" in the sense that these are the incremental costs associated with the minimum of the total costs as determined by the LP. Moreover, they are determined on the basis of the MIC associated with each switch from technique i to j.

Appendix

In this appendix we give the detailed mathematical structure of the LP model for computing the minimal incremental costs of an abatement program which ensures that the economy remains on a protocol mandated emissions path and at the same time does not jeopardise its growth objective.

The elements of the LP model are :

(1) A discrete set of techniques :

$$\{i\} = \{1,2,......,N\}$$

(2) A discrete set of time periods :

$$\{t\} = \{1,2,t,......,T\}$$

(3) GHGs intensity of each technique (GHGs emitted per unit of capacity, however defined

e.g., MW of electricity) g_i, and without loss of generality (w.l.o.g.) $g_i > g_{i+1}$ for all i ; i.e : the more benign techniques are numbered lower in the series and $g_i \geq \leq 0$; i.e. techniques may be sources, sinks, or zero net emitters of GHGs.

(4) Capacity installed in each technique at time t :

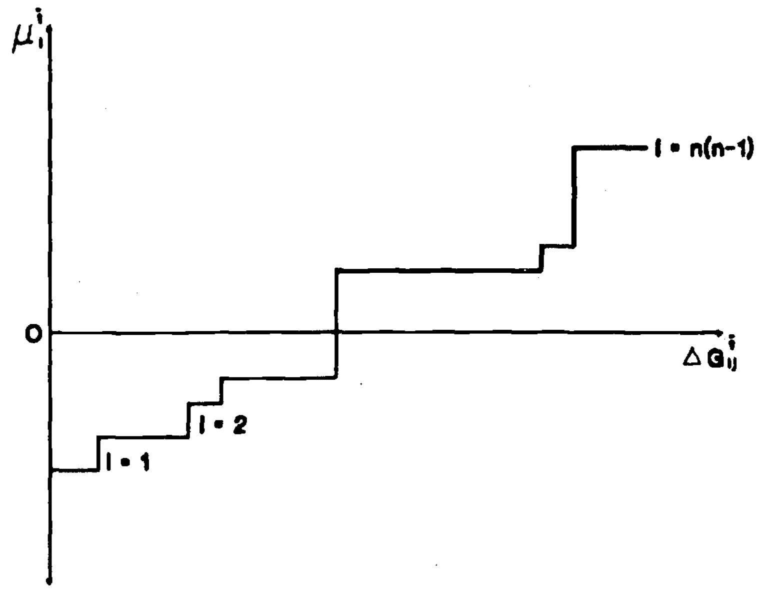
Q_i^t, for all i

(5) Specific cost of a given change in technique at time t:

$$\mu_{ij}^{t} = \frac{MIC_{ij}^{t}}{Q_i^{t}} \qquad (A1)$$

where MIC_{ij}^t is the minimal incremental cost of a change in technique from i to j at time t (see main text).

The specific costs may be illustrated as follows:



where:

$$\Delta G_{ij}^{t} = (g_i - g_j)\,Q_i^{t} \qquad (A2)$$

i.e., the abatement potential of the change in technique i to j at time t, and

$$\mu_l^{t} = \mu_{ij}^{t}; \qquad \{l\} = \{i x j \backslash l\} \qquad (A3)$$

and w.l.o.g

$$\mu_l^{t} < \mu_{l+1}{}^{t}$$

(6) An allowable set of technique changes:

$\{h \times k\} \subseteq \{i \times j\}$ (A4)

$h > k,\ i > j$

The definition of an allowable set may be such as to allow only changes in technique within given sectors. Additionally, the allowable set may exclude abatement options which are repugnant to other policy considerations.

(7) Protocol mandated paths, which may be, either

(i) Target GHGs intensity of the economy :

$$\overline{g_t} = \frac{\sum_i g_i Q_i^t}{\sum_i Q_i^t} \qquad (A5)$$

or

(ii) Target aggregate emissions :

$$\overline{G_t} = \sum_i g_i Q_i^t \qquad (A6)$$

Model :

The starting model assumption is that the protocol mandated path is adhered to at the current period t. The LP model calculates the minimal costs of a program to ensure that the economy remains on the protocol mandated path at time t + 1, given the economy's growth objectives. These are specified as capacity levels in each sector at time t + 1. The planning objective (by assumption) is that the policy maker minimizes the net costs (maximizes net benefits) of the transition along the protocol mandated path for each period.

Suppose the economy at t moves to t + 1, along the protocol path. Then the change in capacity of each technique j, is given by :

$$\Delta Q_j^t = \sum_{i<j} q_{ij}^t - \sum_{k>j} q_{jk}^t + k_j^t \qquad (A7)$$

where: $\Sigma_{i<j}\, q_{ij}^t$ is the aggregate of switches to j from less benign techniques; $\Sigma_{k>j}\, q_{jk}^t$ is the aggregate of switches from j to more benign techniques; and k_j^t is the new capacity (retirement) in j at t

The incremental program cost is then given by :

where a_{ij} etc. is a logic driven parameter, such that :

$a_{ij}^t = 1$ if $\mu_{ij}^t > o$,

$= o$ otherwise

$$IPC^t = \sum_j \{ \sum_{i<j} a_{ij}^t \cdot \mu_{ij}^t \cdot q_{ij}^t + \sum_{k>j} a_{jk}^t \cdot \mu_{jk}^t \cdot q_{jk}^t \} \qquad (A8)$$

This definition of IPC' includes the net costs of only those switches which have positive net cost.

Now, let C_j^t be the specific net cost (positive net benefit) of new capacity in j, and r_j^t the specific net cost (positive net benefit) of retirement of j, at t in each case. The total cost of the program is then given by :

$$TC^t = \sum_j [\{\sum_{i<j} a_{ij}^t \mu_{ij}^t q_{ij}^t + \sum_{k>j} a_{jk}^t \mu_{jk}^t q_{jk}^t\} + f_j^t c_j^t k_j^t + h_j^t r_j^t k_j^t] \qquad (A9)$$

where f_j, h_j are logic driven parameters :

$f_j^t = 1$ if $k_j^t > o$,

$= o$ otherwise

$h_j^t = o$ if $k_j^t > o$,

$= 1$ otherwise.

(The total program cost nets out the net costs of technique switches having positive net benefits)

The growth constraints may be written as :

$$\sum_{j \in s} [Q_j^t + \Delta Q_j^t] \geq \bar{Q}_s^{t+1} \qquad (A10)$$

The right hand side is an exogenous specification of capacity in sector s, {s = 1, 2,--, n}, where s represents different sectors of the economy.

The policy problem is then written as :

Minimize TC^t

q_{ij}^t, q_{ik}^t, k^t

s.t. (1)

$$\sum_{j \in s} [Q_j^t + \Delta Q_j^t] \geq \bar{Q}_s^{t+1}$$

(2) Either :

$$\sum_i g_i Q_i^{t+1} - \bar{G}_{t+1} \leq 0$$

(aggregate GHGs constraint by protocol),

or

$$\bar{g}^{t+1} \sum_i Q_i^{t+1} - \sum_i g_i Q_i^{t+1} \leq 0$$

(economy's GHGs intensity constrained by protocol).

(3) $\{hxk\} \subseteq \{ixj\}$

(only allowable set of technique changes may be considered).

As with all LPs, only specific numerical solutions are possible, employing computer based algorithms. The solution will yield the following sets : $\{q_{ij}^t\}$, $\{q_{jk}^t\}$, $\{k^t_j\}$. The first two will enable the computation of the least cost IPC^t, using equation (A8) given above.

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