LOCKHEED MARTIN ENERGY RESEARCH LIBRARIES

3 4456 0452032 9

ORNL/TM-7789

ornl

OAK
RIDGE
NATIONAL
LABORATORY

UNION
CARBIDE

Adjoint Sensitivity Theory and Its Application to Leap Model 22C

R. G. Alsmiller, Jr.
J. Barish
J. D. Drischler
J. E. Horwedel
J. L. Lucius
J. W. McAdoo

OAK RIDGE NATIONAL LABORATORY
CENTRAL RESEARCH LIBRARY
CIRCULATION SECTION
4500N ROOM 175
LIBRARY LOAN COPY
DO NOT TRANSFER TO ANOTHER PERSON
If you wish someone else to see this report, send in name with report and the library will arrange a loan.
UCN-7969 (3 9-77)

OPERATED BY
UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A06; Microfiche A01

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ORNL/TM-7789

Contract No. W-7405-eng-26

Engineering Physics Division

ADJOINT SENSITIVITY THEORY AND ITS APPLICATION TO LEAP MODEL 22C*

R. G. Alsmiller, Jr.
J. Barish[+]
J. D. Drischler
J. E. Horwedel[+]
J. L. Lucius[+]
J. W. McAdoo[§]

*Submitted for Journal publication

[+]Computer Sciences Division

[§]Presently at TVA, Knoxville

Date Published - June 1981

This Work Sponsored by
Department of Energy
Office of Energy Information
Validation

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

LOCKHEED MARTIN ENERGY RESEARCH LIBRARIES

3 4456 0452032 9

ACKNOWLEDGMENTS

Thanks are extended to Mary Hutzler of the Long-Term Energy Analysis Division of the Office of Applied Analysis in the Energy Information Administration for many helpful discussions concerning the equations of LEAP and the results obtained with LEAP.

The authors also thank R. W. Peelle, C. R. Weisbin, M. Goldstein, E. M. Oblow and L. Stewart for their help on many occasions and for the use we have made of their work prior to its publication.

TABLE OF CONTENTS

Section		Page
ABSTRACT		vii
I.	INTRODUCTION	1
II.	ADJOINT SENSITIVITY THEORY	3
III.	LEAP MODEL 22C	7
IV.	APPLICATION OF THE THEORY TO LEAP-78	22
	A. Elements of the A Matrix	22
	B. Elements of the $\overline{S}$ Vector	27
	C. Responses of Interest	31
	D. Numerical Determination of Sensitivities	34
V.	RESULTS AND DISCUSSION	38
VI.	SUMMARY	72
APPENDIX A	Numerical Determination of the Elements of the A Matrix	73
APPENDIX B	Relative Sensitivities	75
APPENDIX C	Data Elements in the Process Submodels	86
REFERENCES		104

ABSTRACT

There has been available for some time a mathematical methodology, called adjoint sensitivity theory, for determining the sensitivity of results of interest to each of the data elements that enter into the calculations. In this paper adjoint sensitivity theory is discussed and its applicability to a large energy-economics model is demonstrated by applying it to a specific calculation carried out with the Long-Term Energy Analysis Program (LEAP). Numerical results for $\frac{dR}{dx}$, where R is the result of interest and x is any one of the data elements, are presented for all x for which $\frac{dR}{dx}$ is appreciable and for several definitions of R. In a number of cases the accuracy of the $\frac{dR}{dx}$ obtained by adjoint methods has been verified by direct calculations and these comparisons are also presented.

The application of the theory as presented here requires extensive development work in that a large amount of analytic differentiation must be carried out and a substantial effort is needed to evaluate these derivatives. In the course of the work, a method was developed that would allow all of the required derivatives to be obtained numerically using LEAP and this method is presented and discussed. This numerical method is applicable only to codes with the very special modular structure of LEAP.

I. INTRODUCTION

Large energy-economic models often rely on a data field that contains thousands of elements, i.e., for such models thousands of numbers must be specified before a result of interest can be calculated. In general, not all of these data elements are of equal importance in producing a given result, but in the past it has been very difficult to systematically determine which data elements have the most influence in producing a given result. This can be done by systematically varying the data elements one at a time and completely re-doing the calculations each time, but this method is prohibitive unless the computing time for each variation is very short.

There has been available for some time, a mathematical methodology, hereinafter called adjoint sensitivity theory, for determining, in principle, the sensitivity of results of interest to each of the elements in the data field that enters into the calculations (Cacuci (1980), Oblow (1978), and Oblow (1979)). More precisely, if R is a result of interest, obtained by solving larger sets of nonlinear equations, the methodology provides a means, in principle, of calculating $\frac{dR}{dx}$, hereinafter called the sensitivity of R to x, for every element x in the data field. After $\frac{dR}{dx}$ is known for all x it is a small matter to determine those x's for which $\frac{dR}{dx}$ is large. It should be emphasized that the methodology provides only the first derivatives and gives no information about the higher derivatives. The qualifier, in principle, in the above two sentences is introduced because in applications such as those considered here the very small sensitivities are difficult to calculate accurately and since they are of little interest no attempt is made to improve their accuracy. The methodology has been

applied in a variety of physical cases, (see Cacuci (1980)) but it has not, to our knowledge, been applied to large energy-economics models. In this paper adjoint sensitivity theory is described and its applicability to a large energy-economics model is demonstrated by applying it to a particular (see below) large energy-economics model. The derivatives, $\frac{dR}{dx}$, obtained by adjoint sensitivity theory can, in principle, be obtained by direct calculations and some comparisons between the results obtained using adoint methods and direct calculations are presented.

The Long-Term Energy Analysis Program (LEAP) is an energy-economics modeling system that resides in the Long-Term Energy Analysis Division of the Integrative Analysis Group of the office of Applied Analysis, Energy Information Administration of the U.S. Department of Energy (see Pearson (1979)). LEAP is similar to but distinct from the Generalized Equilibrium Modeling System (GEMS) currently available from Decision Focus, Inc., Adler (1979). LEAP is a modeling system that may be used to construct a variety of energy-economic models. The particular LEAP model considered here is termed Model 22C, and is the model that was used to prepare projections through the year 2020 that were included in the 1978 Energy Information Administration Annual Report to Congress, Pearson (1979). A FORTRAN listing of the LEAP code used and the model input tables that completely specify this model will be found in Ford (1981). For convenience, LEAP Model 22C will hereinafter be designated as LEAP-78. Sufficient information on LEAP-78 to understand the work reported here is given in Sections III and V of this paper, but the interested reader will find much additional information concerning LEAP in general and LEAP-78 in particular in Ford (1981), Diedrick (1979), Cherniavsky (1980), Falk (1979),

Alsmiller (1980), Goldstein (1981), Stewart (1981), Oblow (1981), Hansen (1981) and Peelle (1981).

II. ADJOINT SENSITIVITY THEORY

In this section adjoint sensitivity theory is described and discussed. Adjoint sensitivity theory is similar to the method of comparative statics sometimes used in economics (see Samuelson (1976)). A more complete development of the theory together with references to the earlier literature and previous applications of the theory will be found in the work of D. G. Cacuci (Cacuci (1980)). For convenience a general notation is used in this section, the particularization of the notation to LEAP-78 will be made in the next section. Also, in the application considered here only algebraic equations occur so the development will be made for this type of equation. The methodology is, however, applicable to more general types of equations as indicated in Cacuci (1980).

Let the system under consideration be represented by N nonlinear algebraic equations in N unknown which may be written symbolically as

$$\overline{F}(\overline{p},\overline{x}) = 0, \tag{II.1}$$

where $\overline{F}$ is an N-vector function of the unknown dependent variable N-vector $\overline{p}$ and all data elements are represented by the vector $\overline{x}$. The form of the equations are given explicitly in Eq. (IV.1) and are discussed in Section IV.A. It is to be understood that the number of elements in $\overline{x}$ is not at all related to N and can be substantially larger. In the following it is assumed that for a specific choice of $\overline{x}$ a unique solution of Eq. (II.1) exists and is represented by $\overline{p}$. The vector $\overline{p}$ is thus a

function of $\overline{x}$.

Let R represent any result, hereinafter also called a response, of the calculations that are of interest. In particular, let

$$R \equiv R(\overline{p},\overline{x}), \tag{II.2}$$

where $R(\overline{p},\overline{x})$ is any given nonlinear function of $\overline{p}$ and $\overline{x}$. The response R is a scalar that may be calculated from Eq. (II.2) when the solution $\overline{p}$ of Eq. (II.1) has been obtained for a given specification of $\overline{x}$.

If now x is defined to be a general element of $\overline{x}$ the sensitivity of R to x is defined to be $\frac{dR}{dx}$ and the general problem of sensitivity theory is to determine $\frac{dR}{dx}$ for each and every one of the elements of $\overline{x}$. To accomplish this let us differentiate Eq. (II.2) with respect to x to obtain

$$\frac{dR}{dx} = \frac{\partial R}{\partial x} + \frac{\partial R}{\partial \overline{p}} \cdot \frac{d\overline{p}}{dx} , \tag{II.3}$$

where $\frac{\partial R}{\partial \overline{p}}$ is a row vector. The first term on the right-hand side of Eq. (II.3) is termed the "direct effect" of x on R and the second term on the right-hand side in Eq. (II.3) is called the "indirect effect" of x on R, since it reflects the implicit effect of x on R through $\overline{p}$.

The evaluation of the second term on the right-hand side of Eq. (II.3) begins with the differentiation of Eq. (II.1) with respect to x to give

$$\frac{\partial \overline{F}}{\partial x} + \frac{\partial \overline{F}}{\partial \overline{p}} \cdot \frac{d\overline{p}}{dx} = 0 \quad . \tag{II.4}$$

Now defining two new N-vectors

$$\overline{\Phi} \equiv \frac{d\overline{p}}{dx} \tag{II.5}$$

$$\overline{S} \equiv -\frac{\partial F}{\partial x} , \tag{II.6}$$

and the N by N matrix

$$A \equiv \frac{\partial \overline{F}}{\partial \overline{p}} , \tag{II.7}$$

Eq. (II.4) may be rewritten as

$$A\overline{\Phi} = \overline{S} . \tag{II.8}$$

Here Φ is the differential change in the solution $\overline{p}$ with respect to a change in x and it solves the linear inhomogeneous equation whose source is the negative of the partial differential change in $\overline{F}$ with respect to x. The fact that A is a linear operator is clear from Eq. (II.4) since it cannot, in principle, depend on $\frac{d\overline{p}}{dx}$. The matrix A does depend on both $\overline{p}$ and $\overline{x}$.

The expression for $\frac{dR}{dx}$ in Eq. (II.3) can now be evaluated by solving Eq. (II.8) for $\overline{\Phi}$. The difficulty here lies in the fact that $\overline{S}$ depends explicitly on the particular dx being considered and thus, in general, very large systems of linear equations represented by Eq. (II.8) must be solved for each dx to obtain $\frac{dR}{dx}$. For very large systems where $\overline{x}$ contains thousands of elements this is impractical. It should be noted that the explicit assumption is being made here that it is not feasible to numerically construct the inverse of the matrix A. If this inverse could be obtained then the need for solving the large systems of linear equations many times would be ameliorated and the above objection would not be valid.

The adjoint formulation of sensitivity theory is of interest because it avoids the necessity of solving a large set of linear equations for every x in $\overline{x}$. The set of equations adjoint to the Eq. (II.8) will be written

$$A^* \overline{\Phi}^* = \overline{S}^* , \tag{II.9}$$

where the N by N matrix A^* is defined to be

$$A^* = \tilde{A}, \tag{II.10}$$

where a superscript * is used to denote adjoint and a ∿ over a symbol is used to indicate the transpose and where $\overline{S}^*$ is yet to be defined. If now the inner product of $\tilde{\overline{\Phi}}$ with Eq. (II.9) and $\tilde{\overline{\Phi}}^*$ with Eq. (II.8) is taken one obtains by using Eq. (II.10)

$$\tilde{\overline{\Phi}} \cdot \overline{S}^* = \tilde{\overline{\Phi}}^* \cdot \overline{S}, \tag{II.11}$$

and if $\overline{S}^*$ is defined by

$$\overline{S}^* = \frac{\partial \tilde{R}}{\partial \overline{p}} , \tag{II.12}$$

then using Eqs. (II.11) and (II.12) Eq. (II.3) may be written

$$\frac{dR}{dx} = \frac{\partial R}{\partial x} + \tilde{\overline{\Phi}}^* \cdot \overline{S}, \tag{II.13}$$

where $\overline{\Phi}^*$ is the solution of Eq. (II.9) with $\overline{S}^*$ given by Eq. (II.12).

Equation (II.13) is the important result of adjoint sensitivity theory. The quantity $\overline{\Phi}^*$ must be obtained by solving the, often large, set of linear equations given in Eq. (II.9), but this $\overline{\Phi}^*$ may be used in Eq. (II.13) for all x of the vector $\overline{x}$. Thus, one calculation of

$\overline{\Phi}^*$ enables the calculation of $\frac{dR}{dx}$ for all x in $\overline{x}$ for a specific R. Each new response, R, that is considered requires a new calculation $\overline{\Phi}^*$ because of Eq. (II.12).

III. LEAP MODEL 22C

LEAP Model 22C, also referred to here as LEAP-78, is a rather complex energy-economics model and considerable information about the model is needed to understand the application of adjoint sensitivity theory to the model. In this section some information about the model is provided to enable the reader to understand the remainder of this report. The interested reader will find additional information about the LEAP system and LEAP-78 in Oblow (1979), Adler (1979), Ford (1981), Diedrick (1979), Cherniavsky (1980), Falk (1979), Alsmiller (1980), Goldstein (1981), Stewart (1981) and Oblow (1981).

LEAP is a member of a particular family of long-term modeling systems called "generalized equilibrium" models. The modeling system allows a modeler to represent part or all of the energy-related portion of the economy in terms of generic aggregated activities and the energy and dollar flows that link these activities over the time interval to be modeled. The activities that are modeled range from extraction of resources (e.g., oil) to conversion of form (e.g., synfuel or electricity production) and to representation of the time-dependent end-use demand for energy services (e.g., space heat and industrial direct heat). Import and export activities can represent energy transfers outside of the main geographic region of interest. Each of the activities is modeled with a "process" subroutine that represents the intertemporal supply and

demand functions for that activity. The flexibility of this type of model is (1) that the modeler can choose a network appropriate to his problem, and (2) that process subroutines from a relatively small library can be fed data elements to make them represent those activities of interest. In operation, the computer program begins with an initial set of guesses for the energy and dollar flows and iterates with the goal to satisfy the price-quantity equations contained in each process subroutine. For the considerations of this paper the actual iteration procedure is not relevant and therefore it will not be discussed, but the interested reader will find more information on this topic in Oblow (1981).

LEAP-78 was developed by the Office of Applied Analysis of EIA to provide long-range projection for energy flows and prices suitable for inclusion in EIA's 1978 Annual Report To Congress, Pearson (1979). LEAP-78 is precisely defined by the model input tables which are input to the LEAP program by the modeler to (1) determine the model network of economic activities and energy flows, (2) identify the computer process subroutines chosen to represent the various energy-economic activities, and (3) give numerical values for all of the input parameters. The model input tables and the FORTRAN code for LEAP-78 are given in Ford (1981)

Figure 1.A, based on a figure supplied by the Office of Applied Analysis (Diedrick (1979)) illustrates the overall (sector) design of LEAP-78. The model is for the United States and the energy demand market is represented by the four sectors illustrated at the top of the figure and coal exports. Energy supplies that deplete domestic fixed-resource bases are represented by Coal, Oil/Gas, and Uranium sectors at the bottom of the figure. Additional energy is supplied by import and by renewable

ORNL-DWG 80-7672R 2

LEAP MODEL 22C INTERSECTORAL LINKS

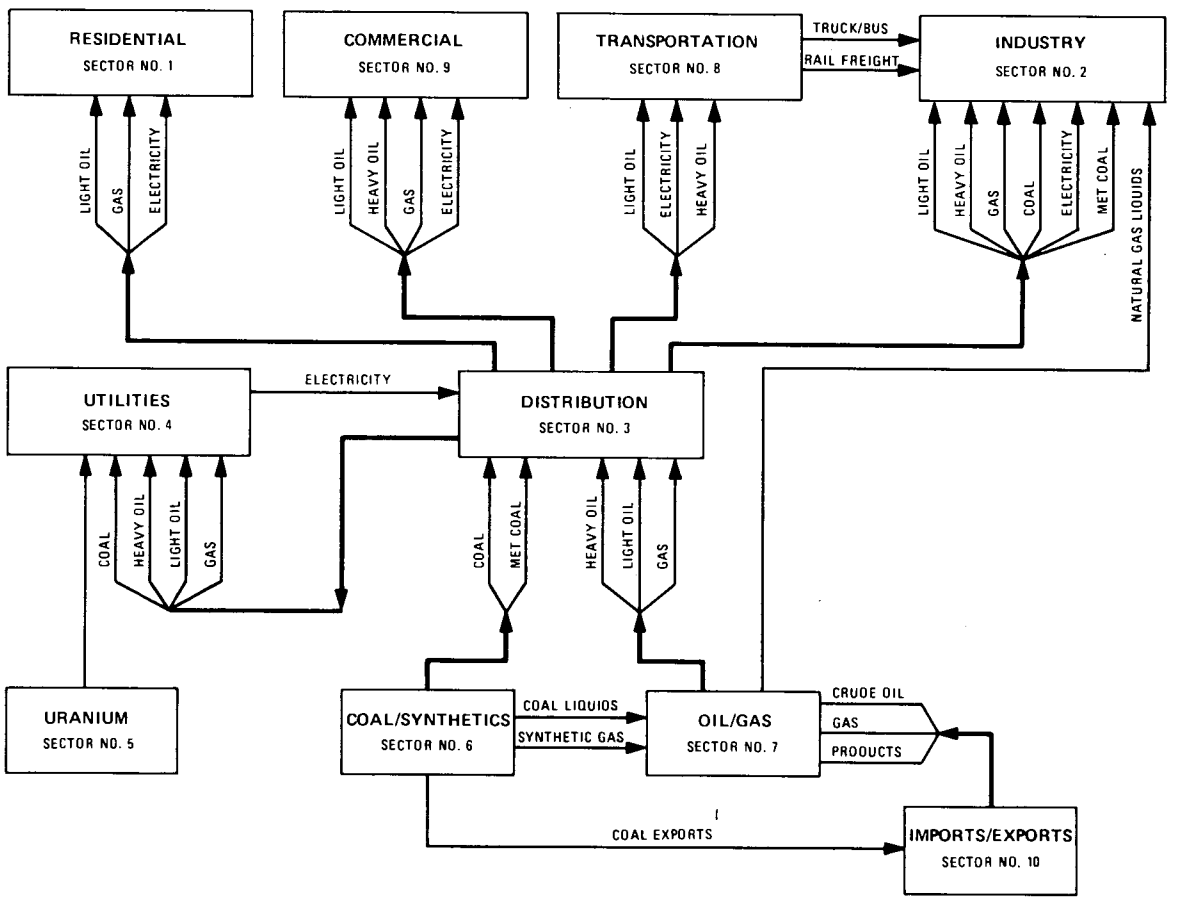

Fig. 1.A. Overall network diagram for LEAP-78.

resources represented within the individual sectors. The energy conversion facilities for central electric production are included in the Utility sector. The Distribution sector in this model has little function other than to allow for disaggregation of the total energy supply to meet the requirements of various demand sectors and to correct for the differences in average prices paid by the consumers in these sectors.

Figure 1.A is an encapsulation of the central properties of LEAP-78. In Figs. 1-9 the detailed network diagrams of the individual sectors are shown (Diedrick (1979)). [The figure numbers in each case are the same as the sector number, except that sector 10 is shown on the same figure with sector 5.] Each geometric element in Figs. 1-9 represents an activity; i.e., a process submodel and is identified by a number that is called the "node" number. The line joining two nodes is termed a link and represents an annual energy-related commodity flow and the price per unit energy at the ten time points (1975 to 2020 in five-year intervals) considered in LEAP-78. The link that leaves the top of a geometric element is termed an "output" link while the link that enters the bottom of a geometric element is termed an "input" link. Every link is an output link of one node and an input link to a different node. In Figs. 1-9 when there is more than one input or output link the links are numbered to facilitate the latter discussion.

Each of the process submodels (represented by a different geometric shape in Figs. 1-9) represent a different type of activity. A very brief discussion of the submodels is given below.

The allocation process (indicated by a circulat or upper semicircular configuration in Figs. 1-9) is used to allocate demand for energy

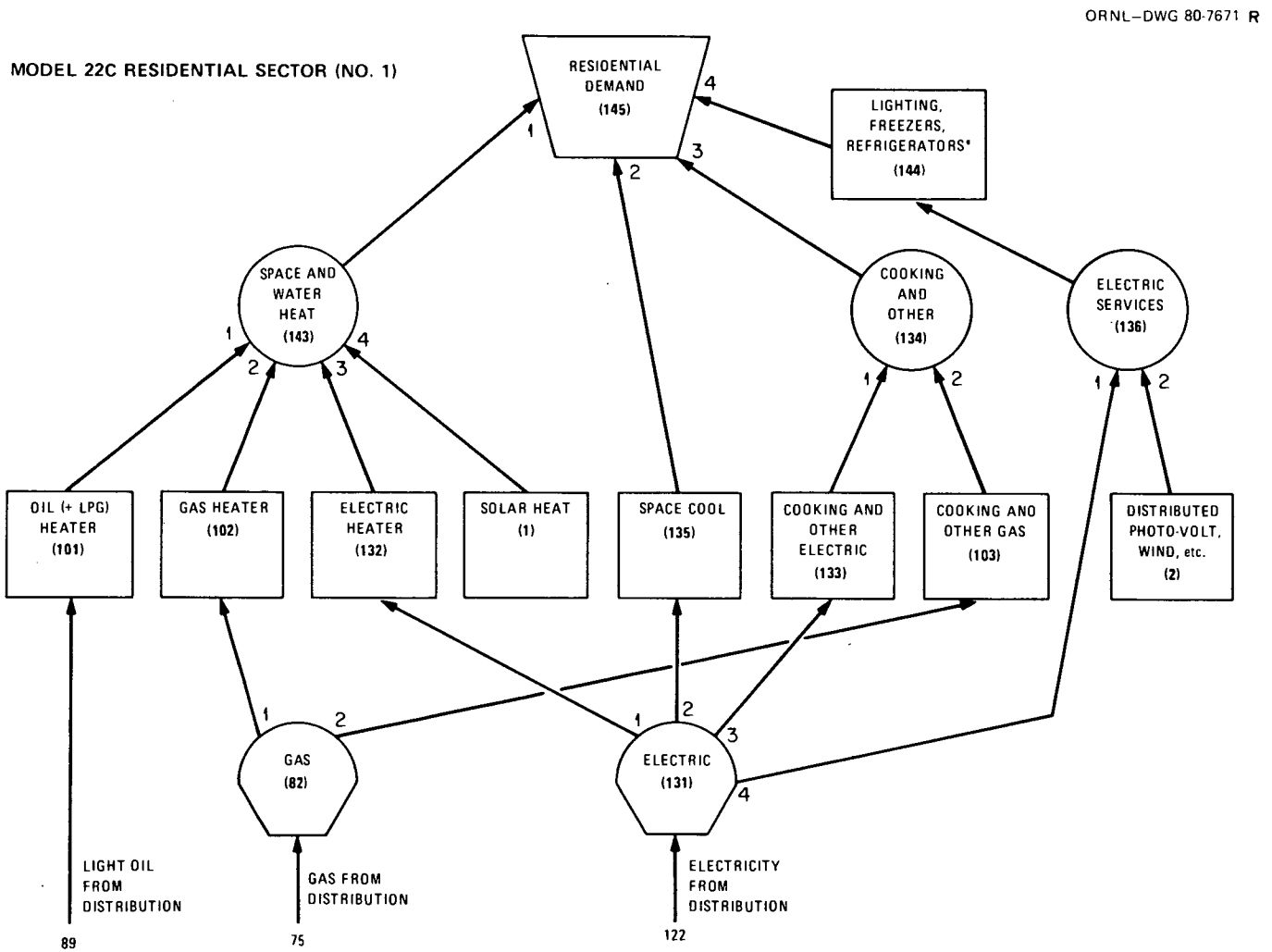

Fig. 1. Network diagram for the residential sector of LEAP-78.

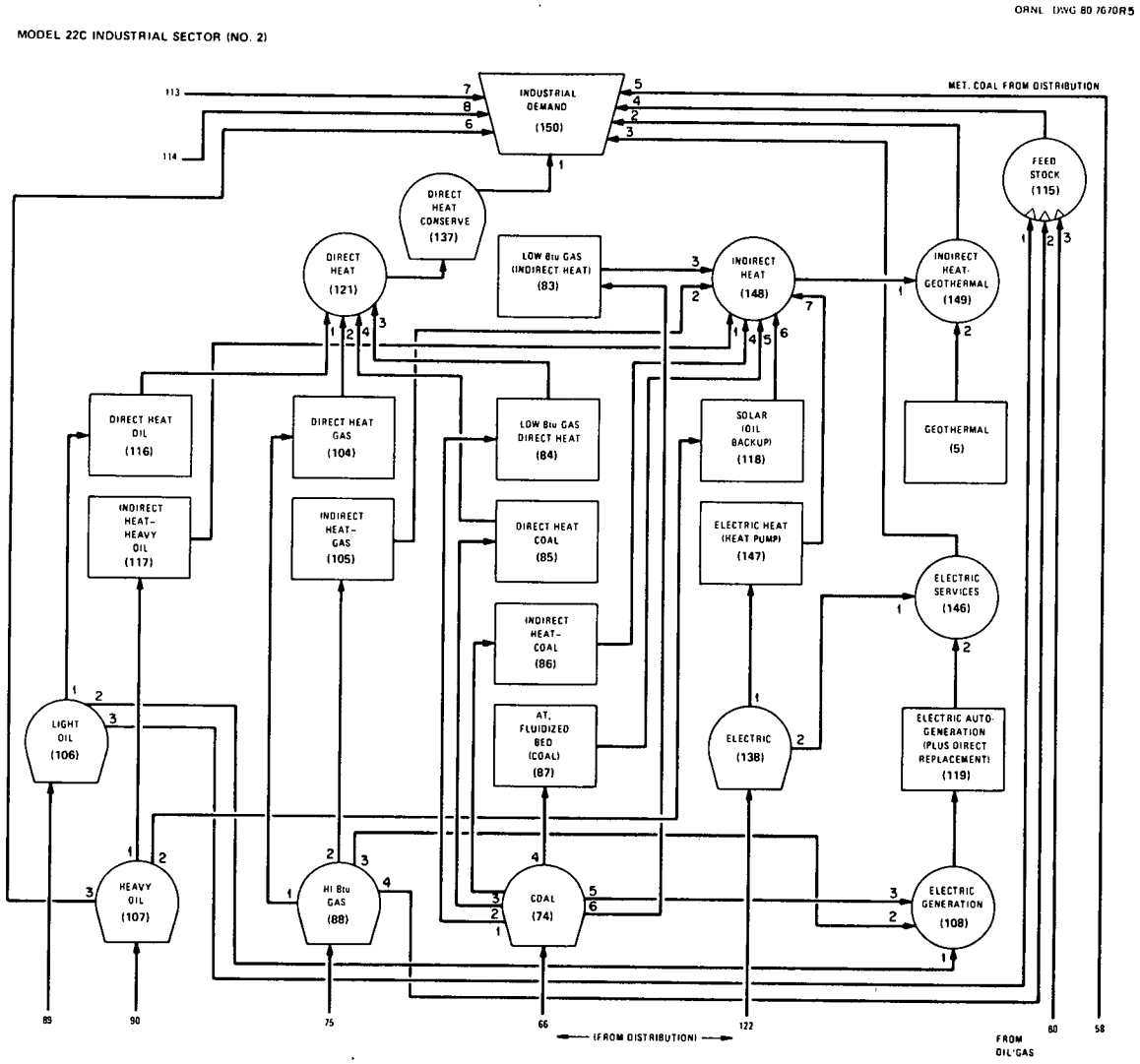

Fig. 2. Network diagram for the industrial sector of LEAP-78

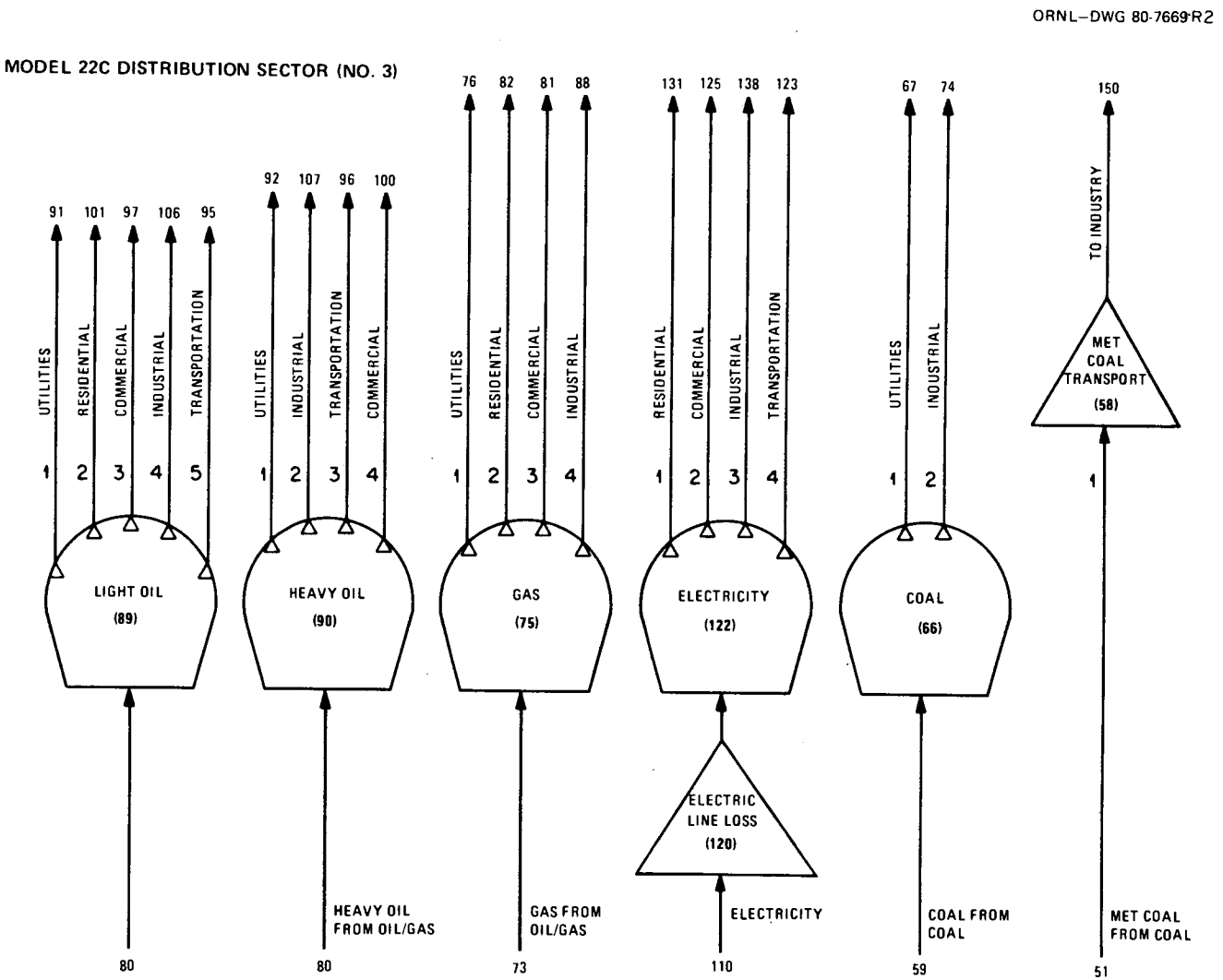

Fig. 3. Network diagram for the distribution sector of LEAP-78.

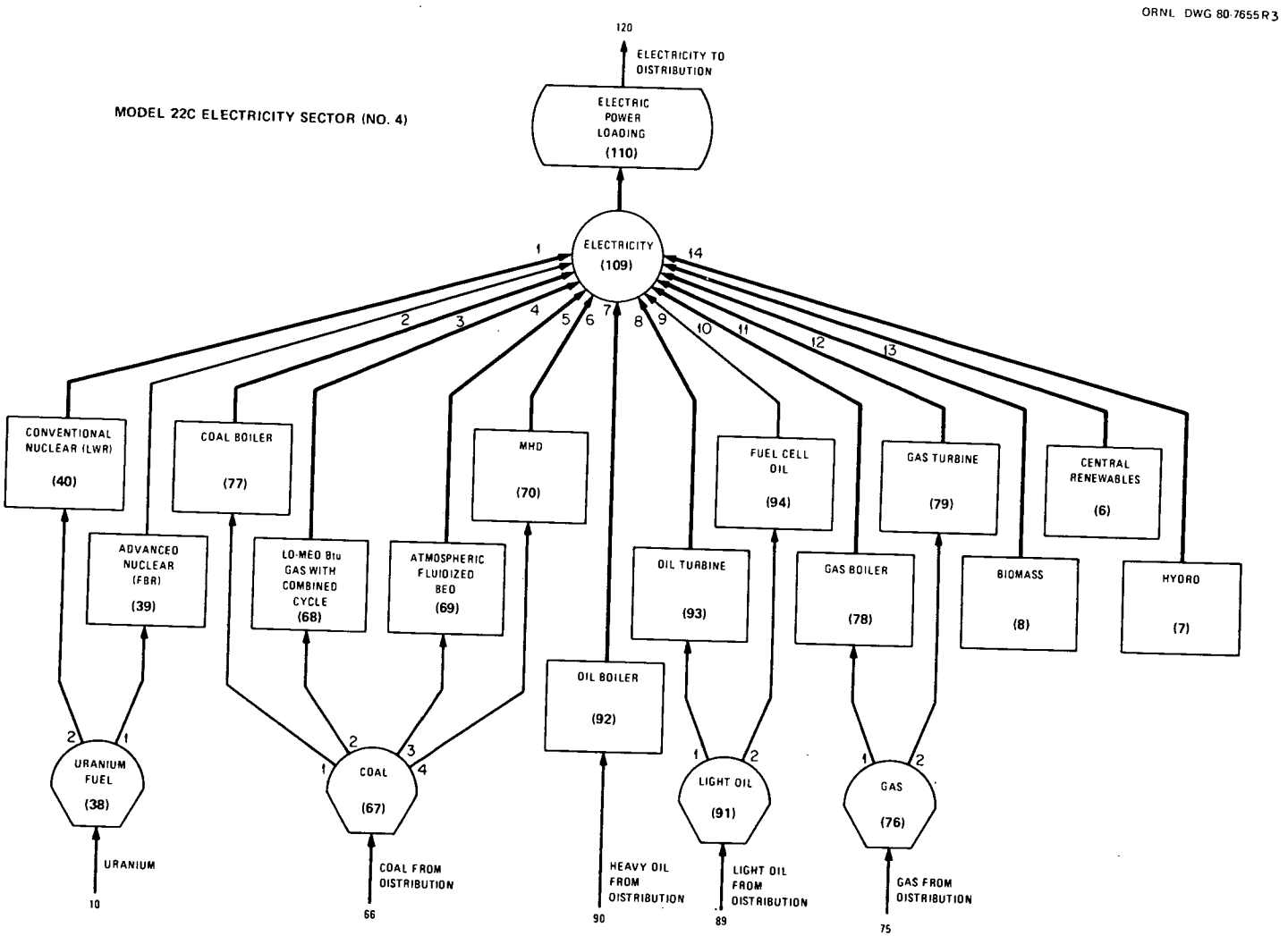

Fig. 4. Network diagram for the elctricity sector of LEAP-78.

ORNL–DWG 80-7677 R

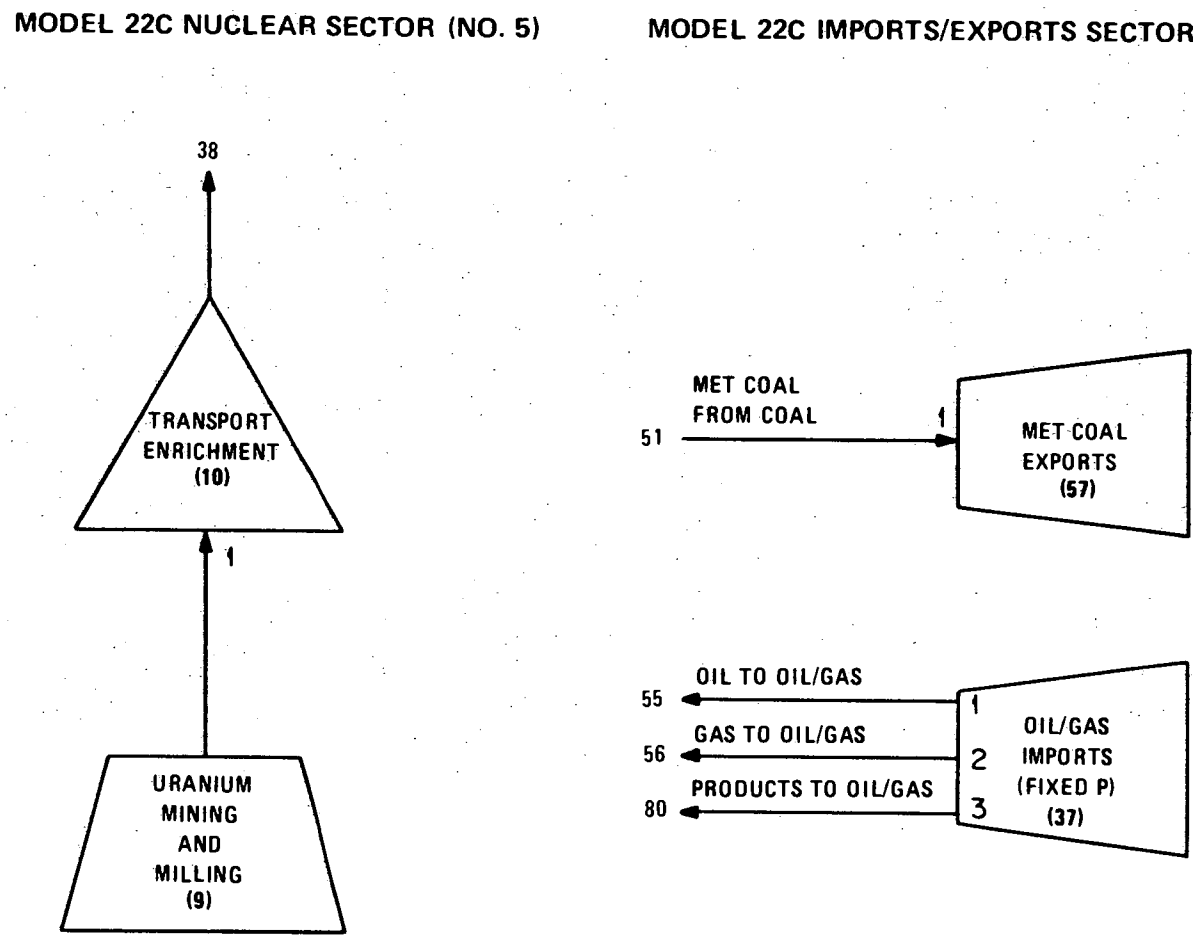

Fig. 5. Network diagrams for the nuclear and imports/exports sectors of LEAP-78.

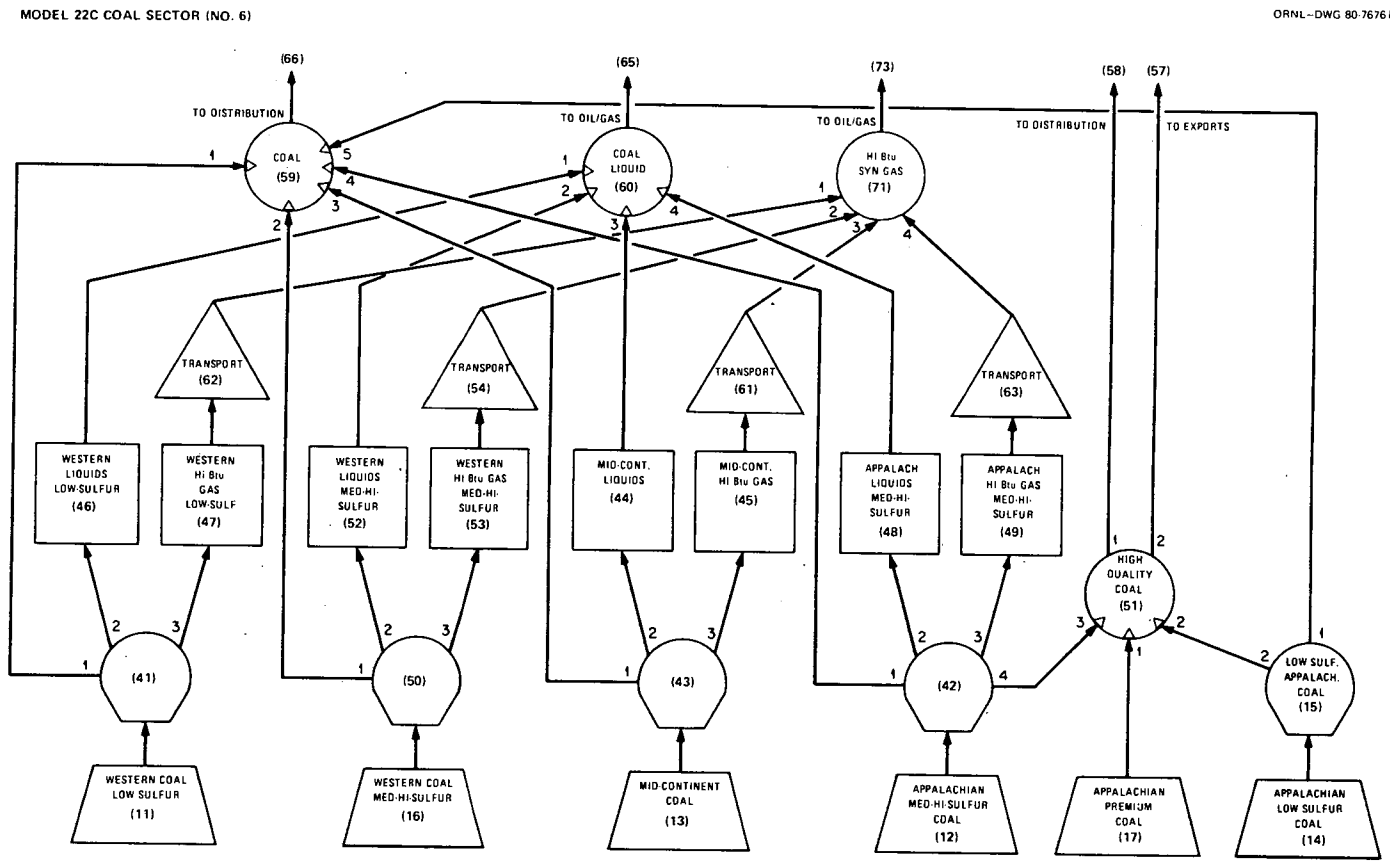

Fig. 6. Network diagram for the coal sector of LEAP-78.

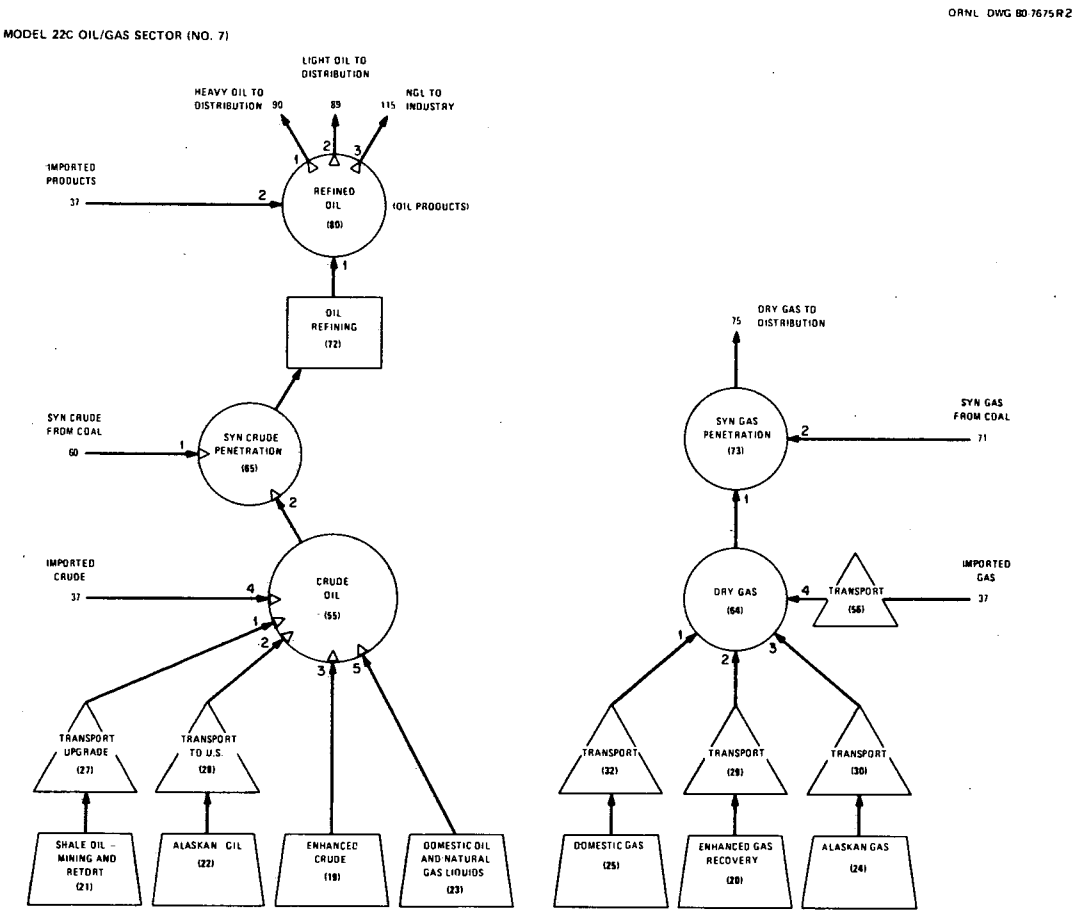

Fig. 7. Network diagram for the oil/gas sector of LEAP-78.

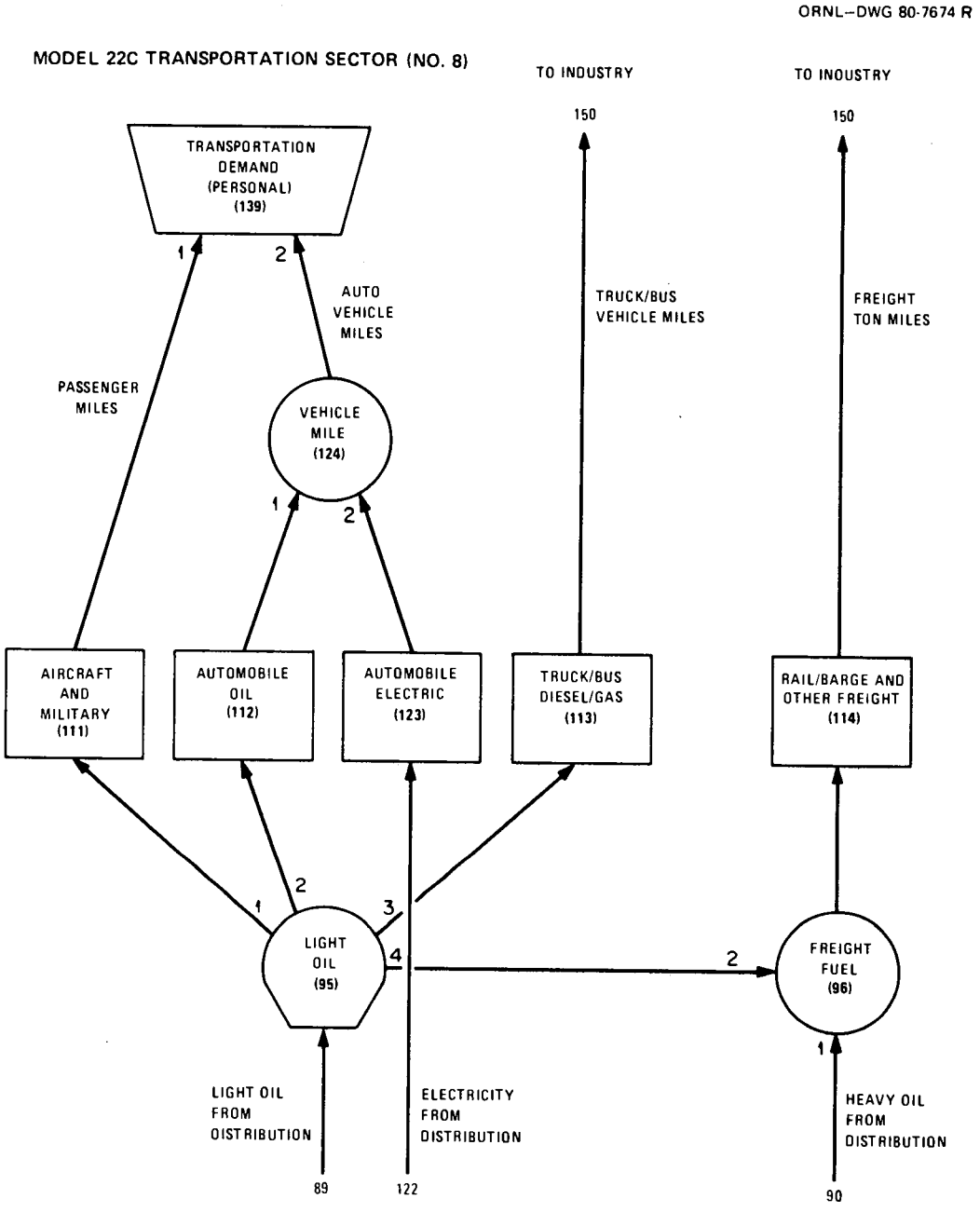

Fig. 8. Network diagram for the transportation sector of LEAP.

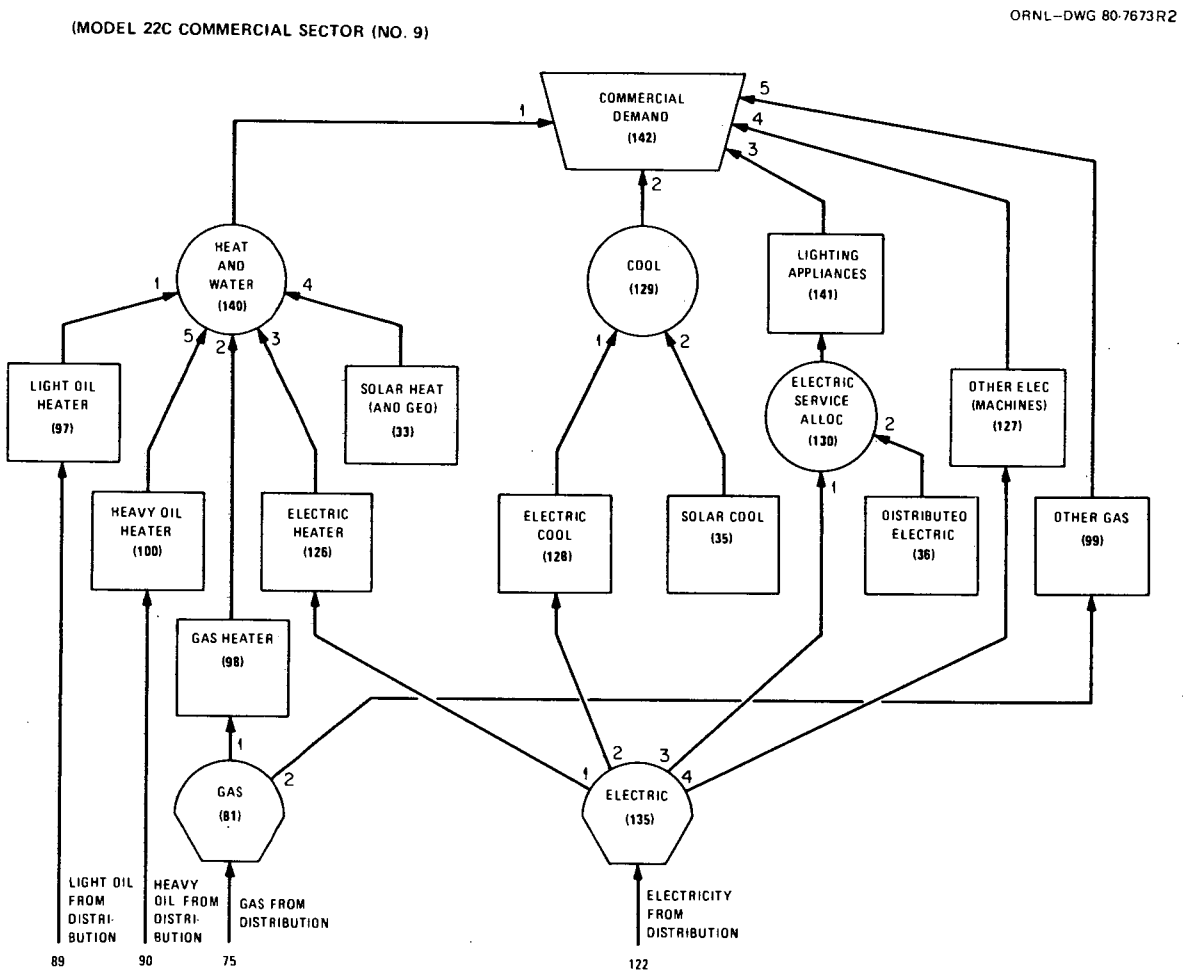

Fig. 9. Network diagram for the commercial sector of LRAP Model 22C.

or an energy-related service among competing suppliers and to set the average price of the combined energy flow. The output market shares depend on the relative prices, the market shares in the prior period, and the input parameters. In the special case in which only one supplier is linked to an allocation activity, the process simply combines demands for each model time point and links them to the common supplier.

The conversion process (represented by a square in Figs. 1-9) is used to model all manner of generic energy conversion facilities. Prices of the energy form supplied by the modeled activity for each model year are computed from (1) the input parameters, (2) the stream of quantities of energy demanded for that activity, and (3) the price vector (vs. time) for the input energy supply to the process. The conversion process may be used with several load categories to model electricity generation. Here, the term conversion process will be used to denote the case of only one load category and the term electric power conversion will be used to denote electricity generation. The term conversion process as used here has the same meaning as the term "basic conversion process" that has sometimes been used.

The resource process (represented by a trapezoid in Figs. 5-7) is used to model declining reserves. The resource process gives for its single output link the vector of prices required to provide the stream of quantities of the demanded resource. There are two different but similar resource processes: RESOURCE, that describes the situation when the reserves decline exponentially, and C-RESOURCE that describes the situation when production is taken as constant over the facility life (see Cherniavsky (1980)). In the remainder of this paper the term

"resource process" will always mean the case of exponentially declining reserves and "c-resource process" will be used to indicate the constant production case.

The transportation process (represented by a triangle in Figs. 1-9) is used to model the cost of transporting energy. The capital cost of transport facilities are not explicitly included, but transportation cost and energy losses are modeled.

The import process (see Fig. 5) models the importation of oil, gas, and oil/gas products from the world outside the U.S. In this process the price over time is input exogeneously and any desired quantity is available at this price.

The export process (see Fig. 5) models the export of coal from the U.S. The price of any exogeneously specified quantity over time is determined from the process.

Finally, the demand process (represented by inverted trapezoids in Figs. 1, 2, 8 and 9) is used to model the end-use demand for energy-related quantities for the vector of offered prices. Although the demand is parameterized in terms of increases in the gross national product and exogeneous demand sensitivity coefficients, the formula reduces to specification at input time of a stream of demand over time that is modified during iteration by a lagged-price elasticity for times after 1995.

The equations of each submodel are the same, but the data values in the submodels at different nodes will, in general, be different. The equations for each submodel are given in Goldstein (1979) and additional information on the parameters in the equations will be found in Stewart (1981). A discussion of the underlying assumptions of the submodels will be found

in Hansen (1981). Also, some additional information about the model will be given in Section V in conjunction with the discussion of the results.

IV. APPLICATION OF THE THEORY TO LEAP-78

A. Elements of the A Matrix

To apply adjoint sensitivity theory to LEAP-78 the individual elements of the A matrix (see Eq. (II.7)) must be calculated, and before this can be done the quantities that are considered the system variables must be specified.

In the work reported here the variables of LEAP-78 are taken to be the quantities (except for initial values — see below — and quantities that are specified exogeneously) and prices (except prices that are specified exogeneously) on the output links of all nodes at all time points considered (1975 to 2020 in five-year intervals). Capacity additions are not considered as variables here as they were in Alsmiller (1980) and Goldstein (1981). This means only that the equations for determining capacity additions have been used to eliminate capacity additions as variables. This procedure is used because it reduces substantially the size of the A matrix which even so is quite large (see Section IV.D). On each input link to a demand node the quantity in 1975 is specified as an initial value and on each input link to an allocation node (except when there is only one input link) the quantity in 1975 divided by the sum of the quantities in 1975 on all input links to the allocation node are used as initial conditions so these quantities are not to be considered as system variables. Also, in some cases, e.g., import and export, prices and quantities are specified exogeneously, so these prices and quantities

are not to be considered as system variables. The system variables will then by Q_{ni} and P_{ni} where

n = node index,

i = index that designates both output link and time (see below),

Q_{ni} = the quantity of energy per year on one of the output links of node n at a specific time,

P_{ni} = the price per unit energy on one of the output links of node n at a particular time.

The subscript i will, in general, take values from 1 to $N_n \cdot N$ where

N_n = the number of output links from node n,

N = the number of time points,

but this must be modified to account for initial conditions and exogeneously specified prices or quantities. For example, if M is the number of output links from node n that are input links to demand processes or allocation processes that have more than one input link, then i takes values from 1 to $N_n \cdot N-M$. Also, in those cases where the prices or quantities are specified exogeneously on an output link it is to be understood that these prices or quantities are not included in the variable list. This complication in the subscript i is important in actually determining the number of variables in the LEAP-78 system, but the values taken by i do not affect the considerations here, so hereinafter the subscript i

will be used without specifying the values it takes. Also, a subscript j that takes the same values as i will sometimes be used.

With the notation established above, the elements of Φ (see Eq. (II.5)) are the derivatives

$$\frac{dQ_{ni}}{dx_{mk}} \text{ and } \frac{dP_{ni}}{dx_{mk}} ,$$

where x_{mk} is one of the data elements in the general vector $\bar{x}$ in Eq. (III.1) that enters into the equations for node m.

To indicate more explicitly the form of the equations corresponding to a particular node it is convenient to introduce the notation

Q_{Inq} = the quantity of energy per year on one of the input links to node n at a particular time,

P_{Inq} = the price per unit energy on one of the input links to node n at a particular time.

The index q specifies both the input link and the time considered. The number of values of the index j is determined by considerations similar to those that determine the number of values of the index i. Also, a subscript r that takes the same values as q will sometimes be used. Since an output link from one node is, of necessity, an input link to another node the set of variables Q_{Inq} and P_{Inq} completely duplicates the set of variables Q_{ni} and P_{ni}.

In terms of these variables the equations for a particular node n may be written

$$\begin{aligned} P_{ni} - F_{ni}(Q_{nj}, P_{Inq}, X_{nk}) &= 0 \\ Q_{Inq} - G_{nq}(Q_{ni}, P_{Inr}, X_{nk}) &= 0 \end{aligned} \qquad \text{(IV.1)}$$

where it is to be understood that all allowed values of i, j, q, r and k occur in the argument of the functions F_{ni} and G_{nq}. The form of the functions F_{ni} and G_{nq} depend on the particular process that occurs at node n. In writing Eq. (IV.1), a fundamental propertly of LEAP, namely, that the equations for a given node can depend only on the system variables that occur on the input and output links for that node, has been introduced. This property arises from the modular structure of LEAP and is extremely important in the remainder of this paper, i.e., in the application of adjoint sensitivity theory. The form of Eq. (IV.1) is convenient for the development here and reflects the fact that in LEAP the number of equations at a given node is such that if all Q_{ni} and P_{Inq} are fixed then all P_{ni} and Q_{Inq} are determined by the equations of the node. It is to be understood that, in principle, the equations can be put in the form of Eq. (IV.1). The equations are very complex and to actually perform the algebra necessary to put the equation in this form would be very difficult and is not necessary.

If the total derivative of Eq. (IV.1) is taken with respect to any data parameter $x_{m\ell}$ one has

$$\frac{dP_{ni}}{dx_{m\ell}} - \sum_j \left[\frac{\partial F_{ni}}{\partial Q_{nj}} \frac{dQ_{nj}}{dx_{m\ell}}\right] - \sum_q \left[\frac{\partial F_{ni}}{\partial P_{Inq}} \frac{dP_{Inq}}{dx_{m\ell}}\right]$$

$$= \frac{\partial F_{ni}}{\partial x_{m\ell}} \delta^n_m$$

$$\frac{dQ_{Inq}}{dx_{m\ell}} - \sum_j \left[\frac{\partial G_{nq}}{\partial Q_{ni}} \frac{dQ_{ni}}{dx_{m\ell}}\right] - \sum_r \left[\frac{\partial G_{nq}}{\partial P_{Inr}} \frac{dP_{Inr}}{dx_{m\ell}}\right]$$

$$= \frac{\partial G_{nq}}{\partial x_{m\ell}} \delta^n_m$$

$$\delta_m^n = 1 \qquad n = m$$
$$= 0 \qquad n \neq m. \tag{IV.3}$$

Equations (IV.2) represent part of the general system of equations given in Eq. (II.8). The partial derivatives of F_{ni} and G_{nq} in Eq. (IV.2) are some of the elements of the A matrix. The subscript notation here is not at all related to the matrix notation that is sometimes used, i.e., the subscripts here do not indicate position in the A matrix as would sometimes be indicated by A_{ij}. The important point to note is that Q_{ni}, P_{ni}, Q_{Inq}, P_{Inq} constitute only a very small number of the totality of all system variables and since only partial derivatives of F_{ni} and G_{nq} with respect to these variables occur in Eq (IV.2) many elements in the rows of the A matrix that are represented by Eq. (IV.2) will be zero. This same consideration extends to all nodes and thus a consequence of the modular form of LEAP, i.e., the form of Eq. (IV.1), is that the A matrix is sparse, i.e., has many zero elements. This feature of the A matrix will be very important when numerical solutions of the adjoint equations are considered.

The equations for all of the processes that are used in LEAP-78 have been given by M. Goldstein, R. G. Alsmiller, Jr. and J. Barish in Goldstein (1981). With the equation known, it is a straightforward but tedious matter to take the required partial derivatives analytically and numerically evaluate these analytic derivatives to obtain the elements of the A matrix. The process of analytically differentiating the process equations is independent of the data values used in the equations and thus the differentiation must be carried out only once for each type of process

that occurs even if that particular process occurs many times in LEAP-78. The analytic derivatives are very lengthy and are not reproduced here, but some examples of the derivatives are given in Alsmiller (1980). The numerical evaluation of the analytic derivatives was done with a computer code written for this purpose and is completely separate from the LEAP code except that the values of the data elements and system variables for the base case being studied must be obtained from LEAP-78 input tables and solution.

B. Elements of $\overline{S}$

The elements of $\overline{S}$ that occur in Eq. (II.6) must be evaluated before sensitivities (see Eq. (II.13)) can be obtained. The elements of $\overline{S}$ are the partial derivatives with respect to the data value of interest (for all values of n, and ℓ) that occur on the right-hand side of Eq. (IV.2). With the process equations known it is again a straightforward but tedious matter to carry out the derivatives analytically and evaluate these partial derivatives. This was, however, not the procedure followed here; rather the elements of $\overline{S}$ were determined numerically directly from the LEAP code. The feasibility of obtaining partial derivatives numerically from the LEAP code became clear only late in the project. (The authors of this paper are indebted to R. W. Peelle* for suggesting this possibility to them.) The procedure of obtaining the elements of the $\overline{S}$ numerically from the LEAP code was instituted to obtain experience in this alternate procedure and to try to evaluate the possibility of obtaining all partial derivatives, i.e., the elements of the A matrix as well as the $\overline{S}$, by numerical means rather than by analytic differentiation followed by numerical evaluation. This possibility will be commented on after the

*Oak Ridge National Laboratory

methods used to obtain the elements of the $\overline{S}$ are described.

From Eq. (IV.2) it is clear that the partial derivatives of interest, i.e., $\frac{\partial F_{ni}}{\partial x_{m\ell}}$ and $\frac{\partial G_{nq}}{\partial x_{m\ell}}$, involve only the equations of one node at a time. Let us then consider a particular node n completely isolated from the remainder of the network and consider what happens if one of the data values at node n, say $x_{n\ell}$, is changed to $x_{n\ell} + \Delta x_{n\ell}$ and the equations of the isolated node solved for new system variables Q'_{ni}, P'_{ni}, Q'_{Inq} for all allowed values of i and q. First, there are not enough equations for the isolated node to determine all of these variables so some of the variables will not be modified by the change from $x_{n\ell}$ to $x_{n\ell} + \Delta x_{n\ell}$. In fact, the LEAP equations at any node are such that for the isolated node one may specify Q_{ni} and P_{Inq} for all allowed i and q and then the equations will determine with the change $x_{n\ell} + \Delta x_{n\ell}$, unambiguously the variables P'_{ni} and Q'_{Inq} (see Eq. (IV.1)). It should be noted that an iteration is, in principle, required because in LEAP capacity additions are not eliminated as is being assumed here, but the convergence is very rapid. Let us then specify

$$Q_{ni} = Q'_{ni}$$
$$P_{Inq} = P'_{Inq} \,, \tag{IV.4}$$

and then write

$$\frac{dQ_{ni}}{dx_n} = \frac{Q'_{ni} - Q_{ni}}{\Delta x_{n\ell}} = 0 \tag{IV.5}$$

$$\frac{dP_{ni}}{dx_{n\ell}} = \frac{P'_{ni} - P_{ni}}{\Delta x_{n\ell}} \tag{IV.6}$$

$$\frac{dQ_{Inq}}{dx_{n\ell}} = \frac{Q'_{Inq} - Q_{Inq}}{\Delta x_{n\ell}} \tag{IV.7}$$

$$\frac{dP_{Inq}}{dx_{n\ell}} = \frac{P'_{Inq} - P_{Inq}}{\Delta x_{n\ell}} = 0 \tag{IV.8}$$

for all allowed i, q and ℓ. Equation (IV.2) considered only for those data values in node n, i.e., with n=m, may be considered as equations for determining the partial derivatives on the right-hand side of the equations if everything on the left-hand side is known. The calculations of the partial derivatives on the left-hand side of Eq. (IV.2) have been described in the previous subsection of this paper. Thus, with the estimates of the total derivatives given by Eqs. (IV.5) to (IV.8) estimates of $\frac{\partial F_{ni}}{\partial x_{n\ell}}$ and and $\frac{\partial G_{nq}}{\partial x_{n\ell}}$ may be obtained from Eq. (IV.2). This procedure may be repeated for all parameters at node n and for all nodes so estimates of all elements of $\overline{S}$ can be obtained.

Difficulties arise in the numerical procedure when data values are at the end of their allowed range, e.g., if a data value can not be larger than unity and the modeler has given it the value unity so it can not be increased. This difficulty can be circumvented by changing the parameter in the direction that is allowed, but a question concerning the modeler's intention arises. A data value may be put at the end of its range by the modeler as an artifice to eliminate some features of the code from consideration and thus some questions arises as to whether this is a true data value. Difficulties also arise with data values that are set equal to zero because usually the changed data values are taken to be fixed percentage of the base case value. This difficulty can again be circumvented, but there is again a question as to the modeler's intention. In the work reported here, it is assumed that data values at the end of their

range and zero data values are not to be varied. There are only a few data elements at the end of their range, but there are many data elements that have a zero value in LEAP-78 (Stewart (1981)).

To obtain the elements of the S vector numerically requires a fair amount of computing and substantial data handling, but saves substantially on the analytical differentiations required, and the programming.

While it is not done here, it is possible to obtain the elements of the A matrix by numerical means in much the same manner as the elements of the $\overline{S}$ were obtained. The procedure for doing this is described in Appendix A. As with the numerical determination of $\overline{S}$ this procedure replaces the process of taking analytic derivatives and evaluating them with significant amounts of additional computing and data handling. Also, the numerical procedure is less accurate because of the finite difference approximations used.

Given a code with the modular structure of LEAP, and it must be emphasized that the numerical procedure outlined above is applicable only to systems with the very special modular structure of LEAP, the question as to whether the procedure of using analytic or numerical derivatives is preferable depends on a variety of factors, e.g., complexity of equations, available documentation of the equations, etc. Perhaps the most overriding consideration is how frequently the equations are expected to change and how extensive these changes are likely to be. If the equations change the analytic derivatives must be changed and reprogrammed. On the other hand, the numerical procedures are independent of the form of the equations and therefore do not become obsolete with equation changes. Since, in the work reported here, only the elements of the $\overline{S}$ and not the elements of the

A matrix are determined numerically, we can not, from experience, recommend the complete numerical procedure, but it is our impression that, for LEAP, a code designed to determine sensitivities completely numerically would be very useful.

C. Responses of Interest

From Section II it is clear that sensitivities, as considered here, are defined only with respect to a particular result or response of interest. As explained with regard to Eq. (II.2), a response may be any function of the system variables and the elements of the data field. In this section the four responses that are considered here are defined. The responses considered here were suggested by Mary Hutzler of the Office of Applied Analysis of the Energy Information Administration.

The first response considered is the ratio of the total annual energy cost to all end uses in the year 2020 to the Gross National Product in the year 2020. This response, $R_1(10)$, may be obtained by putting $J = 10$ in the equation

$$R_1(J) = \frac{1}{G_{NP}(J)} \sum_n \sum_i Q_{Ini}(J) P_{Ini}(J), \qquad \text{(IV.16)}$$

where J takes values 1 to 10 corresponding to the 10 model years, 1975, 1980, 1985, . . . , 2020 considered in LEAP-78, and

i = the input links to node n (A slight change in notation has been introduced. Previously, the subscript i was used to represent both input links and time, but in Eq. (IV.16) time is given explicitly by J and i represents only input links.),

$\sum_i$ = a sum over all input links to node n,

$\sum_n$ = a sum over all end-use nodes, i.e., node 145 in Fig. 1, node 150 in Fig. 2, node 139 in Fig. 8, and node 142 in Fig. 9.

The quantity $G_{NP}(J)$ is defined by

$$G_{NP}(J) = G_{NP}(1) \prod_{K=2}^{J} [1+y(K)]^{\Delta} \qquad J = 2 \text{ to } 10 \qquad \text{(IV.17)}$$

where $\prod$ is used to indicate product, and

y(K) = the rate of change of G_{NP} in year K (The quantities y(K) for K = 2 to 10 are input data to LEAP-78 and are therefore elements of $\bar{x}$ (see Eq. (II.1).),

Δ = 5 (corresponding to the fact that LEAP-78 uses five-year intervals),

and $G_{NP}(1)$ is taken to be $1.53 \cdot 10^3$ billion dollars. The product $Q_{Ini}P_{Ini}$ has units of billions of dollars so $R_1(J)$ is dimensionless. The derivatives of R_1 with respect to the system variables that occur in R_1 are needed in Eq. (II.12) and can easily be obtained from Eq. (IV.16). It is to be understood from Section II that a new solution of Eq. (II.9) must be obtained for each new response considered.

The second response considered is the ratio of the total annual cost of imported oil, oil products, and gas in the year 2020 to the Gross National Product in the year 2020. This response, $R_2(10)$ may be obtained by putting J = 10 in the equation

$$R_2(J) = \frac{1}{G_{NP}(J)} \sum_i Q_{37,i}(J) P_{37,i}(J) \qquad \text{(IV.18)}$$

where J and $G_{NP}(J)$ are as defined previously and

$\sum_i$ = a sum over all of the output links from node 37 (see Fig. 5),

$Q_{37,i}(J)$ = the quantity of energy per year at time J on output link i from node 37,

$P_{37,i}(J)$ = the price per unit of energy at time J on output link i of node 37.

In LEAP-78 the prices of imports are specified exogeneously and therefore the prices, $P_{37,i}$ in Eq. (IV.18) are data values and not system variables. This means that the derivatives of $R_2(J)$ with respect to these prices do not occur in Eq. (II.12), but these prices are elements of $\bar{x}$ (see Eq. (II.1)) and must be so treated. The response $R_2(10)$ is dimensionless.

The third response considered is the total annual imports of oil and oil products in 2020. This response, $R_3(10)$, may be obtained by putting J = 10 in the equation

$$R_3(J) = Q_{37,1}(J) + Q_{37,3}(J) \qquad \text{(IV.19)}$$

where

$Q_{37,1}(J)$ = the quantity of energy per year at time J on output link 1 of node 37 (see Fig. 5),

$Q_{37,3}(J)$ = the quantity of energy per year at time J on output link 3 of node 37 (see Fig. 5).

The response $R_3(J)$ has units and is measured in quadrillion Btu.

The final response considered is the ratio of the total annual liquid fuels input to all demand sectors in the year 2020 to the total annual fuel input to all demand sectors in the year 2020. This response, $R_4(10)$, may be obtained by putting J = 10 in the equation

$$R_4(J) = \frac{\sum_i [Q_{89,i}(J) + Q_{90,i}(J)}{Q_{80,3}(J)+Q_{58,1}+\sum_i[Q_{89,i}(J)+Q_{90,i}(J)+Q_{75,i}(J)+Q_{122,i}(J)+Q_{66,i}(J)]} \tag{IV.20}$$

where

$\sum_i$ = a sum over all output links of the indicated nodes, except that output link 1 of nodes 89, 90, 75, and 66 are excluded (see Fig. 3).

This completes the definitions of the responses considered. It should be understood that many other responses could be of interest and could be considered, but these four responses are those for which sensitivity results will be presented and discussed in Section V.

D. Numerical Calculations

After all of the individual elements in A^* and $\overline{S}^*$ (see Eqs. (II.9), (II.10) and (II.12)) have been determined, the elements of $\overline{\Phi}^*$ must be determined by solving the set of linear equations given by Eq. (II.9). The total number of system variables (as defined here) in LEAP-78 are 4359 so there are in Eq. (II.2) this many linear equations to be solved for each response. This is a formidable task, in general, but here one is helped immensely by the fact that the A matrix is sparse,

i.e., contains many zero elements. The actual number of zero elements in the A matrix depends on the form of the equations, i. e., the A matrix can be developed before the equations are reduced to the form of Eq. (IV.1), and on the actual magnitude of the elements that is considered zero, i.e., there are many elements that are very small and it is convenient to set them equal to zero before the equations are solved. In the work reported here, it was determined by trail and error that no significant error was introduced if all elements of the A matrix with absolute values $<10^{-15}$ were considered to be zero. Because the number of nonzero elements in the A matrix depends on the form of the equations (see above) it is not possible to give, with any precision, the number of nonzero elements, but very approximately in the work reported here the A matrix has $\sim 10^7$ elements and $\sim 4 \cdot 10^4$ of these elements were taken to be nonzero.

To solve numerically large sets of linear equations involving a sparse matrix there are available very efficient FORTRAN subroutines. In the work reported here the subroutines written by J. S. Duff, Peelle (1981), were used. (Thanks are due to M. Heath of the Computer Sciences Division of the Union Carbide Corporation, Oak Ridge, Tennessee for making us aware of these subroutines and for helpful discussions concerning their usage and operation.)

The LEAP-78 equations are very nonlinear and are solved by iteration so there is a limit to the accuracy of the calculated system variables. The solution used here was converged to .05% so this is the accuracy to which the system variables are known and is at least very approximately the accuracy to which any response, R, is known.

In calculating the elements of $\overline{S}$ numerically it is necessary to assume a change Δx in every parameter x to be considered. If the change in

x is too small then spurious results will be obtained because the change in the system variables induced by this change in x may be too small to be meaningful because of the accuracy to which the system variables were determined. If on the other hand, the change in x is too large one may be out of the linear range and the approximation of derivatives by finite differences may not be accurate. In the work reported here, Δx was taken to be

$$\Delta x = (.01)x \tag{IV.21}$$

for noninteger data elements and

$$\Delta x = x + 1 \tag{IV.22}$$

for integer data elements. In the case of integer data elements, the change used is the smallest change allowed without modification of the code. There is no necessity for choosing Δx by Eq. (IV.21) and (IV.22) for all x, i.e., the magnitude of Δx can be varied by different amounts depending on the meaning of the parameter, x, but this is not done here.

With the elements of $\overline{\Phi}^*$ and $\overline{S}$ determined, it is a straightforward matter to calculate $\frac{dR}{dx}$ from Eq. (II.13) for every element x of $\overline{x}$. It should be noted that the data element x may occur in many different nodes and the $\frac{dR}{dx}$ given by Eq. (II.3) is the rate of change of R with respect to x irrespective of whether it occurs at one or several nodes. In comparing the sensitivities of different data elements it is usually more meaningful to consider the relative sensitivities defined by $\frac{x}{R}\frac{dR}{dx}$ where x and R are the base case values and this is done in the next section when the results are discussed. The relative sensitivity may be interpreted

as the percent increase in the response due to a one percent increase in the data element.

In some cases at least the changes given by Eq. (IV.21) and (IV.22) will not be large enough to induce meaningful changes in the system variables and thus the smaller values of $\frac{dR}{dx}$ calculated here can not be expected to be accurate. One, very approximate, criterion for determining when $\frac{dR}{dx}$ is too small to be trustworthy is to calculate $\frac{\Delta R}{R}$ from

$$\frac{\Delta R}{R} = \frac{\Delta x}{R} \left(\frac{dR}{dx}\right) \tag{IV.23}$$

where $\frac{dR}{dx}$ is the value given by the adjoint formulation and Δx is the value used in calculating the elements of $\overline{S}$. If it is assumed (see discussion above) that the accuracy to which $\frac{\Delta R}{R}$ is known is

$$\frac{\Delta R}{R} \lesssim .0005 \tag{IV.24}$$

then the calculated relative sensitivity $\frac{x}{R}\frac{dR}{dx}$ is untrustworthy unless

$$\frac{x}{R}\frac{dR}{dx} \gtrsim \frac{x}{\Delta x}\,(.0005). \tag{IV.25}$$

For noninteger data elements where $\frac{\Delta x}{x} = 10^{-2}$ has been used this gives

$$\frac{x}{R}\frac{dR}{dx} \gtrsim 5 \cdot 10^{-2} \tag{IV.26}$$

as a very approximate criterion for when the calculated relative sensitivities should be trustworthy.

In principle, an estimate of $\frac{dR}{dx}$ can always be obtained, independently of the procedure outlined here, by changing a parameter, x, by an amount Δx and calculating $\frac{\Delta R}{\Delta x}$ by completely repeating the LEAP calculations. The problem of the magnitude of Δx to be used is much the same here as that

discussed in determining the $\overline{S}$. In the next section of this paper some comparisons are given between the $\frac{dR}{dx}$ calculated by adjoint methods and by the direct use of the LEAP-78 code. In the direct calculations, Δx was taken to be 0.10x for noninteger data values and 1 year for integer data values except when otherwise indicated.

V. RESULTS AND DISCUSSION

Calculations have been carried out to determine the relative sensitivity (see Section IV.D) of the four responses described in Section IV.C to all of the data elements in LEAP-78. For each response there are 1614 non-zero sensitivities. The large majority of these sensitivities are very small and are therefore of little interest. Furthermore, as explained in Section IV.D, the sensitivities are not expected to be accurate when they are very small because of the convergence criterion ($5 \cdot 10^{-2}$%) used in the base case calculation, i.e., the system variables for the base case are, in principle, known only to an accuracy of $5 \cdot 10^{-2}$%. In this section only the 20 largest relative sensitivities for each response are given and discussed. It should be emphasized, however, that for each response considered, the relative sensitivity has been calculated for each data element, and thus those data elements that are considered in this section are, to within the accuracy of the calculations, known to be the data elements with the largest absolute relative sensitivity. In Appendix B all of the data elements for each response considered here that has an absolute relative sensitivity $>5 \cdot 10^{-2}$ are given.

The accuracy of the calculations can be tested by calculating the relative sensitivity of a given response to a particular data element

directly from LEAP-78 (see Section IV.d). In this section some comparisons between relative sensitivities obtained by adjoint methods and direct calculations are also presented.

The calculated results for the responses $R_1(10)$, $R_2(10)$, $R_3(10)$, and $R_4(10)$ (see Section IV.C) are given in Tables 1 to 4, respectively. In these tables the first column gives the node number at which the data element, x, occurs and in parenthesis the figure number in which the node is shown. The term "many" in the first column is used to indicate that the data element occurs at more than one node and the relative sensitivity expresses the rate of change of the response with respect to an increase in the data element everywhere it occurs. The second column gives the descriptive name of the activity that is used in Figs. 1 to 9 if only one node is involved and the process submodel that is used at this node. When more than one node is involved the comments in the second column give an indication of the activities that are included. The third column gives the name of the data element x being considered and the time (or other) index that is needed to completely specify the data element. When Link i is specified the i refers to the numbers on the links in Figs. 1 to 9. The data element name given in the tables is the FORTRAN name used in the LEAP-78 computer code. Some information on the meaning of these data elements is given in the footnotes to the tables and in the discussion below, but explicit definitions for these data elements will be found in Stewart (1981) and the manner in which the data elements enter into the equations of the process submodels is shown in Goldstein (1981). The symbols used in Goldstein (1981) are not the FORTRAN names, but a complete cross reference between the symbols and the FORTRAN names is given in

Stewart (1981). The fourth column in each table gives the value of the data element, x, in the base case. The fifth column gives the relative sensitivity obtained by adjoint methods and the sixth column gives the relative sensitivity obtained by direct calculations using LEAP-78. Relative sensitivities have been obtained by direct calculations for only some of the parameters considered in Tables 1-4 and thus values are not given in column 6 for all parameters. The relative sensitivities are listed in column 5 of the tables in order of decreasing absolute magnitude.

The response considered in Table 1 is the ratio of the total annual cost of energy to end uses in 2020 to the gross national product in 2020. The largest absolute sensitivity in Table 1 is to the data element POSTLM. In LEAP-78 the change of operating cost due to technological changes is modeled and POSTLM is a data element in this modeling. Basically, POSTLM is the data element that determines the ultimate change that can be obtained in production. This data element occurs in many conversion processes and it is the option of the modeler to determine whether the value should be the same or different for many different conversion processes. If the modeler determines that it should be the same in many places he may specify this to be the case in the input data tables and thereby simplify the input tables. In LEAP-78 this was done with the data element POSTLM and that is what is indicated by "many" in the first column of Table 1. In the sensitivity analysis the convention established by the modeler has been followed and the relative sensitivity given in Table 1 is for a change in POSTLM at all nodes where the modeler specified the same value should be used. (See Table C.7) in Appendix C) To some extent it should be expected that a data element that is used very often

Table 1. Relative Sensitivity of the Ratio of the Total Annual Energy Cost to All End Uses in the Year 2020 to the Gross National Product in the Year 2020. The response $R_1(10)$ has the value .14 in the base case. The relative sensitivities are listed in the order of decreasing absolute value.

Node Number[a]	Descriptive Name and Process Type	Data Element Name	Data Element Value	Relative Sensitivity $\frac{x}{R_1(10)}$ Adjoint	Relative Sensitivity $\frac{dR_1(10)}{dx}$ Direct
Many	Many CONV. processes (see 809 in Table C.7 of Appendix C)	POSTLM[b]	1.0	0.52	0.53
120(3)	Electric Line Loss: TRANS.	EFF[c]	0.90	-0.37	-0.36
Many	All CONV., ELE. P. CONV., RES., C-RES.	PMI(10)[d]	1.0	0.30	
72(7)	Oil Refining: CONV.	EFF[c]	0.92	-0.26	
Many	All CONV., ELE. P. CONV., RES., C-RES.	PMI(5)[d]	1.0	0.22	0.23
12(6)	Appalachian Medium-High Sulfur	INRCST[e]	.98	-0.19	-0.23[f]
Many	All CONV., ELE. P. CONV., RES., C-RES.	PLI(10)[g]	1.0	0.16	
150(2)	Industrial Demand for Electric Services	QUAN1Y (Link 3)[h]	2.66	0.17	0.18
145(1)	Residential Demand for Space and Water Heat	QUAN1Y (Link 1)[h]	5.64	0.16	
40(4)	Conventional Nuclear (LWR): ELE. P. Conv.	SCC[i]	24.3	0.15	
Many	All CONV., ELE. P. CONV., RES., C-RES.	PMI(6)[d]	1.0	-0.15	-0.16

Table 1 (Cont'd)

Node Number[a]	Descriptive Name and Process Type	Data Element Name	Data Element Value	Relative Sensitivity $\frac{x}{R_1(10)}$ Adjoint	Relative Sensitivity $\frac{dR_1(10)}{dx}$ Direct
40(4)	Conventional Nuclear (LWR): ELE. P. CONV.	EFF[c]	0.32	-0.14	-0.11
150(2)	Industrial Demand for Indirect Heat	QUAN1Y (Link 2)[h]	2.99	0.14	
40(4)	Conventional Nuclear (LWR): ELE. P. CONV.	LOADFE(1)[j]	0.88	-0.14	
40(4)	Conventional Nuclear (LWR): ELE. P. CONV.	AVAIL(1)[k]	0.80	-0.14	
12(6)	Appalachian Medium-High Sulfur Coal: C-RES.	BASEPR[l]	.99	0.13	0.16,0.09[m]
139(8)	Transportation Demand for Vehicle Miles	QUAN1Y (Link 2)[h]	1.05	0.12	0.12
112(8)	Automobile Oil: CONV.	EFF[c]	0.10	-0.12	
Many	All CONV., ELE. P. CONV., RES., C-RES.	PLI(5)[g]	1.0	0.11	
Many	Many ELE. P. CONV. processes (see 803 in Table C.7 of Appendix C)	ROE[n]	0.10	0.11	0.10
Many	All CONV., ELE. P. CONV., RES., C-RES.	PMI(9)[d]	1.0	-0.10	

Footnotes to Table 1

[a]Numbers in parentheses indicate the figure in which the node occurs.

[b]POSTLM is the production time-based operating technological change limit. It is the ratio of the operating input-output coefficients, after taking into account industry operating experience in terms of time, since commercial availability of the technology, to the base operating input-output coefficient (See def. 17 in Appendix A of Stewart (1981)).

[c]EFF is the thermal efficiency of the process in 1975 or in the year the process becomes commercially available whichever is later. (See def. 9 in Appendix A of Stewart (1981)).

[d]PMI(J) is the price of materials at time index J (before these prices are modified by aging and technological time-dependent factor in Goldstein (1981)) relative to the price at J = 1 where J takes values 1 to 10 corresponding to the years 1975 to 2020 in five-year intervals (See def. A-10 in Appendix A of Stewart (1981)).

[e]INRCST is the initial resource cost in 1975 billion dollars per quadrillion Btu (See def. 40 in Appendix A of Stewart (1981)).

[f]INRCST was increased by 1% to obtain this sensitivity.

[g]PLI(J) is the price of labor at time index J (before these prices are modified by aging and technological time-dependent factor in Goldstein (1981)) relative to the price at J = 1 where J takes values 1 to 10 corresponding to the years 1975 to 2020 in five-year intervals. (See def. A-9 in Appendix A of Stewart (1981))

[h]QUAN1Y (Link i) is the quantity in 1975 on input link i of the specified node. For industrial, residential and commercial demands this data element has units of quadrillion Btu per year. For transportation demand the units vary with input link. (See def. 30 in Appendix A of Stewart (1981))

[i]SCC is the capital cost of a representative facility per unit of capacity in 1975 or the year the facility becomes commercially available, whichever is later. This data element has units of 1975 billion dollars per unit of capacity where a unit of capacity can produce a quadrillion Btu per year. (See def. 5 in Appendix A of Stewart (1981))

[j]LOADFE(i) is the fraction of time that a demand in category i is placed on a production facility. In conversion processes, LOADFE is called LOADFC and has no argument. (See def. 21 of Appendix A of Stewart (1981))

[k]AVAIL(i) is the fraction of demand in category i that a plant can satisfy considering scheduled and unscheduled down time. In conversion processes, AVAIL has no argument. (See def. 20 in Appendix A. of Stewart (1981))

[l]BASEPR is the base resource price and is such that specifying the resources available at this price and at twice this price determines the relevant part of the resource curve. This data element has units of 1975 billion dollars per quadrillion Btu. (See def. 41 in Appendix A of Stewart (1981))

Footnotes to Table 1 (Cont'd)

[m]The two sensitivity values correspond to increasing BASEPR by 1% and 10%, respectively.

[n]ROE is the return on equity and is in some cases time dependent. In the case shown, ROE is assumed constant at all model time points and thus the relative sensitivity here is for a change in ROE at all model time points. (See def. A.7 in Appendix A of Stewart (1981))

in the model will have a larger relative sensitivity than a data element that is used only once, but this is not always the case. In the case of POSTLM, the base case value of 1.0 greatly simplifies the equations and may have been used by the modeler for this purpose. Thus, it may not be a data element that the modeler intended to be changed. If this is the case, then at least for the modeler, the sensitivity to POSTLM has no significance. On the other hand, if the value is changed the model does show the sensitivity indicated and this may be significant. It should be clear that all of the sensitivities in the tables are independent and thus if the reader feels that POSTLM or any other data element should not be varied he may ignore a particular sensitivity. The equations that contain POSTLM (see Goldstein (1981)) are such that if POSTLM is increased above 1.0 the operating costs are increased and thus the cost of energy to end uses in 2020 will be increased as indicated by the positive relative sensitivity to POSTLM. In the case of POSTLM, calculations have been carried out by direct as well as adjoint methods and the two results are in good agreement.

The second largest absolute sensitivity in Table 1 is that due to the efficiency (EFF) of the transportation process that is used to model the cost of transporting electricity, i.e., electric line loss. The equations of the transportation process are quite simple, and an increase in efficiency has the effect of increasing the quantity out of the process for a given quantity of input and decreasing the price of the output for a given input price (see Goldstein (1981)). A substantial fraction of the energy supplied to the demand sectors is in the form of electricity and this form of energy has a somewhat higher price than the other energy

supplied to the demand sectors. An increase in the transmission efficiency decreases the price of electrical energy and increases the quantity, and thus has a substantial effect on decreasing the total cost of energy to end users. That the effect of increasing the efficiency decreases the response is indicated by the negative sign of the relative sensitivity. For this data element the relative sensitivity has also been calculated by both adjoint and direct means and the two results are in good agreement. In various places throughout Tables 1-4 direct and adjoint sensitivities are given. Hereinafter, the comparisons will be mentioned only if for some reason they are thought to be of particular interest.

The efficiency of the conversion process that is used to model oil refining also has a significant negative relative sensitivity. Efficiency is defined in the standard manner, that is, the ratio of the units of energy out per unit of energy into the process. Since oil accounts for a substantial fraction of the cost of energy to end uses it is to be expected that an improvement in the efficiency of oil refining would significantly decrease the cost of energy to end uses.

The data element PMI(J) represents the price of materials, (before these prices are modified by aging and technological time-dependent factors (Goldstein (1981)) at the time indicated by the index J relative to the price of materials in 1975 (J takes values 1 to 10 corresponding to years 1975 to 2020 in five-year intervals). Likewise, PLI(J) represents the price of labor (before these prices are modified by aging and technological time-dependent factors (Goldstein (1981)) at time J relative to the price of labor in 1975. The data elements PMI(J) for each J and PLI(J) for each J have the same value in all conversion, electric power conversion,

resource and c-resource processes. That is, it is assumed that in a given year the price of materials and the price of labor is the same at every node where one of these processes occur. Thus, an increase in either PMI(J) or PLI(J) at a particular J induced changes at many nodes simultaneously and can affect the model results in a variety of complex ways. In LEAP-78, the quantities PMI(J) and PLI(J) are given the value 1.0 for all J. There is again some question about the intention of the modeler, but here it is assumed that each PMI(J) and PLI(J) for all J may be varied independently. The fact that PMI(10) and PLI(10) have appreciable positive relative sensitivities appears reasonable since increases in these quantities in the year 2020 should have rather direct effect on increasing the cost of energy to end users in 2020. The fact that PMI(5) has an appreciable positive relative sensitivity in Table 1 is not so obvious. An increase in PMI(5) can increase the annual cost of energy to end uses in 2020 because the LEAP equations are coupled in time, but one might expect that an increase in PMI(9) would have a more appreciable effect in 2020 than an increase in PMI(5). The explanation for the importance of PMI(5) probably lies in the demand equations. These equations are such that the demand is independent of the price of energy before 1995 and is dependent on the ratio of the price of energy in later years to the price of energy in 1995 (see Goldstein (1981)). Thus, the price of energy in 1995 has a direct influence on the demand for energy in 2020 and the price of energy in 1995 is directly affected by the data element PMI(5).

The relative sensitivity of the data elements PMI(5) and PMI(10) are positive while the relative sensitivity of PMI(6) is negative. The fact

that an increase in PMI(6) decreases the cost of energy to end users in 2020 is probably again due to the form of the demand equations. For years after 1995 the demand equations contain a price elasticity that decreases demand as prices increase. Thus, an increase in PMI(6) can decrease the quantity demanded in 2020. Furthermore, this decrease in quantity demanded can also decrease the price of energy in 2020. Thus, it is quite possible, as is the case here, that an increase in PMI(6) will decrease the annual cost of energy to end uses in 2020.

The sixth largest absolute relative sensitivity in Table 1 is for the parameter INRCST (initial resource cost) that appears in the c-resource process that is used to model the mining of Appalachian Medium-High Sulfur Coal. It is convenient to consider this parameter in conjunction with the parameter BASEPR (base resource price) since if one of these parameters has a high absolute relative sensitivity the other often does also and the two parameters are related. In the resource and c-resource process the increase in both capital and operating cost as the resource is depleted is modeled (see Adler (1979), Cherniavsky (1980), and Goldstein (1981)). The data elements INRCST and BASEPR enter into the determination of the increase in cost as the resource is depleted. These data elements enter in a rather complex manner that is discussed in detail in Adler (1979) and Cherniavsky (1980). It is not, in general, possible to determine how changes in these parameters will affect the resource curves without considering the base case values of these parameters as well as several others that enter into the determination of the resource curve. In Table 1 INRCST at node 12 has a negative relative sensitivity and BASEPR has a positive relative sensitivity. The high relative sensitivity of

Appalachian Medium-High Sulfur Coal to INRCST and BASEPR appears to arise because changes in these parameters have a significant effect on the price and quantity of energy from node 59 in Fig. 6. These parameters also have some effect on the price of energy from nodes 60 and 71 in Fig. 6, but this does not appear to be a major cause of the observed sensitivities. In the case of INRCST and BASEPR sensitivities have also been obtained by direct calculations. In the case of INRCST a 1% increase was considered and in the case of BASEPR a 1% and a 10% increase was considered. A 10% INRCST could not be used because BASEPR must be greater than INRCST and this is not the case at node 12 if INRCST is increased by 10%. The agreement between the adjoint and direct sensitivities are satisfactory. In the case of BASEPR the difference between the two direct relative sensitivities may be indicative of a nonlinear effect, i.e., may indicate that $\frac{\Delta R}{\Delta x}$ is not an accurate value for $\frac{dR}{dx}$. Also, R may not be a continuous function of x. In the calculations of resource rents (Goldstein (1981)) a maximization procedure is used and because the function being maximized is calculated only at discrete points a parameter change might induce a discontinuous change in the maximum value obtained. This effect is, as far as is known, very minor.

The relative sensitivities of the data element, QUAN1Y, on specific input links into various demand nodes appear in Table 1. The quantity of energy per year in 1975 on each input link, i, of a demand node is called QUAN1Y (Link i) and is specified in LEAP-78 as an initial value, i.e., is not changed during the calculations. The demand for energy (or an energy related quantity in the case of transportation demand) on a given input link at all later years is directly affected by an increase in QUAN1Y

and thus one would expect, as shown in Table 1, that the relative sensitivity to QUAN1Y would be positive. The data elements QUAN1Y (Link 3) for node 150 and QUAN1Y (Link 2) for node 145 have an appreciable effect on the annual cost to all end uses in 2020 because the industrial demand for electric services and the residential demand for space and water heat constitute an appreciable fraction of the total demand for energy in 2020.

The specific capital cost (SCC) of the electric power conversion process that models the production of electricity by conventional nuclear facilities has a significant positive sensitivity. The capital cost of a production facility is directly influenced by this data element and thus the price of electricity generation by a conventional nuclear facility will be increased when this data element is increased. In the year 2020 conventional nuclear facilities produce a sizeable fraction of the total electricity demand at a cost that is somewhat below that of other types of production facilities would be expected to increase significantly the annual cost of energy to end users in 2020. Several other data elements from this electric power conversion process appear in the table and the reasons for these sensitivities are much the same as those given for SCC. In particular, the data elements LOADFE(1) and AVAIL(1) enter into the determination of the capacity factor at which a plant operates at a given time. Increases in either of these data elements increase the capacity factor and thus decrease cost to end users as indicated by the negative sensitivities in Table 1.

The cost of vehicle travel is a substantial fraction of the annual cost of end uses in 2020 and thus it is to be expected that parameters in transportation demand and the conversion process that represents automobile

oil should have appreciable relative sensitivities. An increase in QUAN1Y on Link 2 into node 139 (Fig. 8) increases the demand in 2020 and thus gives a positive sensitivity while an increase in efficiency at node 112 (Fig. 8) decreases cost and thus gives a negative sensitivity.

Finally, near the bottom of Table 1 the data element ROE, return on equity occurs. This data element is sometimes time-dependent in LEAP-78, but it is also the option of the modeler to make it time-independent and this is the case that appears in Table 1. Also, this data element has been specified to be the same at many nodes in LEAP-78 as indicated in the first and second column of Table 1. An increase in ROE for electric power generation processes increases capital cost, and thus the cost of electricity generation, and this has the effect of increasing import cost.

In Table 2 the relative sensitivities of the ratio of the annual cost of imported oil, oil products, and gas in the year 2020 to the Gross National Product in 2020 are given.

The data element POSTLM has the largest relative sensitivity for essentially the same reasons as those discussed in conjunction with Table 1. The disagreement between the direct and adjoint sensitivity for POSTLM in Table 2 is somewhat larger (∿20%) than in Table 1, but considering the rather elaborate calculations that are involved and the fact that there is, because of convergence considerations, an uncertainty in the base case variables the agreement is considered satisfactory.

The data elements INRCST and BASEPR for node 12 have quite large sensitivities. These data elements were discussed in conjunction with Table 1 and much of that discussion is applicable here, e.g., INRCST has a negative sensitivity and BASEPR has a positive sensitivity. The reason

Table 2. Relative Sensitivity of the Ratio of the Total Annual Cost of Imported Oil, Oil Products and Gas in the year 2020 to the Gross National Product in the Year 2020. The response $R_2(10)$ has the value $6.8 \cdot 10^{-3}$ in the base case. The sensitivities are listed in the order of decreasing absolute magnitude.

Node Number[a]	Descriptive Name and Process Type	Data Element Name	Data Element Value	Relative Sensitivity $\frac{x}{R_2(10)}$ Adjoint	Relative Sensitivity $\frac{dR_2(10)}{dx}$ Direct
Many	Many CONV. processes (see 809 in Table C.7 of Appendix C)	POSTLM[b]	1.0	0.79	0.96
12(6)	Appalachian Medium-High Sulfur Coal: C-RES.	INRCST[c]	0.98	-0.67	-0.84[d]
55(7)	Crude Oil: ALLOC.	PRICIT(10)[e]	4.35	0.59	
72(7)	Oil Refining: CONV.	EFF[f]	0.92	-0.59	-0.65
12(6)	Appalachian Medium-High Sulfur Coal: C-RES.	BASEPR[g]	0.99	0.48	0.59,0.31[h]
56(7)	Transport of Imported Gas: TRANS.	EFF[f]	0.98	0.47	0.47
120(3)	Electric Line Loss: TRANS.	EFF[f]	0.90	-0.43	-0.35
52(6)	Western Liquids Medium-High Sulfur: CONV.	IYRAVL[i]	1995-1975	0.41	0.38,0.20,0.11[j]
21(7)	Shale Oil-Mining and Retort: C-RES.	BASEPR[g]	2.57	0.40	
Many	All CONV., ELE. P. CONV., RES., C-RES.	PMI(1)[k]	1.0	-0.27	-0.29
139(8)	Transportation Demand for Auto Vehicle Miles	QUAN1Y (Link 2)[l]	1.05	0.35	0.44
112(8)	Automobile Oil: CONV.	EFF[f]	0.10	-0.35	
27(7)	Transport Upgrade (Shale Oil): TRANS.	EFF[f]	0.95	-0.35	
Many	All CONV., ELE. P. CONV., RES., C-RES.	PMI(9)[k]	1.0	0.32	

Table 2 (Cont'd)

Node Number[a]	Descriptive Name and Process Type	Data Element Name	Data Element Value	Relative Sensitivity $\frac{x}{R_2(10)}$ Adjoint	Relative Sensitivity $\frac{dR_2(10)}{dx}$ Direct
40(4)	Conventional Nuclear (LWR): ELE. P. CONV.	SCC[m]	24.3	0.31	
Many	All CONV. ELE. P. CONV., RES., C-RES.	PMI(5)[k]	1.0	0.30	0.37
52(6)	Western Liquids Medium-High Sulfur: CONV.	SCC[m]	10.8	0.27	
52(6)	Western Liquids Medium-High Sulfur: CONV.	AVAIL[n]	0.90	-0.27	
55(7)	Crude Oil: ALLOC.	FREQPR (Link 4)[p]	0.20	0.26	
40(4)	Conventional Nuclear (LWR): ELE. P. CONV.	LOADFE(1)[q]	0.88	-0.26	

Footnotes to Table 2

[a]Numbers in parentheses indicate the figure in which the node occurs.

[b]POSTLM is the production time-based operating technology change limit. It is the ratio of the operating input-output coefficiency, after taking into account industry operating experience in terms of time, since commercial availability of the technology, to the base operating input-output coefficient (See def. 17 in Appendix A of Stewart (1981)).

[c]INRCST is the initial resource cost in 1975 billion dollars per quadrillion Btu. (See def. 40 in Appendix A of Stewart (1981))

[d]INRCST was increased by 1% to obtain this sensitivity.

[e]PRICIT(J) is the exogeneously specified price of imported oil at time index J. This data element has units of 1975 billion dollars per quadrillion Btu. (See def. A-14 in Appendix A of Stewart (1981))

[f]EFF is the thermal efficiency of the process in 1975 or in the year the process becomes commercially available whichever is later. (See def. 9 in Appendix A of Stewart (1981))

[g]BASEPR is the base resource price which is such that specifying the resources available at this price and at twice the price determines the relevant part of the resource curve. This data element has units of 1975 billion dollars per quadrillion Btu. (See def. 41 in Appendix A of Stewart (1981))

[h]The two sensitivity values correspond to increasing BASEPR by 1% and 10%, respectively.

[i]IYRAVL is the year when the technology first became available. The code uses the actual year available, e.g., 1995. To define relative sensitivity here the data element year IYRAVL has been defined by subtracting 1975. (See def. 12 in Appendix A of Stewart (1981))

[j]IYRAVL was increased .25, 1, and 2 years, respectively, to obtain these sensitivities. LEAP-78 expects IYRAVL to be an integer so the code was changed internally to make the .25 year change.

[k]PMI(J) is the price of materials (before these prices are modified by aging and technological time-dependent factors (Goldstein (1981)) relative to the price at J = 1 where J takes values 1 to 10 corresponding to the years 1975 to 2020 in five-year intervals. (See def. A-10 in Appendix A of Stewart (1981))

[l]QUAN1Y (Link i) is the quantity in 1975 on input link i of the specified node. For industrial, residential, and commercial demands this data element has units of quadrillion Btu per year. For transportation demand the units vary with input link. (See def. 30 in Appendix A of Stewart (1981))

[m]SCC is the capital cost of a representative facility per unit of capacity in 1975 or the year the facility becomes available whichever is later. This data element has units of 1975 billion dollars per unit of capacity where a unit of capacity can produce a quadrillion Btu per year. (See def. 5 in Appendix A of Stewart (1981))

Footnotes to Table 2 (Cont'd)

[n]AVAIL(i) is the fraction of demand in category i that a plant can satisfy considering scheduled and unscheduled down time. In conversion processes, AVAIL has no argument. (See def. 20 in Appendix A of Stewart (1981))

[p]FREQPR (Link i) is the equal price share on link i. It is the fraction of demand that would be allocated to link i if all input links to the allocation process had equal prices. (See def. 3 in Appendix A of Stewart (1981))

[q]LOADFE(i) is the fraction of time that a demand in category is as placed on a production facility. In conversion processes, LOADFE is called LOADFC and has no argument. (See def. 21 of Appendix A of Stewart (1981))

for the high sensitivity of the response $R_2(10)$ to INRCST and BASEPR at node 12 appears to be, as in the case of the response $R_1(10)$, that these parameters have a significant effect on the price and quantity of coal from node 59 and this has the effect of changing the quantities of imported oil, oil products, and gas needed to satisfy demand. The price of these imported products are fixed exogeneously so any change in the imported quantities has a direct influence on the cost. Changes in INRCST and BASEPR also have an influence on the production of coal liquids (node 60) and high Btu synthetic gas (node 71), but this does not appear to be a major effect. Direct sensitivities have again been obtained for a 1% increase in INRCST and for a 1% and 10% change in BASEPR. The difference between the adjoint and forward results are again of the order of 20%. The large difference between the 1% and 10% BASEPR direct calculations appears to be due to nonlinear effects. As stated previously, it could, in principle, be due to a discontinuity, but in this instance this is not thought to be the case. That is, the difference is not due to a change in the time index at which the maxima (see previous discussion) in node 12 occurred, but there are many resource and c-resource processes and, in principle, a discontinuity in the response can be caused by a change in the time index of the maxima in any of these processes.

The third largest sensitivity in Table 2 is for the data element PRICIT(10) that represents the exogeneously specified price of imported oil in 2020. Since the response being considered is the cost of imported oil, oil products, and gas in 2020 it is not surprising that the price of imported oil in 2020 should have a large positive sensitivity.

The fourth largest sensitivity in Table 2 is for the efficiency of the conversion process that is used to model oil refining. Since the cost of imported crude oil accounts for a substantial part of the cost of imported oil, oil products, and gas, and since imported crude oil goes through the oil refining process (see Fig. 7) it is not surprising that an increase in the efficiency of oil refining would significantly reduce the response being considered.

The efficiency of the transport process that is used to model the cost of transporting imported gas has a rather large positive sensitivity. The sign of the sensitivity in this case is interesting because an increase in the transportation efficiency caused an increase in import cost. The positive sign arises because the increase in efficiency reduced the price of gas of the transport process and because of this reduced price imported gas becomes competitive with the other source of gas and more gas was imported.

The efficiency of the transportation process that is used to model electric line loss is negative since any improvement in this process will decrease the quantity and thus the total cost of imported products needed to satisfy demand.

The year of commercial availability (IYRAVL) of the conversion process that is used to model the production of liquids from medium-high sulfur western coal has an appreciable positive relative sensitivity. In the model the year of availability is input as an absolute integer time, e.g., 1995. To define a relative sensitivity this data element was defined by subtracting 1975. This definition is somewhat arbitrary and does affect the magnitude of the relative sensitivity; i.e., if some year other

than 1975 had been used in the definition a different relative sensitivity would be obtained. In the conversion process the year of availability is not used to be the time before which production is not possible, but at times prior to the year of availability a price premium is required and because of this higher price very little is produced. The fact that a delay in the year of availability which is 1995 in the base case has a significant effect on the cost of imports in 2020 appears to be due to the behavioral lag that is built into the allocation process (Goldstein (1981)). If liquid production is delayed beyond 1995 at node 52 then only a small share of the market is allocated to node 52 by the allocation process at node 60 in 1995. Then, because of the behavioral lag, this small share influences the share allocated to node 52 in subsequent years. The behavioral lag is only three years at node 60 so it is interesting that the effect persists into years as late as 2020. The direct relative sensitivities in this case are rather interesting because they show an appreciable nonlinearity. It is to be noted that, in general, those quantities that are specified to be integers in the input to LEAP-78 can be changed by nothing smaller than 1 year. In the present case, a change of .25 years was used (by changing the code internally) because the 1 year change was too large to obtain agreement between the forward and the adjoint results.

The data element BASEPR for the c-resource process that is used to model Shale Oil-Mining and Retort has an appreciable positive relative sensitivity in Table 2. When this base price is increased the price of oil from shale oil is increased and oil is imported to replace the more expensive oil from shale.

The data elements PMI(J) occur in a variety of places in Table 2. These data elements have been discussed in conjunction with Table 1 and much of the discussion there applies equally as well here. Some discussion is, however, required because of the appearnace of PMI(1). The data element PMI(J) is defined relative to PMI(1) and therefore by definition PMI(1) is unity and presumably should not be varied. On the other hand, it does have an appreciable sensitivity if it is varied. The meaning of a variation of PMI(1) is that the price of material is being changed relative to the price of labor in 1975 and it is interesting that this change does produce an appreciable negative sensitivity.

The data element QUAN1Y that appears on link 2 into the transportation demand has a reasonably large positive sensitivity. An increase in this data element increases the demand for oil in 2020 and thus increases oil imports and the cost of oil imported in 2020. Conversely, an increase in the efficiency of the automobile oil conversion process increases the quantity of oil available and decreases the amount of imported oil and thus the cost of imported oil.

An increase in the efficiency of the transport process that is used to model the transport of shale oil has a negative sensitivity as one would expect because an increase in this efficiency would decrease the amount of imported oil.

An increase in the specific capital cost of a conventional nuclear facility raises the cost of electricity from such facilities and thus increases the amount and cost of imported oil. Similarly, an increase in the specific capital cost of western liquids from medium-high sulfur coal increases the cost of imported oil.

The data element AVAIL(I) and LOADFE(I) were discussed in conjunction with Table 1. (In conversion processes these quantities have the same meaning as in electric power conversion processes, but have no arguments and LOADFE is called LOADFC.)

In Table 2 the data elements of AVAIL for western liquids from medium-high sulfur coal and AVAIL(1) and LOADFE(1) from conventional nuclear generation of electricity all have negative relative sensitivities as would be expected from the previous discussion.

The data element FREQPR (Link 4) for the allocation process that is used to model crude oil allocation occurs near the end of Table 2. The data element FREQPR(i) designates the fraction of the demand that would be allocated to a given supplier if all suppliers had the same price. Input link 4 to node 55 (see Fig. 7) represents the allocation of crude oil demand to imported crude oil. In the base case FREQPR (Link 4) has the value 0.20 and thus if there were no price differential between the supplier to node 55 only 0.20 of the demand would be allocated to imported crude oil. Even when there is a price differential this data element still enters into the determination of the fraction of the demand that is allocated to a given supplier, and an increase in this data element on link i increases the fraction of the demand that is allocated to the supplier on link i. In Table 2 an increase in FREQPR (Link 4) increases the fraction of the demand that is supplied by imported crude oil and thus increases the cost of imported crude oil.

In Table 3 the relative sensitivities of the total annaul imports of oil and oil products in 2020 are presented. This reponse is in some ways similar to that considered in Table 2, but because quantities are

Table 3. Relative Sensitivity of the Total Annual Imports of Oil and Oil Products in the Year 2020. The response $R_3(10)$ has the value 7.4 quadrillion Btu per year in the base case. The relative sensitivities are listed in the order of decreasing absolute value.

Node Number[a]	Descriptive Name and Process Type	Data Element Name	Data Element Value	Relative Sensitivity $\frac{x}{R_3(10)}$ Adjoint	Relative Sensitivity $\frac{dR_3(10)}{dx}$ Direct
Many	Many CONV. processes (see 809 in Table C.7 of Appendix C)	POSTLM[b]	1.0	0.72	0.89
72(7)	Oil Refining: CONV.	EFF[c]	0.92	-0.57	-0.64
12(6)	Appalachian Medium-High Sulfur Coal: C-RES.	INRCST[d]	0.98	-0.53	-0.52[e]
52(6)	Western Liquids Medium-High Sulfur: CONV.	IYRAVL[f]	1995-1975	0.50	0.46,0.20,0.11[g]
21(7)	Shale Oil-Mining: C-RES.	BASEPR[h]	2.57	0.45	
27(7)	Transport Upgrade (Shale Oil): TRANS.	EFF[c]	0.95	-0.39	
12(6)	Appalachian Medium-High Sulfur Coal: C-RES.	BASEPR[h]	0.99	0.38	0.49,0.26[i]
139(8)	Transportation Demand Auto Vehicle Miles	QUAN1Y (Link 2)[j]	1.05	-0.38	-0.48
112(8)	Automobile Oil: CONV.	EFF[c]	0.10	-0.37	
Many	All CONV., ELE. P. CONV., RES., C-RES.	PMI(1)[k]	1.0	-0.34	-0.24

Table 3 (Cont'd)

Node Number[a]	Descriptive Name and Process Type	Data Element Name	Data Element Value	Relative Sensitivity $\frac{x}{R_3(10)}$ Adjoint	Relative Sensitivity $\frac{dR_3(10)}{dx}$ Direct
52(6)	Western Liquids Medium-High Sulfur: CONV.	SCC[l]	10.8	0.32	
52(6)	Western Liquids Medium-High Sulfur: CONV.	AVAIL[m]	0.90	-0.32	
23(7)	Domestic Oil and Natural Gas Liquids: RES.	NEWRS2[n]	47.3	0.32	
55(7)	Crude Oil: ALLOC.	FREQPR (Link 4)[p]	0.20	0.30	
Many	All CONV., ELE. P. CONV., RES., C-RES.	PMI(5)[k]	1.0	0.29	0.35
55(7)	Crude Oil: ALLOC.	QUAN1Y (Link 4)[j]	8.68	0.28	
55(7)	Crude Oil: ALLOC.	QUAN1Y (Link 5)[j]	20.2	-0.28	
120(3)	Electric Line Loss: TRANS.	EFF[c]	0.90	-0.28	
52(6)	Western Liquids Medium-High Sulfur: CONV.	VOC[q]	1.18	0.26	
Many	All demands	Y(2)[r]	4.6	0.25	

Footnotes to Table 3

[a]Numbers in parentheses indicate the figure in which the node occurs.

[b]POSTLM is the production time-based operating technological change limit. It is the ratio of the operating input-output coefficiency, after taking into account industry operating experience in terms of time, since commercial availability of the technology, to the base operating input-output coefficient. (See def. 17 in Appendix A of Stewart (1981)).

[c]EFF is the thermal efficiency of the process in 1975 or in the year the process becomes commercially available, whichever is later. (See def. 9 in Appendix A of Stewart (1981))

[d]INRCST is the initial resource cost in 1975 billion dollars per quadrillion Btu. (See def. 40 in Appendix A of Stewart (1981))

[e]INRCST was increased by 1% to obtain this sensitivity.

[f]IYRAVL is the year when the technology first became available. The code uses the actual year available, e.g., 1995. To define relative sensitivity here the data element year IYRAVL has been defined by subtracting 1975. (See def. 12 in Appendix A of Stewart (1981))

[g]IYRAVL was increased .25, 1, and 2 years, respectively, to obtain these sensitivities. LEAP-78 expects IYRAVL to be an integer so the code was changed internally to make the .25 year change.

[h]BASEPR is the base resource price which is such that specifying the resources available at this price and at twice the price determines the resource curve. This data element has units of 1975 billion dollars per quadrillion Btu. (See def. 41 in Appendix A of Stewart (1981))

[i]The two sensitivity values correspond to increasing BASEPR by 1% and 10%, respectively.

[j]QUAN1Y (Link i) is the quantity in 1975 on input link i of the specified node. For industrial, residential, and commercial demands this data element has units of quadrillion Btu per year. For transportation demand the units vary with input link. (See def. 30 in Appendix A of Stewart (1981))

[k]PMI(J) is the price of materials at time index J (before the prices are modified by aging and technological time-dependent factors (Goldstein (1981)) relative to the price at J = 1 where J takes values 1 to 10 corresponding to the years 1975 to 2020 in five-year intervals. (See def. A-10 in Appendix A of Stewart (1981))

[l]SCC is the capital cost of a representative facility per unit of capacity in 1975 or the year the facility becomes available, whichever is later. This data element has units of 1975 billion dollars per unit of capacity where a unit of capacity can produce a quadrillion Btu per year. (See def. 5 in Appendix A of Stewart (1981))

Footnotes to Table 3 (Cont'd)

[m]AVAIL(i) is the fraction of demand in category i that a plant can satisfy considering scheduled and unscheduled down time. In conversion processes, AVAIL has no argument. (See def. 20 in Appendix A of Stewart (1981))

[n]NEWSRS2 is the new resource at double base price. It is the amount of resources in addition to resources at the beginning of the model horizon, including expected new discoveries that could be produced without a loss. It has units of quadrillion Btu. (See def. 42 in Appendix A of Stewart (1981))

[p]FREQPR (Link i) is the equal price share on link i. It is the fraction of the demand that would be allocated to link i if all input links to the allocation process had equal prices. (See def. 3 in Appendix A of Stewart (1981))

[q]VOC is the variable operating cost in 1975 or the year of commercial availability, whichever is later. It has units of 1975 billion dollars per quadrillion Btu. (See def. 7 in Appendix A of Stewart (1981))

[r]Y(J) is the rate of change (% per year) Gross National Product at time index J where J takes values 1 to 10 corresponding to the years 1975 to 2020 in five-year intervals. (See def. A.3 in Appendix A of Stewart (1981))

considered rather than costs and because imported gas is omitted the sensitivities are different. Many of the data elements in Table 3 are similar to those discussed in Table 1 and 2 so they will not be discussed again. Also, in Table 3 as in Tables 1 and 2 a variety of comparisons between adjoint and direct sensitivities are given. For the most part these comparisons are similar to those given previously and they will be discussed only if they are thought to be of particular interest.

Near the end of Table 3 the data element NEWRS2, for the resource process that is used to model Domestic Oil and Natural Gas Liquids, appears. This data element represents new resources at twice the base price and is related to the data elements INRCST and BASEPR in that it is used in the determination of the increase in capital and operating cost as a resource is depleted (Adler (1979), Cherniavsky (1980) and Goldstein (1981)). The actual manner in which this data element enters in the determination of the resource curve is complicated and is explained in detail in Adler (1979) and Cherniavsky (1980). For the present purposes, it is only necessary to know that an increase in NEWRS2 increases both the capital and operating cost for a given level of commitment of the resource. An increase in NEWRS2 for domestic oil and natural gas liquids increases the cost as the reserves are depleted and this increase makes domestic oil less competitive so more oil and oil products are imported.

Near the bottom of Table 3 the data elements QUAN1Y on Link 4 and 5 into the process to allocate crude oil (node 55 in Fig. 7) occurs. The data elements QUAN1Y on input links to allocation processes serve as initial conditions in somewhat the same way as the data elements QUAN1Y

on input links to demand processes, but there are significant differences. For allocation processes QUAN1Y (Link i) is not itself the initial value that is used, but rather the quantity $\frac{QUAN1Y(j)}{\sum_i QUAN1Y(i)}$, where the sum over i is over all input links to a given allocation node, is used as an initial value. That is, the quantity on link i in the final solution is not in general the QUAN1Y (Link i) that was specified initially. An increase in QUAN1Y (Link 4) increases the share of the demand in 1975 that is allocated to imported crude oil and because of the behavioral lag, which is 15 years in this case, increases the share of the demand in 2020 that is allocated to imported crude oil. Thus, an increase in this data element increases the quantity of crude oil imported and has a positive sensitivity. On the other hand, an increase in QUAN1Y (Link 5) increases the share of the demand in 2020 that is allocated to domestic oil and natural gas liquids thus decreasing the amount of imported oil and producing a negative sensitivity.

Near the bottom of Table 3 the data element, VOC, variable operating cost, (exclusive of fuel) for the production of liquids from western medium-high sulfur coal appears. An increase in this data element increases the cost of production in all years after the technology becomes commercially available. Thus, an increase in this data element increases the cost of the liquids and makes them less competitive with imported oil so more oil is imported.

Finally, at the end of Table 3 the data element Y(2) appears. This data element represents the rate of change of the Gross National Product in 1980. It enters into the demand equations (Goldstein (1981)) in such a manner that it tends to increase demand in all subsequent years, except for modifications that arise because of price elasticities. Since an

increase in Y(2) increases demand in 2020 it has a positive sensitivity because more oil and oil products are imported to satisfy this demand.

In Table 4 the relative sensitivities of the ratio of the total annual liquid fuels input to all demand sectors to the total annual fuel input to all demand sectors (see Section IV.C) are given. This response is somewhat different from those considered previously in that it involves many more links and is therefore more complex. Again, many of the data elements that appear in Table 4 are similar to those that appear in Tables 1, 2, and 3 so only those that are thought to be of particular interest will be discussed. Also, the comparisons between the adjoint and direct sensitivities are very similar to those given previously and will therefore not be discussed.

In the early part of Table 4 the data element VOCRAT from the conversion process that is used to model automobile oil occurs. This data element is used to model the change of cost and efficiency with time due to technological changes. Its value determines how long it will take for the ultimate change allowed due to technological change to be reached. An increase in this data element has the effect of increasing efficiency and decreasing cost. In the case of automobile oil an increase in VOCRAT decreases the quantity of liquid fuel needed to satisfy transportation demand and thus causes a decrease in the response considered in Table 4.

Also, early in Table 4 the data element EFLIM, efficiency limit, for the conversion process that is used to model automobile oil occurs. This data element determines the ultimate change in efficiency that can occur due to technological change. An increase in this data element increases the ultimate efficiency that can be achieved. An increase in this data

Table 4. Relative Sensitivity of the Ratio of the Total Annual Liquid Fuels Input to All Demand Sectors in the Year 2020 to the Total Annual Fuel Input to All Demand Sectors in the Year 2020. The response $R_4(10)$ has a value of .32 in the base case. The sensitivities are listed in the order of decreasing absolute value.

Node Number[a]	Descriptive Name and Process Type	Data Element Name	Data Element Value	Relative Sensitivity $\frac{x}{R_4(10)}$ Adjoint	Relative Sensitivity $\frac{dR_4(10)}{dx}$ Direct
139(8)	Transportation Demand for Vehicle Miles	QUAN1Y (Link 2)[b]	1.05	0.25	0.25
112(8)	Automobile Oil: CONV.	EFF[c]	0.10	-0.25	
72(7)	Oil Refining: CONV.	EFF[c]	0.92	0.22	0.22
150(2)	Industrial Demand for Electric Services	QUAN1Y (Link 2)[b]	2.99	-0.16	
112(8)	Automobile Oil: CONV.	VOCRAT[d]	0.035	-0.16	
12(6)	Appalachian Medium-High Coal: C-RES.	INRCST[e]	0.98	-0.15	-0.13[f]
150(2)	Industrial Demand for Electric	QUAN1Y (Link 3)[b]	2.66	-0.11	-0.11
112(8)	Automobile Oil: CONV.	EFLIM[g]	4.5	-0.10	
150(2)	Industrial Demand for Truck/Bus Vehicle Mile	QUAN1Y (Link 7)[b]	0.28	0.099	
113(8)	Truck, Bus, Diesel/Gas: CONV.	EFF[c]	0.067	-0.097	
12(6)	Appalachian Medium-High Coal: C-RES.	BASEPR[h]	.99	0.093	0.090,0.49[i]

Table 4 (Cont'd)

Node Number[a]	Descriptive Name and Process Type	Data Element Name	Data Element Value	Relative Sensitivity $\frac{x}{R_4(10)}$ Adjoint	Relative Sensitivity $\frac{dR_4(10)}{dx}$ Direct
Many	Many CONV. processes (see 809 in Table C.7 of Appendix C)	POSTLM[j]	1.0	0.088	0.12
113(8)	Truck, Bus, Diesel/Gas: CONV.	EFLIM[g]	1.5	-0.086	
101(1)	Oil (+LPG) Heater: CONV.	IDLIFE[k]	5	-0.084	
150(2)	Industrial Demand for Electrical Services	G2(6)	1.70	-0.083	
5(2)	Geothermal: CONV.	SCC[m]	2.84	-0.082	-0.60
139(8)	Transport Demand for Auto Vehicle Miles	G2(6)[l]	1.1	0.082	
5(2)	Geothermal: CONV.	AVAIL[n]	0.90	0.082	
150(2)	Industrial Demand for Direct Conserv.	QUAN1Y (Link 1)[b]	0.96	-0.072	
101(1)	Oil (+LPG) Heater: CONV.	SCC[m]	51.0	-0.072	

Footnotes to Table 4

[a]Numbers in parentheses indicate the figure in which the node occurs.

[b]QUAN1Y (Link i) is the quantity in 1975 on input link i of the specified node. For industrial, residential, and commercial demands this data element has units of quadrillion Btu per year. For transportation demand the units vary with input link. (See def. 30 in Appendix A of Stewart (1981))

[c]EFF is the thermal efficiency of the process in 1975 or in the year the process becomes commercially available, whichever is later. (See def. 9 in Appendix A of Stewart (1981))

[d]VOCRAT is the operating change rate (% per year) and is used to model change in cost due to experience. (See def. 18 in Appendix A of Stewart (1981))

[e]INRCST is the initial resource cost in 1975 billion dollars per quadrillion Btu. (See def. 40 in Appendix A of Stewart (1981))

[f]INCRST was increased by 1% to obtain this sensitivity.

[g]EFLIM is the thermal efficiency limit and is the ratio of the thermal efficiency (for fuel) to the initial efficiency at the year of commercial availability or in 1975, whichever comes later. (See def. 19 in Appendix A of Stewart (1981))

[h]BASEPR is the base resource price which is such that specifying the resources available at this price and at twice the price determines the resource curve. This data element has units of 1975 billion dollars per quadrillion Btu. (See def. 41 in Appendix A of Alsmiller (1980))

[i]The two sensitivity values correspond to increasing BASEPR by 1% and 10%, respectively.

[j]POSTLM is the production time-based operating technological change limit. It is the ratio of the operating input-output coefficiency, after taking into account industry operating experience in terms of time, since commercial availability of the technology, to the base operating input-output coefficient. (See def. 17 in Appendix A of Stewart (1981))

[k]IDLIFE is the term on long-term corporate debt. It is an integer and is expressed in years. (See def. 25 of Stewart (1981)0

[l]GI(J) is the demand sensitivity on input link i at time J to a demand node. The demand sensitivity is the rate of change in the demand with respect to the rate of change in GNP. (See def. A-4 in Appendix A of Stewart (1981))

[m]SCC is the capital cost of a representative facility per unit of capacity in 1975 or the year the facility becomes available, whichever is later. This data element has units of 1975 billion dollars per unit of capacity where a unit of capacity can produce a quadrillion Btu per year. (See def. 5 in Appendix A of Stewart (1981))

element decreases the quantity of liquid fuel needed to satisfy demand and thus has a negative sensitivity.

Near the end of Table 4 the data element IDLIFE, debt life, occurs for the conversion process that is used to model oil (+LPG) heaters. An increase in the debt life in this case increases the capital cost and thus the price of heat from node 101. This increase in price tends to make oil (+LPG) heaters noncompetitive with other forms of heat (see Fig. 1) and as a consequence the liquid used in the residential sector is reduced compared to the other form of fuel. Thus, an increase in IDLIFE has a negative sensitivity in Table 4. The relative sensitivity is small because the energy used at node 101 is small compared to the total liquids fuel and the total fuel used in all of the demand sectors.

Finally, near the end of Table 4 the data elements G2(6) into node 150 and G2(6) into node 139 occur. The 2 in these data elements specifies Link 2 and the 6 is the usual time index. An increase in these data elements has the effect of increasing demand on Link 2 into node 150 and 139 in all subsequent years. The time index 6 has a special significance because G2(J) values for J = 7,8,9 are obtained by linear interpolation between G2(6) and G2(10) (Goldstein (1981)). The two data elements are interesting because the relative sensitivities have opposite signs. In the case of Link 2 into transportation demand an increase in G2(6) increases the demand for liquid fuel and thus for the response being considered the sensitivity is positive. In the case of Link 2 into industrial demand an increase in G2(6) increases the demand for energy, but not necessarily in the form of liquid fuel and thus for the response considered the change in the denominator is larger than the change in the numerator so the sensitivity is negative.

VI. SUMMARY

The applicability of adjoint sensitivity methodology to large energy-economics models has been demonstrated by applying the methodology to LEAP Model 22C. The agreement between the adjoint and direct sensitivities in Tables 1-4 indicate that the methodology can be applied successfully and gives reasonably reliable results.

The method is limited in that it provides only first derivatives, but it is very powerful in that it treats all data elements and determines for a given response which data elements have appreciable sensitivities.

The methodology, as used here, requires considerable development time in that considerable analytical differentiation is required and a substantial effort is needed to evaluate these analytic derivatives numerically. In the course of the work, a method was developed that would allow all of these derivatives to be obtained numerically using the LEAP computer code and this method is presented and discussed.

Appendix A

Numerical Determination of the Elements of the A Matrix

In this Appendix the procedure for estimating the elements of the A matrix (see Eq. (II.8)) directly from the LEAP code rather than by first differentiating the equations analytically is desirable.

Consider again the equations for a single node, i.e., Eq. (IV.1) and Eq. (IV.2) with n = m. The elements of the A matrix that are to be determined numerically are the derivatives $\frac{\partial F_{ni}}{\partial Q_{nj}}$, $\frac{\partial F_{ni}}{\partial P_{Inq}}$, $\frac{\partial G_{nq}}{\partial Q_{ni}}$ and $\frac{\partial G_{nq}}{\partial P_{Inr}}$. From Eq. (IV.2) it follows immediately that

$$\frac{\partial P_{ni}}{\partial Q_{ni}} = \frac{\partial F_{ni}}{\partial Q_{ni}} \tag{A.1}$$

$$\frac{\partial P_{ni}}{\partial P_{Inq}} = \frac{\partial F_{ni}}{\partial P_{Inq}} \tag{A.2}$$

$$\frac{\partial Q_{nq}}{\partial Q_{ni}} = \frac{\partial G_{nq}}{\partial Q_{ni}} \tag{A.3}$$

$$\frac{\partial Q_{nq}}{\partial P_{Inr}} = \frac{\partial G_{nq}}{\partial P_{Inr}} \tag{A.4}$$

so the problem is to estimate the partial derivatives on the left-hand side of Eqs. (A.1) to (A.4). Equation (IV.2) expresses the fact that for an isolated node the LEAP code is such that if Q_{ni} and P_{Inq} for all i and q are given then P_{ni} and Q_{Inq} for all i and q are determined. Then, consider the values P_{ni} and Q_{Inq} based on the values Q_{ni} and P_{Inq} and determine new values P'_{ni} and Q'_{Inq} by solving the equations for the isolated node with $Q_{n\ell}$ replaced by $Q_{n\ell} + \Delta Q_{n\ell}$ for a particular ℓ and Q_{ni} for $i \neq \ell$ and P_{Inq} unchanged. Then, approximately

$$\frac{\partial P_{ni}}{\partial Q_{n\ell}} = \frac{P'_{ni} - P_{ni}}{\Delta Q_{n\ell}}$$

$$\frac{\partial Q_{Inq}}{\partial Q_{n\ell}} = \frac{Q'_{Inq} - Q_{Inq}}{\Delta Q_{n\ell}}$$

and if one repeats the procedure by systematically varying the Q_{ni} and P_{Inq} one at a time, estimates of all elements of the A matrix at node n can be estimated. The procedure can be repeated for all nodes and thus all elements of the A matrix can be estimated using only the LEAP code.

Appendix B

Relative Sensitivities

In Section V only the 20 largest relative sensitivities for each response were given and discussed. In this Appendix all of the relative sensitivities with absolute value $>5 \cdot 10^{-2}$ for each response are given. Results are given for the responses $R_1(10)$, $R_2(10)$, $R_3(10)$ and $R_4(10)$ (see Section IV.d) in Tables B.1 to B.4, respectively. The form of the tables is similar to that in Tables 1 to 4, but here the sensitivities, $\frac{dR}{dx}$, as well as the relative sensitivities, $\frac{x}{R}\frac{dR}{dx}$, are given. When a node number of 999 is specified the data element is the same in all conversion, electric power conversion, resource, and c-resource processes. When a node number is greater than 500 and less than 999 is specified the explanation is given in Appendix C and Table C.7 of Appendix C. For a definition of those data elements that occur in Tables C.1 to C.4 and did not occur in Tables 1 to 4, the reader should see Appendix A of Stewart (1981).

Table B.1 Relative Sensitivity of the Ratio of the Total Annual Energy Cost to All End Uses in the Year 2020 to the Gross National Products in the Year 2020. The response $R_1(10)$ has the value .14 in the base case. All relative sensitivities with absolute value $>5 \cdot 10^{-2}$ are given.

NODE	PROCESS	COMMON	VARIABLE	LINK	PARAMETER	SENSITIVITY	RELATIVE SENS.
809	CONVERS.	GPAT19	POSTEM, 1		1.000E 00	7.563E-02	5.208E-01
120	TRANSPT	SPAT20	EFF , 1		9.000E-01	-6.031E-02	-3.737E-01
999	GLOBAL	TIME2	PMI ,10		1.000E 00	4.444E-02	3.060E-01
72	CONVERS.	SPAT20	EFF , 1		9.200E-01	-4.099E-02	-2.597E-01
999	GLOBAL	TIME2	PMI , 5		1.000E 00	3.187E-02	2.194E-01
12	RESOURCE	SPAT20	INRCST, 1		9.780E-01	-2.862E-02	-1.927E-01
999	GLOBAL	TIME2	PLI ,10		1.000E 00	2.496E-02	1.719E-01
150	DEMAND	DTSL24	QUANTY, 1,	3	2.660E 00	9.364E-03	1.715E-01
145	DEMAND	DTSL24	QUANTY, 1,	1	5.640E 00	4.092E-03	1.589E-01
40	E.P.CONV	SPAT20	SCC , 1		2.432E 01	9.223E-04	1.544E-01
999	GLOBAL	TIME2	PMI , 6		1.000E 00	-2.238E-02	-1.541E-01
40	E.P.CONV	SPAT20	EFF , 1		3.198E-01	-6.409E-02	-1.411E-01
150	DEMAND	DTSL24	QUANTY, 1,	2	2.987E 00	6.674E-03	1.373E-01
40	E.P.CONV	SPSL27	AVAIL , 1		8.000E-01	-2.454E-02	-1.352E-01
40	E.P.CONV	SPSL27	LOADFE, 1		8.800E-01	-2.231E-02	-1.352E-01
12	RESOURCE	SPAT20	BASERR, 1		9.920E-01	1.918E-02	1.310E-01
139	DEMAND	DTSL24	QUANTY, 1,	2	1.050E 00	1.731E-02	1.252E-01
112	CONVERS.	SPAT20	EFF , 1		1.043E-01	-1.695E-01	-1.217E-01
999	GLOBAL	TIME2	PLI , 5		1.000E 00	1.545E-02	1.064E-01
802	E.P.CONV	GPAT19	DUMMY1, 1		9.980E-02	1.512E-01	1.039E-01
999	GLOBAL	TIME2	PMI , 9		1.000E 00	1.497E-02	1.031E-01
150	DEMAND	DTSL24	QUANTY, 1,	4	2.220E 00	6.739E-03	1.030E-01
802	CONVERS.	GPAT19	CFMULT, 1		1.000E 00	1.267E-02	8.727E-02
142	DEMAND	DTSL24	QUANTY, 1,	1	2.490E 00	4.909E-03	8.418E-02
10	TRANSPT	SPAT20	VOC , 1		6.400E-01	1.839E-02	8.107E-02
999	GLOBAL	TIME2	PLI , 9		1.000E 00	1.171E-02	8.060E-02
999	GLOBAL	TIME2	PLI , 6		1.000E 00	-1.123E-02	-7.733E-02
40	E.P.CONV	SPAT20	CLIM , 1		9.000E-01	1.247E-02	7.726E-02
999	GLOBAL	TIME2	RDE , 5		9.980E-02	1.090E-01	7.489E-02
40	E.P.CONV	SPAT20	EGFR , 1		4.500E-01	2.377E-02	7.366E-02
999	GLOBAL	TIME2	RDE , 9		9.980E-02	1.024E-01	7.035E-02
150	DEMAND	TMAT33	G3 , 6		1.508E 00	6.478E-03	6.725E-02
142	DEMAND	DTSL24	QUANTY, 1,	2	1.440E 00	6.602E-03	6.545E-02
999	GLOBAL	TIME2	PMI , 1		1.000E 00	-9.341E-03	-6.432E-02
150	DEMAND	TMAT33	G2 , 6		1.698E 00	5.457E-03	6.379E-02
112	CONVERS.	SPAT20	VCCRAT, 1		3.500E-02	-2.615E-01	-6.303E-02
9	RESOURCE	SPAT20	UNRCPS, 1		1.310E 03	-6.876E-06	-6.203E-02
10	TRANSPT	SPAT20	EFF , 1		1.000E 00	-8.841E-03	-6.088E-02
112	CONVERS.	SPAT20	EFLIM , 1		4.500E 00	-1.861E-03	-5.766E-02
150	DEMAND	DTSL24	QUANTY, 1,	7	2.808E-01	2.978E-02	5.758E-02
145	DEMAND	DTSL24	QUANTY, 1,	2	6.800E-01	1.196E-02	5.601E-02
40	E.P.CONV	SPAT20	IDLIFE, 1		3.000E 01	-2.695E-04	-5.567E-02
113	CONVERS.	SPAT20	EFF , 1		6.680E-02	-1.157E-01	-5.323E-02
999	GLOBAL	TMAT33	Y ,10		2.400E 00	-3.184E-03	-5.263E-02
9	RESOURCE	SPAT20	ICLIFE, 1		2.000E 01	3.705E-04	5.102E-02
132	CONVERS.	SPAT20	IDLIFE, 1		5.000E 00	1.477E-03	5.084E-02
150	DEMAND	TMAT33	G2 , 3		2.266E 00	3.219E-03	5.021E-02

Table B.2 Relative Sensitivity of the Ratio of the Total Annual Cost of Imported Oil, Oil Products and Gas in the Year 2020 to the Gross National Products in the Year 2020. The response $R_2(10)$ has the value $6.8 \cdot 10^{-3}$ in the base case. All relative sensitivities with absolute value $>5 \cdot 10^{-2}$ are given.

NODE	PROCESS	COMMON	VARIABLE LINK	PARAMETER	SENSITIVITY	RELATIVE SENS.
809	CONVERS.	GPAT19	POSTLM, 1	1.000E 00	5.357E-03	7.887E-01
12	CESOURCE	SPAT20	INRCST, 1	9.780E-01	-4.680E-03	-6.738E-01
55	ALLOCAT.	PRIN29	PRICIT,10	4.350E 00	9.252E-04	5.926E-01
72	CONVERS.	SPAT20	EFF , 1	9.200E-01	-4.362E-03	-5.909E-01
12	CESOURCE	SPAT20	BASEPR, 1	9.920E-01	3.310E-03	4.834E-01
56	TRANSPT	SPAT20	EFF , 1	9.780E-01	3.249E-03	4.678E-01
120	TRANSPT	SPAT20	EFF , 1	9.000E-01	-3.243E-03	-4.298E-01
52	CONVERS.	SPAT20	IYRAVL, 1	1.995E 03	1.424E-04	4.192E-01
21	CESOURCE	SPAT20	BASEPR, 1	2.570E 00	1.050E-03	3.973E-01
999	GLOBAL	TIME2	PMI , 1	1.000E 00	-2.511E-03	-3.697E-01
139	DEMAND	OTSL24	QUANIY, 1, 2	1.050E 00	2.298E-03	3.553E-01
112	CONVERS.	SPAT20	EFF , 1	1.043E-01	-2.290E-02	-3.516E-01
27	TRANSPT	SPAT20	EFF , 1	9.500E-01	-2.481E-03	-3.470E-01
999	GLOBAL	TIME2	PMI , 9	1.000E 00	2.193E-03	3.228E-01
40	E.P.CONV	SPAT20	SCC , 1	2.432E 01	8.751E-05	3.133E-01
999	GLOBAL	TIME2	PMI , 5	1.000E 00	2.072E-03	3.051E-01
52	CONVERS.	SPAT20	SCC , 1	1.076E 01	1.718E-04	2.722E-01
52	CONVERS.	SPSL27	AVAIL , 1	9.000E-01	-2.035E-03	-2.697E-01
55	ALLOCAT.	ILSP25	FREQPR, 4	2.000E-01	8.932E-03	2.630E-01
40	E.P.CONV	SPSL27	LOADFE, 1	8.800E-01	-1.992E-03	-2.581E-01
40	E.P.CONV	SPSL27	AVAIL , 1	8.000E-01	-2.191E-03	-2.581E-01
23	RESOURCE	SPAT20	NEWRS2, 1	4.730E 02	3.596E-06	2.504E-01
40	E.P.CONV	SPAT20	EFF , 1	3.198E-01	-5.274E-03	-2.483E-01
150	DEMAND	OTSL24	QUANIY, 1, 4	2.220E 00	7.400E-04	2.418E-01
55	ALLOCAT.	OTSL24	QUANIY, 1, 4	8.680E 00	1.853E-04	2.368E-01
999	GLOBAL	TIME2	ROE ,10	9.980E-02	-1.607E-02	-2.361E-01
55	ALLOCAT.	OTSL24	QUANIY, 1, 5	2.021E 01	-7.910E-05	-2.354E-01
80	ALLOCAT.	PRIN29	PRICIT,10	4.950E 00	3.180E-04	2.318E-01
999	GLOBAL	TIME2	PLI , 9	1.000E 00	1.552E-03	2.285E-01
52	CONVERS.	SPAT20	VOC , 1	1.180E 00	1.277E-03	2.218E-01
112	CONVERS.	SPAT20	VOCRAT, 1	3.500E-02	-4.126E-02	-2.126E-01
55	ALLOCAT.	SPAT20	BELAG , 1	1.500E 01	-9.365E-05	-2.068E-01
52	CONVERS.	SPAT20	EFF , 1	7.000E-01	-1.990E-03	-2.051E-01
52	CONVERS.	SPAT20	ICLIFE, 1	2.000E 01	-6.963E-05	-2.050E-01
806	RESOURCE	GPAT19	ROWN , 1	7.980E-02	-1.657E-02	-1.946E-01
21	CESOURCE	SPAT20	ICLIFE, 1	3.000E 01	4.356E-05	1.924E-01
999	GLOBAL	TIME2	PMI , 8	1.000E 00	1.295E-03	1.906E-01
23	RESOURCE	SPAT20	UNRCRS, 1	3.080E 02	-4.146E-06	-1.880E-01
23	RESOURCE	SPAT20	BASEPR, 1	2.170E 00	5.747E-04	1.836E-01
32	TRANSPT	SPAT20	EFF , 1	8.860E-01	-1.402E-03	-1.828E-01
80	ALLOCAT.	SPAT20	BELAG , 1	2.000E 01	6.061E-05	1.785E-01
999	GLOBAL	TIME2	PMI , 2	1.000E 00	1.181E-03	1.738E-01
65	ALLOCAT.	SPAT20	BELAG , 1	1.500E 01	7.643E-05	1.688E-01
80	ALLOCAT.	OTSL24	QUANIY, 1, 2	3.760E 00	3.011E-04	1.667E-01
80	ALLOCAT.	OTSL24	QUANIY, 1, 1	2.614E 01	-4.293E-05	-1.652E-01
21	CESOURCE	SPAT20	CLIM , 1	1.000E 00	1.121E-03	1.650E-01
999	GLOBAL	TIME2	PLI , 8	1.000E 00	1.071E-03	1.577E-01
10	TRANSPT	SPAT20	VOC , 1	6.400E-01	1.672E-03	1.576E-01
16	CESOURCE	SPAT20	NEWRS2, 1	4.512E 02	-2.341E-06	-1.555E-01

Table B.2 (Cont'd)

150	DEMAND	OTSL24	QUANIY, 1, 3	2.650E 00	3.835E-04	1.502E-01
40	E.P.CONV	SPAT20	EQFR , 1	4.500E-01	2.255E-03	1.494E-01
56	TRANSPT	PRIT23	PRICIT,41	4.350E 00	-2.279E-04	-1.459E-01
59	ALLOCAT.	SPAT20	TRANSI, 2	9.300E-01	-1.057E-03	-1.447E-01
56	TRANSPT	PRIT23	PRICIT,46	4.350E 00	-2.249E-04	-1.440E-01
906	MIXED	SC9	INCTAX, 1	5.200E-01	1.872E-03	1.434E-01
28	TRANSPT	SPAT20	EFF , 1	1.000E 00	-9.567E-04	-1.409E-01
999	GLOBAL	TIME2	ROE , 8	9.980E-02	9.334E-03	1.371E-01
150	DEMAND	OTSL24	QUANIY, 1, 7	2.808E-01	3.298E-03	1.363E-01
145	DEMAND	OTSL24	QUANIY, 1, 1	5.640E 00	1.626E-04	1.350E-01
113	CONVERS.	SPAT20	EFF , 1	6.6[illegible]0E-02	-1.369E-02	-1.346E-01
112	CONVERS.	SPAT20	EFLIM , 1	4.800E 00	-1.991E-04	-1.319E-01
62	TRANSPT	SPAT20	EFF , 1	9.600E-01	-9.163E-04	-1.295E-01
999	GLOBAL	TIME2	PLI , 5	1.000E 00	8.762E-04	1.290E-01
54	TRANSPT	SPAT20	EFF , 1	9.600E-01	-9.091E-04	-1.285E-01
999	GLOBAL	TIME2	PMI ,10	1.000E 00	8.678E-04	1.278E-01
999	GLOBAL	TIME2	ROE , 5	9.980E-02	8.220E-03	1.208E-01
13	CESOURCE	SPAT20	BASEPR, 1	7.780E-01	1.044E-03	1.195E-01
150	DEMAND	OTSL24	QUANIY, 1, 2	2.987E 00	2.689E-04	1.182E-01
109	ALLOCAT.	SPAT20	BELAG , 1	5.000E 00	1.578E-04	1.162E-01
25	RESOURCE	SPAT20	NEWRS2, 1	5.550E 02	-1.411E-06	-1.153E-01
113	CONVERS.	SPAT20	EFLIM , 1	1.510E 00	-5.182E-04	-1.152E-01
40	E.P.CONV	SPAT20	IDLIFE, 1	3.000E 01	-2.557E-05	-1.130E-01
52	CONVERS.	SPAT20	EQFR , 1	6.000E-01	1.247E-03	1.102E-01
23	RESOURCE	SPAT20	TRMULT, 1	1.880E 00	-3.859E-04	-1.068E-01
65	ALLOCAT.	ILSP25	FREQPR, 1	5.000E-01	-1.447E-03	-1.065E-01
65	ALLOCAT.	ILSP25	FREQPR, 2	5.000E-01	1.439E-03	1.059E-01
142	DEMAND	OTSL24	QUANIY, 1, 1	2.490E 00	2.888E-04	1.059E-01
999	GLOBAL	TIME2	PMI , 7	1.000E 00	7.178E-04	1.057E-01
46	CONVERS.	SPAT20	SCC , 1	1.101E 01	6.443E-05	1.044E-01
999	GLOBAL	TIME2	PLI ,10	1.000E 00	7.042E-04	1.037E-01
46	CONVERS.	SPSL27	AVAIL , 1	9.000E-01	-7.803E-04	-1.034E-01
139	DEMAND	TMAT33	G2 , 6	1.077E 00	6.484E-04	1.028E-01
999	GLOBAL	TMAT33	Y , 3	3.500E 00	1.984E-04	1.022E-01
999	GLOBAL	TIME2	PLI , 7	1.000E 00	6.870E-04	1.011E-01
19	RESOURCE	SPAT20	NEWRS2, 1	1.820E 02	-3.697E-06	-9.905E-02
16	CESOURCE	SPAT20	ICLIFE, 1	2.500E 01	2.669E-05	9.824E-02
55	ALLOCAT.	ILSP25	FREQPR, 5	2.000E-01	-3.333E-03	-9.815E-02
40	E.P.CONV	SPAT20	CLIM , 1	9.000E-01	7.386E-04	9.787E-02
11	CESOURCE	SPAT20	BASEPR, 1	4.419E-01	1.492E-03	9.708E-02
21	CESOURCE	SPAT20	INRCST, 1	2.140E 00	-3.035E-04	-9.561E-02
150	DEMAND	TMAT33	G4 , 6	1.431E 00	4.485E-04	9.449E-02
999	GLOBAL	TMAT33	Y , 4	3.000E 00	2.137E-04	9.437E-02
10	TRANSPT	SPAT20	EFF , 1	1.000E 00	-6.288E-04	-9.257E-02
906	MIXED	SC9	ITCRAT, 1	9.980E-02	-6.268E-03	-9.210E-02
40	E.P.CONV	SPAT20	IPTLIM, 1	1.300E 01	4.769E-05	9.128E-02
802	CONVERS.	GPAT19	CFLDR , 1	1.698E-01	3.634E-03	9.085E-02
999	GLOBAL	TIME2	PLI , 1	1.000E 00	-6.130E-04	-9.026E-02

Table B.2 (Cont'd)

150	DEMAND	OTSL24	QUANIY, 1, 6	1.530E 00	3.996E-04	9.000E-02
803	E.P.CONV	GPAT19	DUMMY1, 1	9.980E-02	6.071E-03	8.921E-02
46	CONVERS.	SPAT20	EFF , 1	7.000E-01	-8.608E-04	-8.872E-02
46	CONVERS.	SPAT20	ICLIFE, 1	2.000E 01	-2.997E-05	-8.826E-02
132	CONVERS.	SPAT20	EFF , 1	9.560E-01	-6.244E-04	-8.788E-02
16	CESOURCE	SPAT20	BASEPR, 1	4.098E-01	1.403E-03	8.465E-02
77	E.P.CONV	SPAT20	SCC , 1	1.419E 01	-4.040E-05	-8.439E-02
999	GLOBAL	TIME2	ROE , 2	9.980E-02	5.641E-03	8.288E-02
46	CONVERS.	SPAT20	VOC , 1	1.180E 00	4.739E-04	8.232E-02
52	CONVERS.	SPAT20	IDLIFE, 1	2.000E 01	-2.780E-05	-8.186E-02
64	ALLOCAT.	ILSP25	FREQPR, 4	8.400E-02	6.618E-03	8.184E-02
999	GLOBAL	TIME2	ROE , 9	9.980E-02	5.330E-03	7.831E-02
55	ALLOCAT.	ILSP25	FREQPR, 1	2.000E-01	-2.649E-03	-7.801E-02
52	CONVERS.	SPAT20	CLIM , 1	1.000E 00	5.250E-04	7.729E-02
906	MIXED	SC9	PTRATE, 1	1.980E-02	2.624E-02	7.650E-02
11	CESOURCE	SPAT20	ICLIFE, 1	2.500E 01	2.070E-05	7.618E-02
56	TRANSPT	PRIT23	PRICIT,36	4.350E 00	-1.169E-04	-7.489E-02
999	GLOBAL	TIME2	ROE , 7	9.980E-02	5.064E-03	7.441E-02
68	E.P.CONV	SPSL27	AVAIL , 1	7.800E-01	6.468E-04	7.428E-02
68	E.P.CONV	SPSL27	LOADFE, 1	8.100E-01	6.228E-04	7.428E-02
999	GLOBAL	TMAT33	Y , 5	2.900E 00	1.682E-04	7.179E-02
140	ALLOCAT.	SPAT20	BELAG , 1	9.000E 00	5.397E-05	7.151E-02
11	CESOURCE	SPAT20	NEWRS2, 1	6.304E 02	-7.704E-07	-7.150E-02
68	E.P.CONV	SPAT20	SCC , 1	1.959E 01	-2.402E-05	-6.928E-02
19	RESOURCE	SPAT20	BASEPR, 1	2.170E 00	2.127E-04	6.796E-02
148	ALLOCAT.	SPAT20	BELAG , 1	9.000E 00	4.950E-05	6.559E-02
150	DEMAND	OTSL24	QUANIY, 1, 8	1.327E 00	3.353E-04	6.550E-02
999	GLOBAL	TIME2	ROE , 4	9.980E-02	4.451E-03	6.540E-02
150	DEMAND	OTSL24	QUANIY, 1, 1	9.560E-01	4.639E-04	6.530E-02
25	RESOURCE	SPAT20	BASEPR, 1	2.122E 00	2.079E-04	6.494E-02
139	DEMAND	TMAT33	G2 , 3	1.083E 00	4.058E-04	6.469E-02
132	CONVERS.	SPAT20	IDLIFE, 1	5.000E 00	8.729E-05	6.426E-02
114	CONVERS.	SPAT20	EFF , 1	9.980E-01	-4.322E-04	-6.351E-02
22	RESOURCE	SPAT20	NEWRS2, 1	1.862E 02	-2.315E-06	-6.347E-02
999	GLOBAL	TMAT33	Y , 2	4.600E 00	9.366E-05	6.343E-02
9	CESOURCE	SPAT20	INRCST, 1	3.198E-01	1.341E-03	6.312E-02
69	E.P.CONV	SPAT20	IYRAVL, 1	1.990E 03	-2.851E-05	-6.296E-02
40	E.P.CONV	SPAT20	ITXLIF, 1	1.600E 01	2.673E-05	6.296E-02
150	DEMAND	TMAT33	G4 , 2	1.173E 00	3.590E-04	6.199E-02
139	DEMAND	TMAT33	G2 , 2	7.726E-01	5.366E-04	6.104E-02
139	DEMAND	TMAT33	G2 , 4	1.206E 00	3.431E-04	6.091E-02
999	GLOBAL	TMAT33	Y ,10	2.400E 00	-1.723E-04	-6.088E-02
68	E.P.CONV	SPAT20	EFF , 1	3.800E-01	1.067E-03	5.971E-02
110	E.P.LOAD	SPSL27	ENERC , 2	7.490E-02	5.390E-03	5.944E-02
139	DEMAND	TMAT33	G2 , 5	1.250E 00	3.227E-04	5.939E-02
12	CESOURCE	SPAT20	CLIM , 1	1.200E 00	3.362E-04	5.939E-02
809	CONVERS.	GPAT19	CFMULT, 1	1.000E 00	-4.006E-04	-5.898E-02
110	E.P.LOAD	SPSL27	ENERC , 1	9.174E-01	-4.259E-04	-5.752E-02
126	CONVERS.	SPAT20	EFF , 1	1.050E 00	-3.706E-04	-5.728E-02
64	ALLOCAT.	ILSP25	FREQPR, 1	7.410E-01	-5.189E-04	-5.660E-02
55	ALLOCAT.	PRIN29	PRICIT, 9	4.350E 00	-8.804E-05	-5.639E-02
132	CONVERS.	SPAT20	SCC , 1	3.672E 01	1.018E-05	5.504E-02

Table B.2 (Cont'd)

40	E.P.CONV	SPAT20	VOC ,	1		6.800E-01	5.485E-04	5.491E-02
132	CONVERS.	SPSL27	AVAIL ,	1		9.000E-01	-4.113E-04	-5.450E-02
150	DEMAND	TMAT33	G4 ,	4		1.553E 00	2.321E-04	5.306E-02
9	RESOURCE	SPAT20	ICLIFE,	1		2.000E 01	1.793E-05	5.280E-02
139	DEMAND	OTSL24	QUANTY,	1,	1	1.626E-01	2.183E-03	5.226E-02
40	E.P.CONV	SPSL27	LOADFE,	2		5.000E-01	-7.085E-04	-5.216E-02
40	E.P.CONV	SPSL27	AVAIL ,	2		8.000E-01	-4.428E-04	-5.216E-02
111	CONVERS.	SPAT20	EFF ,	1		1.228E-01	-2.860E-03	-5.170E-02
22	RESOURCE	SPAT20	BASEPR,	1		2.170E 00	1.611E-04	5.146E-02
101	CONVERS.	SPAT20	IDLIFE,	1		5.000E 00	-6.981E-05	-5.139E-02
999	GLOBAL	TIME2	INFLAT,	2		1.000E 00	-3.430E-04	-5.050E-02
52	CONVERS.	SPAT20	IPTLIM,	1		8.000E 00	4.277E-05	5.038E-02

Table B.3. Relative Sensitivity of the Total Annual Imports of Oil and Oil Products in the Year 2020. The response $R_3(10)$ has the value 7.4 quadrillion Btu per year in the base case. All relative sensitivities with absolute value $>5 \cdot 10^{-2}$ are given.

NODE	PROCESS	COMMON	VARIABLE	LINK	PARAMETER	SENSITIVITY	RELATIVE SENS.
809	CONVERS.	GPAT19	POSTLM,	1	1.000E 00	5.347E 00	7.187E-01
72	CONVERS.	SPAT20	EFF ,	1	9.200E-01	-4.631E 00	-5.727E-01
12	CESOURCE	SPAT20	INRCST,	1	9.780E-01	-3.985E 00	-5.239E-01
52	CONVERS.	SPAT20	IYRAVL,	1	1.995E 03	1.867E-01	5.021E-01
21	CESOURCE	SPAT20	BASEPR,	1	2.570E 00	1.301E 00	4.493E-01
27	TRANSPT	SPAT20	EFF ,	1	9.500E-01	-3.064E 00	-3.913E-01
12	CESOURCE	SPAT20	BASEPR,	1	9.920E-01	2.840E 00	3.787E-01
139	DEMAND	OTSL24	QUANIY,	1, 2	1.050E 00	2.681E 00	3.785E-01
112	CONVERS.	SPAT20	EFF ,	1	1.043E-01	-2.673E 01	-3.748E-01
999	GLOBAL	TIME2	PMI ,	1	1.000E 00	-2.558E 00	-3.439E-01
52	CONVERS.	SPAT20	SCC ,	1	1.076E 01	2.240E-01	3.240E-01
52	CONVERS.	SPSL27	AVAIL ,	1	9.000E-01	-2.654E 00	-3.211E-01
23	RESOURCE	SPAT20	NEWRS2,	1	4.730E 02	4.977E-03	3.164E-01
55	ALLOCAT.	ILSP25	FREQPR,	4	2.000E-01	1.143E 01	3.072E-01
999	GLOBAL	TIME2	PMI ,	5	1.000E 00	2.167E 00	2.913E-01
55	ALLOCAT.	OTSL24	QUANIY,	1, 4	8.680E 00	2.440E-01	2.847E-01
55	ALLOCAT.	OTSL24	QUANIY,	1, 5	2.021E 01	-1.042E-01	-2.830E-01
120	TRANSPT	SPAT20	EFF ,	1	9.000E-01	-2.278E 00	-2.755E-01
52	CONVERS.	SPAT20	VOC ,	1	1.180E 00	1.665E 00	2.641E-01
999	GLOBAL	TMAT33	Y ,	2	4.600E 00	4.100E-01	2.535E-01
999	GLOBAL	TIME2	PMI ,	9	1.000E 00	1.861E 00	2.502E-01
55	ALLOCAT.	SPAT20	BELAG ,	1	1.500E 01	-1.240E-01	-2.499E-01
999	GLOBAL	TIME2	ROE ,10		9.980E-02	-1.857E 01	-2.491E-01
52	CONVERS.	SPAT20	ICLIFE,	1	2.000E 01	-9.059E-02	-2.436E-01
999	GLOBAL	TMAT33	Y ,	3	3.500E 00	5.161E-01	2.428E-01
40	E.P.CONV	SPAT20	SCC ,	1	2.432E 01	7.394E-02	2.417E-01
52	CONVERS.	SPAT20	EFF ,	1	7.000E-01	-2.522E 00	-2.373E-01
150	DEMAND	OTSL24	QUANIY,	1, 4	2.220E 00	7.838E-01	2.339E-01
806	RESOURCE	GPAT19	BOWN ,	1	7.980E-02	-2.168E 01	-2.325E-01
112	CONVERS.	SPAT20	VOCRAT,	1	3.500E-02	-4.870E 01	-2.291E-01
999	GLOBAL	TMAT33	Y ,	4	3.000E 00	5.436E-01	2.192E-01
21	CESOURCE	SPAT20	ICLIFE,	1	3.000E 01	5.397E-02	2.177E-01
23	RESOURCE	SPAT20	UNRCRS,	1	3.080E 02	-5.209E-03	-2.157E-01
23	RESOURCE	SPAT20	BASEPR,	1	2.170E 00	6.968E-01	2.032E-01
999	GLOBAL	TIME2	PMI ,	2	1.000E 00	1.500E 00	2.017E-01
999	GLOBAL	TIME2	PLI ,	9	1.000E 00	1.474E 00	1.981E-01
65	ALLOCAT.	SPAT20	BELAG ,	1	1.500E 01	9.800E-02	1.976E-01
999	GLOBAL	TMAT33	Y ,	5	2.900E 00	5.049E-01	1.968E-01
40	E.P.CONV	SPSL27	LOADFE,	1	8.800E-01	-1.664E 00	-1.968E-01
40	E.P.CONV	SPSL27	AVAIL ,	1	8.000E-01	-1.830E 00	-1.968E-01
40	E.P.CONV	SPAT20	EFF ,	1	3.198E-01	-4.416E 00	-1.898E-01
21	CESOURCE	SPAT20	CLIM ,	1	1.000E 00	1.398E 00	1.879E-01
80	ALLOCAT.	SPAT20	BELAG ,	1	2.000E 01	6.637E-02	1.784E-01
80	ALLOCAT.	OTSL24	QUANIY,	1, 2	3.760E 00	3.330E-01	1.683E-01
999	GLOBAL	TIME2	PMI ,	8	1.000E 00	1.246E 00	1.675E-01
80	ALLOCAT.	OTSL24	QUANIY,	1, 1	2.614E 01	-4.747E-02	-1.668E-01
28	TRANSPT	SPAT20	EFF ,	1	1.000E 00	-1.156E 00	-1.554E-01
59	ALLOCAT.	SPAT20	TRANSI,	2	9.300E-01	-1.184E 00	-1.480E-01
150	DEMAND	OTSL24	QUANIY,	1, 7	2.808E-01	3.865E 00	1.459E-01

Table B.3 (Cont'd)

113	CONVERS.	SPAT20	EFF , 1		6.680E-02	-1.605E 01	-1.441E-01
112	CONVERS.	SPAT20	EFLIM , 1		4.500E 00	-2.369E-01	-1.433E-01
16	CESOURCE	SPAT20	NEWRS2, 1		4.512E 02	-2.363E-03	-1.433E-01
906	MIXED	SC9	INCTAX, 1		5.200E-01	2.025E 00	1.415E-01
999	GLOBAL	TMAT33	Y , 6		2.400E 00	4.298E-01	1.387E-01
999	GLOBAL	TIME2	PLI , 8		1.000E 00	1.003E 00	1.348E-01
52	CONVERS.	SPAT20	EQFR , 1		6.000E-01	1.626E 00	1.311E-01
23	RESOURCE	SPAT20	IRMULT, 1		1.880E 00	-5.088E-01	-1.286E-01
999	GLOBAL	TIME2	ROE , 8		9.980E-02	9.422E 00	1.264E-01
65	ALLOCAT.	ILSP25	FREQPR, 1		5.000E-01	-1.856E 00	-1.247E-01
113	CONVERS.	SPAT20	EFLIM , 1		1.510E 00	-6.133E-01	-1.245E-01
65	ALLOCAT.	ILSP25	FREQPR, 2		5.000E-01	1.846E 00	1.241E-01
10	TRANSPT	SPAT20	VOC , 1		6.400E-01	1.405E 00	1.209E-01
46	CONVERS.	SPAT20	SCC , 1		1.101E 01	8.027E-02	1.188E-01
32	TRANSPT	SPAT20	EFF , 1		8.860E-01	-9.947E-01	-1.185E-01
999	GLOBAL	TIME2	PLI , 5		1.000E 00	8.812E-01	1.185E-01
150	DEMAND	OTSL24	QUANTY, 1,	3	2.660E 00	3.299E-01	1.179E-01
46	CONVERS.	SPSL27	AVAIL , 1		9.000E-01	-9.722E-01	-1.176E-01
999	GLOBAL	TIME2	ROE , 5		9.980E-02	8.743E 00	1.173E-01
55	ALLOCAT.	ILSP25	FREQPR, 5		2.000E-01	-4.350E 00	-1.169E-01
999	GLOBAL	TMAT33	Y , 7		2.400E 00	3.596E-01	1.160E-01
40	E.P.CONV	SPAT20	EQFR , 1		4.500E-01	1.906E 00	1.153E-01
139	DEMAND	TMAT33	G2 , 6		1.077E 00	7.776E-01	1.126E-01
19	RESOURCE	SPAT20	NEWRS2, 1		1.820E 02	-4.500E-03	-1.101E-01
21	CESOURCE	SPAT20	INRCST, 1		2.140E 00	-3.805E-01	-1.095E-01
999	GLOBAL	TIME2	PMI , 7		1.000E 00	7.734E-01	1.040E-01
46	CONVERS.	SPAT20	ICLIFE, 1		2.000E 01	-3.746E-02	-1.007E-01
145	DEMAND	OTSL24	QUANTY, 1,	1	5.640E 00	1.328E-01	1.007E-01
46	CONVERS.	SPAT20	EFF , 1		7.000E-01	-1.054E 00	-9.921E-02
52	CONVERS.	SPAT20	IDLIFE, 1		2.000E 01	-3.625E-02	-9.744E-02
150	DEMAND	OTSL24	QUANTY, 1,	6	1.530E 00	4.713E-01	9.691E-02
999	GLOBAL	TIME2	ROE , 2		9.980E-02	7.046E 00	9.452E-02
999	GLOBAL	TMAT33	Y , 8		2.400E 00	2.909E-01	9.386E-02
46	CONVERS.	SPAT20	VOC , 1		1.180E 00	5.899E-01	9.355E-02
13	CESOURCE	SPAT20	BASEPR, 1		7.780E-01	8.869E-01	9.276E-02
150	DEMAND	TMAT33	G4 , 6		1.431E 00	4.820E-01	9.271E-02
16	CESOURCE	SPAT20	ICLIFE, 1		2.500E 01	2.750E-02	9.243E-02
52	CONVERS.	SPAT20	CLIM , 1		1.000E 00	6.797E-01	9.136E-02
999	GLOBAL	TIME2	PLI , 7		1.000E 00	6.674E-01	8.971E-02
55	ALLOCAT.	ILSP25	FREQPR, 1		2.000E-01	-3.311E 00	-8.900E-02
40	E.P.CONV	SPAT20	IDLIFE, 1		3.000E 01	-2.161E-02	-8.713E-02
77	E.P.CONV	SPAT20	SCC , 1		1.419E 01	-4.521E-02	-8.624E-02
109	ALLOCAT.	SPAT20	BELAG , 1		5.000E 00	1.247E-01	8.378E-02
999	GLOBAL	TIME2	PLI ,10		1.000E 00	6.212E-01	8.350E-02
150	DEMAND	OTSL24	QUANTY, 1,	2	2.987E 00	2.048E-01	8.222E-02
16	CESOURCE	SPAT20	BASEPR, 1		4.098E-01	1.489E 00	8.203E-02
906	MIXED	SC9	ITCRAT, 1		9.980E-02	-5.954E 00	-7.987E-02
11	CESOURCE	SPAT20	BASEPR, 1		4.419E-01	1.333E 00	7.915E-02

Table B.3 (Cont'd)

142	DEMAND	OTSL24	QUANIY,	1, 1	2.490E 00	2.353E-01	7.876E-02
802	CONVERS.	GPAT19	CFLDR ,	1	1.698E-01	3.447E 00	7.869E-02
55	ALLOCAT.	PRIN29	PRICIT,	10	4.350E 00	-1.305E-01	-7.633E-02
101	CONVERS.	SPAT20	IDLIFE,	1	5.000E 00	-1.122E-01	-7.539E-02
999	GLOBAL	TIME2	PLI ,	1	1.000E 00	-5.591E-01	-7.515E-02
19	RESOURCE	SPAT20	BASEPR,	1	2.170E 00	2.536E-01	7.397E-02
999	GLOBAL	TMAT33	Y ,	9	2.400E 00	2.284E-01	7.369E-02
999	GLOBAL	TIME2	ROE ,	7	9.980E-02	5.477E 00	7.347E-02
40	E.P.CONV	SPAT20	CLIM ,	1	9.000E-01	6.066E-01	7.339E-02
22	RESOURCE	SPAT20	NEWRS2,	1	1.862E 02	-2.868E-03	-7.179E-02
140	ALLOCAT.	SPAT20	BELAG ,	1	9.000E 00	5.928E-02	7.172E-02
999	GLOBAL	TIME2	ROE ,	9	9.980E-02	5.334E 00	7.155E-02
40	E.P.CONV	SPAT20	IPTLIM,	1	1.300E 01	4.029E-02	7.041E-02
10	TRANSPT	SPAT20	EFF ,	1	1.000E 00	-5.233E-01	-7.034E-02
150	DEMAND	OTSL24	QUANIY,	1, 8	1.327E 00	3.941E-01	7.029E-02
139	DEMAND	TMAT33	G2 ,	3	1.083E 00	4.762E-01	6.931E-02
114	CONVERS.	SPAT20	EFF ,	1	9.980E-01	-5.100E-01	-6.841E-02
802	CONVERS.	GPAT19	CFMULT,	1	1.000E 00	-4.939E-01	-6.639E-02
906	MIXED	SC9	PTRATE,	1	1.980E-02	2.494E 01	6.638E-02
55	ALLOCAT.	PRIN29	PRICIT,	9	4.350E 00	-1.135E-01	-6.634E-02
999	GLOBAL	TIME2	ROE ,	4	9.980E-02	4.927E 00	6.610E-02
139	DEMAND	TMAT33	G2 ,	4	1.206E 00	4.046E-01	6.558E-02
139	DEMAND	TMAT33	G2 ,	2	7.726E-01	6.261E-01	6.502E-02
68	E.P.CONV	SPSL27	AVAIL ,	1	7.800E-01	6.197E-01	6.497E-02
68	E.P.CONV	SPSL27	LOADFE,	1	8.100E-01	5.967E-01	6.497E-02
101	CONVERS.	SPAT20	SCC ,	1	5.102E 01	-9.412E-03	-6.455E-02
139	DEMAND	TMAT33	G2 ,	5	1.250E 00	3.824E-01	6.426E-02
101	CONVERS.	SPSL27	AVAIL ,	1	9.000E-01	5.282E-01	6.390E-02
132	CONVERS.	SPAT20	EFF ,	1	9.560E-01	-4.808E-01	-6.179E-02
68	E.P.CONV	SPAT20	SCC ,	1	1.959E 01	-2.343E-02	-6.169E-02
11	RESOURCE	SPAT20	ICLIFE,	1	2.500E 01	1.813E-02	6.094E-02
52	CONVERS.	SPAT20	IPTLIM,	1	8.000E 00	5.577E-02	5.997E-02
150	DEMAND	TMAT33	G4 ,	2	1.173E 00	3.803E-01	5.995E-02
77	E.P.CONV	SPAT20	EFF ,	1	3.700E-01	1.205E 00	5.994E-02
55	ALLOCAT.	PRIN29	PRICIT,	8	4.350E 00	-1.009E-01	-5.898E-02
809	CONVERS.	GPAT19	CFMULT,	1	1.000E 00	-4.337E-01	-5.830E-02
52	CONVERS.	SPAT20	ITXLIF,	1	1.600E 01	2.694E-02	5.794E-02
55	ALLOCAT.	PRIN29	PRICIT,	7	4.350E 00	-9.903E-02	-5.790E-02
11	RESOURCE	SPAT20	NEWRS2,	1	6.304E 02	-6.769E-04	-5.736E-02
22	RESOURCE	SPAT20	BASEPR,	1	2.170E 00	1.945E-01	5.674E-02
21	RESOURCE	SPAT20	UNRCRS,	1	5.800E 01	-7.201E-03	-5.614E-02
139	DEMAND	OTSL24	QUANIY,	1, 1	1.626E-01	2.559E 00	5.594E-02
59	ALLOCAT.	SPAT20	TRANSI,	1	8.000E-01	5.172E-01	5.562E-02
111	CONVERS.	SPAT20	EFF ,	1	1.228E-01	-3.356E 00	-5.540E-02

Table B.3 (Cont'd)

44	CONVERS.	SPAT20	IYRAVL, 1	1.995E 03	-2.038E-02	-5.479E-02
55	ALLOCAT.	PRIN29	PRICIT, 6	4.280E 00	-9.457E-02	-5.441E-02
77	E.P.CONV	SPSL27	LOADFE, 1	8.100E-01	4.951E-01	5.391E-02
77	E.P.CONV	SPSL27	AVAIL , 1	7.900E-01	5.076E-01	5.391E-02
68	E.P.CONV	SPAT20	EFF , 1	3.800E-01	1.051E 00	5.370E-02
999	GLOBAL	TIME2	INFLAT, 2	1.000E 00	-3.980E-01	-5.350E-02
46	CONVERS.	SPAT20	IYRAVL, 1	1.995E 03	1.964E-02	5.281E-02
25	RESOURCE	SPAT20	NEWRS2, 1	5.550E 02	-6.993E-04	-5.217E-02
999	GLOBAL	TMAT33	Y ,10	2.400E 00	1.617E-01	5.216E-02
55	ALLOCAT.	ILSP25	FREQPR, 3	2.000E-01	-1.930E 00	-5.190E-02
69	E.P.CONV	SPAT20	IYRAVL, 1	1.990E 03	-2.564E-02	-5.170E-02
150	DEMAND	TMAT33	G4 , 4	1.553E 00	2.471E-01	5.158E-02
110	E.P.LOAD	SPSL27	ENFRC , 2	7.490E-02	5.069E 00	5.104E-02
999	GLOBAL	TIME2	PMI ,10	1.000E 00	3.758E-01	5.052E-02
46	CONVERS.	SPAT20	CLIM , 1	1.000E 00	3.731E-01	5.016E-02

Table B.4. Relative Sensitivity of the Ratio of the Total Annual Liquid Fuels Input to All Demand Sectors in the Year 2020 to the Total Annual Fuel Input to All Demand Sectors in the Year 2020. The response $R_4(10)$ has a value of .32 in the base case. All relative sensitivities with absolute value $>5 \cdot 10^{-2}$ are given.

NODE	PROCESS	COMMON	VARIABLE LINK	PARAMETER	SENSITIVITY	RELATIVE SENS.
139	DEMAND	CTSL24	QUANTY, 1, 2	1.050E 00	7.583E-02	2.522E-01
112	CONVERS.	SPAT20	EFF , 1	1.043E-01	-7.566E-01	-2.499E-01
72	CONVERS.	SPAT20	EFF , 1	9.200E-01	7.484E-02	2.180E-01
150	DEMAND	CTSL24	QUANTY, 1, 2	2.987E 00	-1.731E-02	-1.637E-01
112	CONVERS.	SPAT20	VOCRAT, 1	3.500E-02	-1.421E 00	-1.575E-01
12	CESOURCE	SPAT20	INRCST, 1	9.780E-01	-4.807E-02	-1.489E-01
150	DEMAND	CTSL24	QUANTY, 1, 3	2.660E 00	-1.328E-02	-1.119E-01
112	CONVERS.	SPAT20	EFLIM , 1	4.500E 00	-7.098E-03	-1.011E-01
150	DEMAND	CTSL24	QUANTY, 1, 7	2.808E-01	1.109E-01	9.865E-02
113	CONVERS.	SPAT20	EFF , 1	6.680E-02	-4.614E-01	-9.760E-02
12	CESOURCE	SPAT20	BASEPR, 1	9.920E-01	2.975E-02	9.346E-02
809	CONVERS.	GPAT19	POSTLM, 1	1.000E 00	2.787E-02	8.825E-02
113	CONVERS.	SPAT20	EFLIM , 1	1.510E 00	-1.805E-02	-8.629E-02
101	CONVERS.	SPAT20	IDLIFE, 1	5.000E 00	-5.294E-03	-8.381E-02
150	DEMAND	TMAT33	G2 , 6	1.698E 00	-1.537E-02	-8.261E-02
5	CONVERS.	SPAT20	SCC , 1	2.838E 01	-9.181E-04	-8.251E-02
139	DEMAND	TMAT33	G2 , 6	1.077E 00	2.395E-02	8.171E-02
5	CONVERS.	SPSL27	AVAIL , 1	9.000E-01	2.866E-02	8.168E-02
150	DEMAND	CTSL24	QUANTY, 1, 1	9.560E-01	-2.388E-02	-7.229E-02
101	CONVERS.	SPAT20	SCC , 1	5.102E 01	-4.442E-04	-7.176E-02
101	CONVERS.	SPSL27	AVAIL , 1	9.000E-01	2.493E-02	7.104E-02
150	DEMAND	CTSL24	QUANTY, 1, 6	1.530E 00	1.378E-02	6.675E-02
150	DEMAND	TMAT33	G2 , 3	2.266E 00	-8.432E-03	-6.049E-02
117	CONVERS.	SPAT20	EFF , 1	7.500E-01	2.482E-02	5.895E-02
140	ALLOCAT.	SPAT20	BELAG , 1	9.000E 00	2.011E-03	5.730E-02
115	ALLOCAT.	TLSP25	FREGPR, 1	3.700E-01	4.837E-02	5.667E-02
802	CONVERS.	GPAT19	CFMULT, 1	1.000E 00	-1.774E-02	-5.618E-02
148	ALLOCAT.	SPAT20	SHSELS, 1	5.000E 00	-3.338E-03	-5.284E-02
150	DEMAND	TMAT33	G3 , 6	1.508E 00	-1.101E-02	-5.255E-02
148	ALLOCAT.	SPAT20	BELAG , 1	9.000E 00	1.818E-03	5.180E-02

Appendix C

Data Elements in the Process Submodels

To carry out the numerical determination of the elements of $\overline{S}$ as outlined in Section IV.C, it is necessary to systematically vary each of the data elements in each process submodel at every node. In Tables C.1 to C.6 of this Appendix the data elements in each submodel, as well as the common in which they occur, are listed. The correspondence between the process submodels and the tables are:

Conversion	C.1
Resource	C.2
Allocation	C.3
Electric Power Loading	C.4
Transportation	C.5
Demand	C.6

The data element name in the second column of the tables is the FORTRAN name used in the LEAP-78 computer code. The definition of these data elements will be found in Stewart (1981) and the manner in which the data elements enter into the equation of the processes is given in Goldstein (1981). The symbols used in Goldstein (1981) are not the FORTRAN names, but a complete cross reference between the symbols and the FORTRAN names is given in Stewart (1981).

In some cases data elements that occur in different processes are specified by the modeler to be the same. In Tables C.1 to C.6 this has been indicated where it is very generally true. In a variety of other

cases, specific data elements in LEAP-78 have been specified to be the same at various nodes. The data elements and nodes where this is the case are specified in Table C.7.

Table C.1 Data Elements in the Conversion[+] and Electric Power Conversion Processes[++]

```
COMMON/TIME2/TGLOBL(50),INFLAT(50),PLI(50,PMI(50),ROE(50),RDEBT(50)
COMMON/GR3  /LKNG,IGPG,ISPG,RINF(2)
COMMON/SC9   /LKNS,IGPS,ISPS,INCTAX,ITCRAT,PTRATE,FORPER
COMMON/GPAT19/CLFR,OLFR,CFLDR,DUMMY1,DUMMY2,VOAGRT,DUMMY3,POSTLM,
                        EARLY,NEWFLX,CFMULT,CFSENS
COMMON/SPAT20/SCC,VOC,EFF,IPLTIM,IYRAVL,CLIM,EFLIM,ICLIFE,
              ITXLIF,IDLIFE,EQFR,CRATE,VOCRAT,PRELIM
COMMON/OTSL24/QUAN1Y(5),PRIC1Y(5)RATIN(5),AVEFFI
COMMON/GPSL26/LOADFC(5)
COMMON/SPSL27/AVAIL(5),LOADFE(5)
```

COMMON	DATA ELEMENT NAME	NUMBER OF DATA ELEMENTS			NOTES
TIME2	INFLAT*	N	where	N=1, NPOINT (no. of global times)	
TIME2	PLI*	N	where	N=1, NPOINT (no. of global times)	
TIME2	PMI*	N	where	N=1, NPOINT (no. of global times)	
TIME2	ROE*	N	where	N=1, NPOINT (no. of global times)	
TIME2	RDEBT*	N	where	N=1, NPOINT (no. of global times)	

[+]The terminology "basic conversion process" is sometimes used to denote what is called here the conversion process.

[++]The parameters of the conversion and electric power conversion processes are the same except that in conversion there is only 1 load factor and 1 availability while in electric power conversion there are more than one of each of these data elements.

*These parameters have the same value in all conversion processes and in all resource processes.

Table C.1 (Cont'd)

COMMON	DATA ELEMENT NAME	NUMBER OF DATA ELEMENTS	NOTES
GR3	RINF*	J where J=1,2	
SC9	INCTAX	1	
SC9	ITCRAT	1	
SC9	PTRATE	1	
GPAT19	CLFR	1	
GPAT19	OLFR	1	
GPAT19	OFLDR	1	
GPAT19	DUMMY1	1	If ≠ 0, ROE(J)=DUMMY1
GPAT19	DUMMY2	1	If ≠ 0, RDEBT(J)=DUMMY2
GPAT19	VOAGRT	1	
GPAT19	DUMMY3	1	
GPAT19	POSTLM	1	
GPAT19	EARLY	1	
GPAT19	NEWFLX	1	

*These parameters have the same value in all conversion processes and in all resource processes.

Table C.1 (Cont'd)

COMMON	DATA ELEMENT NAME	NUMBER OF DATA ELEMENTS	NOTES
GPAT19	CFMULT	1	
GPAT19	CFSENS	1	
SPAT20	SCC	1	
SPAT20	VOC	1	
SPAT20	EFF	1	
SPAT20	IPLTIM	1	
SPAT20	IYRAVL	1	
SPAT20	CLIM	1	
SPAT20	EFLIM	1	
SPAT20	ICLIFE	1	
SPAT20	ITXLIF	1	
SPAT20	IDLIFE	1	
SPAT20	EQFR	1	
SPAT20	CRATE	1	

Table C.1 (Cont'd)

COMMON	DATA ELEMENT NAME	NUMBER OF DATA ELEMENTS	NOTES
SPAT20	VOCRAT	1	
SPAT20	PRELIM	1	
OTSL24	AVEFFI	1	
GPSL26	LOADFC	L where L=1, NSL (no. of sublinks out)	
SPSL27	AVAIL	L where L=1, NSL (no. of sublinks out)	
SPSL27	LOADFE	L where L=1, NSL (no. of sublinks out)	

C.2 Data Elements of the Resource Process[+]

```
COMMON/TIME2/TGLOBL(50),INFLAT(50),PLI(50),PMI(50),ROE(50),RDEBT(50)
COMMON/GR3   /LKNG,IGPG,ISPG,RINF(2)
COMMON/SC9   /LKNS,IGPS,ISPS,INCTAX,ITCRAT,PTRATE,FORPER
COMMON/GPAT19/CLFR,OLFR,CFLDR,CRATE,VOCRAT,VOAGRT,PRELIM,
              POSTLM,EARLY,NEWFLX,CFMULT,CFSENS,ROWN
COMMON/SPAT20/IPLTIM,IYRAVL,CLIM,ICLIFE,ITXLIF,IDLIFE,EQFR,INRCST
              BASEPR,UNRCRS,NEWRS2,CCCF,DCLNO,HDCMLT,FDCMLT,REGTST,TRMULT
COMMON/OTSL24/QUAN1Y(5),PRIC1Y(5),RATIN
```

COMMON	DATA ELEMENT NAME	NUMBER OF DATA ELEMENTS	NOTES
TIME2	INFLAT*	N where N=1, NPOINT (no. of global times)	
TIME2	PLI*	N where N=1, NPOINT (no. of global times)	
TIME2	PMI*	N where N=1, NPOINT (no. of global times)	
TIME2	ROE*	N where N=1, NPOINT (no. of global times)	
TIME2	RDEBT*	N where N=1, NPOINT (no. of gobal times)	
GR3	RINF*	J where J=1, 2	
SC9	INCTAX	1	
SC9	ITCRAT	1	
SC9	PTRATE	1	

[+]There are two distinct resource submodels; RESORC and CESORC.[6,9] The data elements in each submodel are the same and are those given here.

*These data elements have the same value in all conversion and resource processes.

Table C.2 Data Elements of the Resource Process (Cont'd)

COMMON	DATA ELEMENT NAME	NUMBER OF DATA ELEMENTS	NOTES
GPAT19	CLFR	1	
GPAT19	OLFR	1	
GPAT19	CFLDR	1	
GPAT19	CRATE	1	
GPAT19	VOCRAT	1	
GPAT19	VOAGRT	1	
GPAT19	PRELIM	1	
GPAT19	POSTLM	1	
GPAT19	EARLY	1	
GPAT19	NEWFLX	1	
GPAT19	CFMULT	1	
GPAT19	CFSENS	1	
GPAT19	ROWN	1	
SPAT20	IPLTIM	1	
SPAT20	IYRAVL	1	

Table C.2 Data Elements of the Resource Process (Cont'd)

COMMON	DATA ELEMENT NAME	NUMBER OF DATA ELEMENTS	NOTES
SPAT20	CLIM	1	
SPAT20	ICLIFE	1	
SPAT20	ITXLIF	1	
SPAT20	IDLIFE	1	
SPAT20	EQFR	1	
SPAT20	INRCST	1	
SPAT20	BASEPR	1	
SPAT20	UNRCRS	1	
SPAT20	NEWRS2	1	
SPAT20	CCCF	1	
SPAT20	DCLNO	1	
SPAT20	REGTST	1	
SPAT20	TRMULT	1	
OTSL24	RATIN	1	

Table C.3 Data Elements of the Allocation Process

```
COMMON/SPAT20/SHSENS,BELAG,TRANSI(18)
COMMON/OTSL24/QUAN1Y(5),PRIC1Y(5)
COMMON/ILSP25/FREQPR(30)
COMMON/PRIN29/QUANIT(50),PRICIT(50),SHPRIT(50),QUANIL(50),QUANOL(50)
```

COMMON	DATA ELEMENT NAME	NUMBER OF DATA ELEMENTS	NOTES
SPAT20	SHENS	1	
SPAT20	BELAG	1	
SPAT20	TRANSI	J where J=1, NOUTS (no. output links) for LKN=8 J=1, NINTS (no. input links) for LKN=7	Only appears for LKN=7 or 8
OTSL24	QUAN1Y	L,J where L=1, NSL (no. sublinks) J=1, NINTS (no. input links)	
ILSP25	FREQPR	J where J=1, NINTS (no. input links)	Change in any FREQPR requires normalizing*
PRIN29	PRICIT	N where N=1, NPOINT (no. of global times)	Only appears if input from IMPORT

*One has $\sum_{J=1}^{NINTS} FREQPR(J)=1$. To maintain this constraint the equations are written in terms of the quantities $\frac{FREQPR(K)}{\Sigma FREQPR(J)}$ K=1 to J so that FREQPR(K) for each K may be varied independently.

Table C.4 Data Elements of the Electric Power Loading Process

COMMON/GPSL26/LOADFC(5)
COMMON/SPSL27/ENFRC(5)

COMMON	DATA ELEMENT NAME	NUMBER OF DATA ELEMENTS		NOTES
GPSL26	LOADFC	L	L=1, NSL (no. of sublinks in)	
SPSL27	ENFRC	L	L=1, NSL (no. of sublinks in)	Change in ENFRC requires normalization (see footnote in Table B.3)

Table C.5 Data Elements of the Transport Process

```
COMMON/AC10  /LKNA,IGPA,ISPA,IWTA,RDIST
COMMON/SPAT20/SCC,  VOC,EFF
COMMON/PRIT23/QUANIT(5,50),PRICIT(5,50),SHRRIT(5,50)
```

COMMON	DATA ELEMENT NAME	NUMBER OF DATA ELEMENTS	NOTES
AC10	DIST	1	Listed as RDIST in COMMON/AC10/
SPAT20	SCC	1	
SPAT20	VOC	1	
SPAT20	EFF	1	
PRIT23	PRICIT	K where K=5*J+1 with J=1, NPOINT (no. of global times)	Only appears if input from IMPORT

Table C.6 Data Elements of the Demand Process

```
COMMON/SPAT20/SENS,ELAS,GSCALE
COMMON/OTSL24/QUAN1Y(5),PRIC1Y(5)
COMMON/TMAT33/Y(50),G1(50),P1(50),G2(50),P2(50),G3(50),P3(50),G4(50),P4(50),G5(50),P5(50),
              G6(50,P6(50),G7(50),P7(50),G8(50),P8(50),G9(50),P9(50),G10(50),P10(50)
```

COMMON	DATA ELEMENT NAME	NUMBER OF DATA ELEMENTS	NOTES
SPAT20	SENS	1	
SPAT20	ELAS	1	
SPAT20	GSCALE	1	
OTSL24	QUAN1Y	1,J where J=1, NOL (no. of input links)	
TMAT33	Y*	N where N=1, NPOINT (no. of global times)	
TMAT33	G1	N where N=1, NPOINT (no. of global times)	
TMAT33	P1	N where N=1, NPOINT (no. of global times)	
TMAT33	G2	N where N=1, NPOINT (no. of global times)	Only appears if NOL $\geqslant$ 2
TMAT33	P2	N where N=1, NPOINT (no. of global times)	Only appears if NOL $\geqslant$ 2

*These data elements share the same value in all demand processes.

Table C.6 Data Elements of the Demand Process (Cont'd)

COMMON	DATA ELEMENT NAME	NUMBER OF DATA ELEMENTS	NOTES
TMAT33	G3	N where N=1, NPOINT (no. of global times)	Only appears if NOL ⩾ 3
TMAT33	P3	N where N=1, NPOINT (no. of global times)	Only appears if NOL ⩾ 3
TMAT33	G4	N where N=1, NPOINT (no. of global times)	Only appears if NOL ⩾ 4
TMAT33	P4	N where N=1, NPOINT (no. of global times)	Only appears if NOL ⩾ 4
TMAT33	G5	N where N=1, NPOINT (no. of global times)	Only appears if NOL ⩾ 5
TMAT33	P5	N where N=1, NPOINT (no. of global times)	Only appears if NOL ⩾ 5
TMAT33	G6	N where N=1, NPOINT (no. of global times)	Only appears if NOL ⩾ 6
TMAT33	P6	N where N=1, NPOINT (no. of global times)	Only appears if NOL ⩾ 6
TMAT33	G7	N where N=1, NPOINT (no. of global times)	Only appears if NOL ⩾ 7
TMAT33	P7	N where N=1, NPOINT (no. of global times)	Only appears if NOL ⩾ 7
TMAT33	G8	N where N=1, NPOINT (no. of global times)	Only appears if NOL ⩾ 8
TMAT33	P8	N where N=1, NPOINT (no. of global times)	Only appears if NOL ⩾ 8
TMAT33	G9	N where N=1, NPOINT (no. of global times)	Only appears if NOL ⩾ 9
TMAT33	P9	N where N=1, NPOINT (no. of global times)	Only appears if NOL ⩾ 9
TMAT33	G10	N where N=1, NPOINT (no. of global times)	Only appears if NOL ⩾10
TMAT33	P10	N where N=1, NPOINT (no. of global times)	Only appears if NOL ⩾10

Table C.7 Node Combinations That Have Common Data Elements

Common/SC9/Conversion, Electric Power Conversion, Resource and C-Resource

This common contains 7 elements, but only three of these elements - INCTAX, ITCRAT, PTRATE - are data elements that are to be varied in LEAP-78. These three data elements are taken to be the same in the combinations of nodes given below. This identification number is 900 + the SC index used in the code.

Identification Number	No. of Nodes	Node Number Combined	Process Types
901	9	1,2,101,102,103,132,133,135,144	CONV.
902	13	5,83,84,85,86,87,104,105,116,117, 118,119,147	CONV.
904	13	6,8,39,40,68,69,70,77,78,79.92,93,94	ELE. P. CONV.
905	1	9	C-RES.
906	14	44,45,46,47,48,49,52,53,11,12,13,14, 16,17	CONV. & C-RES.
907	8	72,19,20,22,23,24,25,21	CONV., RES. & C-RES.
908	5	111,112,113,114,123	CONV.
909	11	33,35,36,97,98.99,100,126,127,128,141	CONV.

Table C.7(Cont'd)

Common/GPAT19/ Conversion, Electric Power Conversion, Resource & C-Resource

All of the data elements in this common are taken to be the same in the combination of nodes given below, but the number of data elements in the common varies with the process. The identification number is 800 + the IGP index used in the code.

Identification Number	No. of Nodes	Node Number Combined	Process Types
802	9	44,45,46,47,48,49,52,53,72	CONV.
803	13	6,8,39,40,68,69,70,77,78,79,92,93,94	ELE. P. CONV.
806	6	19,20,22,23,24,25	RES.
809	38	1,2,5,33,35,36,83,84,85,86,87,97,98,99,100, 101,102,103,104,105,111,112,113,114,116,117, 118,119,123,126,127,128,132,113,135,141,144, 146	CONV.
811	8	9,11,12,13,14,16,17,21	C-RES.

Table C.7 (Cont'd)

Common/SPAT20/ Allocation

All of the data elements in this common are the same in the combination of nodes given below.

Identification Number	No. of Nodes	Node Number Combined	Process Types
741	19	41,42,43,50,67,71,74,76,81,82,88,91,95, 106,107,125,131,137,138	ALLOC.
722	2	130,136	ALLOC.

Common/ILSP25/ Allocation

All of the data elements in this common are the same in the combination of nodes given below.

Identification Number	No. of Nodes	Node Number Combined	Process Types
541	19	41,42,43,50,67,71,74,76,81,82,88,91, 95,106,107,125,131,137,138	ALLOC.
522	2	130,136	ALLOC.

Table C .7 (Cont'd)

Common/GPSL26/ Conversion

All of the data elements in this common are the same in the combination of nodes given below. The identification number is 600 + the IGP index used in the code.

Identification Number	No. of Nodes	Node Number Combined	Process Types
602	9	44,45,46,47,48,49,52,53,72	CONV.
609	39	1,2,5,33,35,36,83,84,85,86,87,97,98,99, 100,101,102,103,104,105,111,112,113,114 116,117,118,119,123,126,127,128,132,133, 135,141,144,147	CONV.

References

R. J. Adler et al. 1979. The DFI Generalized Equilibrium Modeling System, Decision Focus, Inc., 1801 Page Mill Rd., Palo Alto, CA 94304.

R. G. Alsmiller, Jr. et al. 1980. Interim Report on Model Evaluation Methodology and the Evaluation of LEAP, Oak Ridge National Laboratory Report, ORNL-TM-7245.

D. C. Cacuci et al. 1980. Generalized Sensitivity Theory for Systems of Coupled Nonlinear Equations, Nucl. Sci. Eng. 75, 88-110.

E. A. Cherniavsky and L. L. Juang. 1980. Resource Submodels of the Long-Term Energy Analysis Package: Documentation, Energy Information Administration, U. S. Department of Energy, Washington, D.C., Draft Report.

R. Diedrick, C. Cornett, J. Pearson. 1979. LEAP Network and Data Documentation — ARC-78, Energy Information Administration Draft Report, U.S. Department of Eneergy.

J. S. Duff. 1977. MA-28, A Set of Fortran Subroutines for Sparse Unsymmetric Linear Equations, A.E.R.E. Report R.8730.HMSO, London.

J. E. Falk, G. P. McCormick and R. M. Soland. 1979. Research Into the Methodology of LEAP Model, U.S. Department of Energy, Energy Information Administration, DOE/EIA-451887, Washington, D.C.

W. E. Ford, III et al. 1981. Operating Experience with LEAP from the Perspective of a Computing Applications Analyst, Oak Ridge National Laboratory Report, ORNL/TM-7566.

M. Goldstein, R. G. Alsmiller, Jr. and J. Barish. 1981. Specification of the Equations of LEAP Model 22C, Oak Ridge National Laboratory Report, ORNL-5707.

J. A. Hansen, M. Becker and J. L. Trimble. 1981. The Economic Foundations of LEAP Model 22C, Oak Ridge National Laboratory Report, ORNL/TM-7577.

E. M. Oblow. 1978. Sensitivity Theory for General Nonlinear Algebraic Equations With Constants, Nucl. Sci. Eng. 65, 187-191.

E. M. Oblow, C. R. Weisbin, R. G. Alsmiller, Jr. 1979. Sensitivity Analysis for Energy-Economy Modelling, Proceedings of Energy Modeling II, Colorado Springs, Colorado, August 13-17, 1979.

E. M. Oblow. 1981. Mathematical Foundations of LEAP, Oak Ridge National Laboratory Report, ORNL/TM-7566.

J. Pearson et al. 1979. Long-Term Energy Supply and Demand, Annual Report to Congress 1978, Vol. 3, Chapter 5 and Appendix, DOE/EIA-0173/3, p. 403 ff.

R. W. Peelle, C. R. Weisbin and R. G. Alsmiller, Jr. 1981. An Evaluation of the Long-Term Energy Analysis Program Used for the 1978 EIA Administrator's Report To Congress, Oak Ridge National Laboratory Report, ORNL-5741.

P. A. Samuelson. 1976. Foundations of Economic Analysis, Atheneum Press, New York, N.Y.

L. Stewart and M. Goldstein. 1981. Input Parameters for LEAP and Analysis of Model 22C Data Base, Oak Ridge National Laboratory Report, ORNL/TM-7710.

INTERNAL DISTRIBUTION

1-2. L. S. Abbott
3. R. G. Alsmiller, Jr.
4. F. S. Alsmiller
5. S. J. Auerbach
6. J. Barhen
7. J. Barish
8. D. E. Bartine
9. M. A. Bjerke
10. D. Bjornstad
11. D. G. Cacuci
12. S. Cantor
13. G. de Saussure
14. D. J. Downing
15-39. EPIC
40. G. F. Flanagan
41. T. B. Fowler
42. W. E. Ford, III
43. W. Fulkerson
44. D. A. Gardiner
45. D. Gilai
46. H. Goldstein (Consultant)
47. M. Goldstein
48. D. Greene
49. P. M. Haas
50. E. Halbert
51. M. C. G. Hall
52. L. Hill
53. E. Hirst
54. J. Horwedel
55. D. T. Ingersoll
56. J. M. Kallfelz
57-66. A. S. Loebl
67. J. L. Lucius
68. B. J. Jacobs
69. F. C. Maienschein
70. J. J. Manning
71. J. H. Marable
72. B. F. Maskewitz
73. B. D. Murphy
74. D. Nguyen
75. E. M. Oblow
76. J. V. Pace
77. S. C. Parikh
78. C. V. Parks
79-88. R. W. Peelle
89. F. G. Perey
90. R. B. Perez
91. R. Pevey
92. Y. Ronen
93. M. W. Rosenthal
94. R. W. Roussin
95. R. T. Santoro
96. D. L. Selby
97. R. Sharma
98. L. Stewart
99. C. Thomas
100. B. C. Toney
101. J. Trimble
102. D. K. Trubey
103. D. R. Vondy
104. E. Wacholder
105. J. J. Wagschal
106. C. F. Weber
107-116. C. R. Weisbin
117. L. W. Weston
118. J. R. White
119. G. E. Whitesides
120. T. J. Wilbanks
121. M. L. Williams
122. R. Q. Wright
123. A. Zucker
124. P. Greebler (Consultant)
125. H. J. C. Kouts (Consultant)
126. W. B. Loewenstein (Consultant)
127. R. Wilson (Consultant)
128-129. Central Research Library
130. ORNL Y-12 Technical Library - Document Reference Section
131. Laboratory Records
132. ORNL Patent Office
133. Laboratory Records - RC

EXTERNAL DISTRIBUTION

134. Office of Assistant Manager for Energy Research and Development, DOE-ORO, Oak Ridge, TN 37830

135. R. L. Basmann, Department of Economics, Texas A&M University, College Station, Texas 77843

136. M. Becker, Dept. of Nuclear Engineering, Rensselaer Polytechnic Institute, Tibbets Avenue, Troy, NY 12181

137. D. J. Beecy, Acting Director, Division of Policy & Strategic Planning, Office of Fossil Energy, MS C-125, U. S. Department of Energy, Washington, DC 20545

138. W. G. Bentley, Florida Power and Light Company, P.O. Box 529100, Miami, FL 33152

139. T. E. Browne, Energy Supply Studies Program, Electric Power Research Institute, P.O. Box 10412, Palo Alto, CA 94303

140. D. Cato, Office of Energy Information, U. S. Dept. of Energy, Federal Building, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

141. E. Cazalet, Decision Focus, Incorporated, 5 Palo Alto Square, Suite 410, Palo Alto, CA 94303

142. R. Gene Clark, Office of Energy Information, U. S. Department of Energy, Federal Building, 12th and Pennsylvania Avenue, NW Washington, DC 20461

143. S. Cohen, Energy Information Administration, U. S. Dept. of Energy, 12th and Pennsylvania Ave. NW Washington, DC 20461

144. Charles Cook, Office of Energy Information, U. S. Department of Energy, Federal Building, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

145. C. Cornett, Energy Information Administration, U. S. Department of Energy, 12th and Pennsylvania Ave., NW, Washington, DC 20461

146. C. W. Craven, Science Applications, Inc., 800 Oak Ridge Turnpike, Building C, Suite 100, Oak Ridge, TN 37830

147. Robert Crockett, Energy Information Administration, U. S. Department of Energy, 12th and Pennsylvania Ave., NW, Washington, DC 20461

148. Ned Dearborn, Energy Information Administration, U. S. Department of Energy, 12th and Pennsylvania Ave., NW, Washington, DC 20461

149. L. E. DeSimone, San Diego Gas & Electric Company, P.O. Box 1831, San Diego, CA 92112

150. R. C. Diehl, Aerojet Energy Conversion Co., P.O. Box 13222, Sacramento, CA, 95813

151. Mitchell Durst, Office of Energy Information, U. S. Department of Energy, Federal Building, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

152. Energy Systems Library, Brookhaven National Laboratory, Building 475, Upton, Long Island, NY 11973

153. R. T. Eynon, Office of Energy Information, U.S. Department of Energy, Federal Building, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

154. J. Eyster, Office of Energy Information Validation, U.S. Department of Energy, Federal Building, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

155. R. C. Fair, Department of Economics, Yale University, 206 Elm Street, New Haven, Connecticut 06520

156. J. Finucane, Office of Energy Information Validation, U.S. Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

157. A. Ford, Los Alamos Scientific Laboratory, P.O. Box 1663, Los Alamos, NM, 87545

158. D. Freedman, Professor of Statistics, University of California, Berkeley, CA 94708

159. S. I. Gass, College of Business and Management, University of Maryland, College Park, Maryland 20742

160. Donald Gantzer, U.S. Department of Energy, Federal Building, Room 4447, 12th and Pennsylvania Avenue, Washington, DC 20461

161. O. Gildersleeve, Electric Power Research Institute, 3412 Hillview Ave., Palo Alto, CA 94303

162. C. R. Glassey, University of California Berkeley, 1163 Keeler Avenue, Berkeley, CA 94708

163. Neil Goldman, Energy Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

164. L. Gordon, Office of Energy Information Validation, Federal Building, 12th and Pennsylvania Avenue, NW, 20461

165. H. J. Greenberg, U. S. Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

166. M. Greenberger, Stanford University Graduate School of Business, Room 383, Stanford, CA 94305

167. E. Greenspan, University of Illinois, Nuclear Engineering Program, 214 Nuclear Engineering Laboratory, Urbana, IL 61801

168. James Gruhl, Energy Model Analysis Program, Model Validation Group, MIT Energy Laboratory, Cambridge, Massachusetts 02138

169. N. Gruhl, 142 Plain Road, Wayland, Massachusetts 01778

170. D. E. Hale, Office of Energy Information Validation, U.S. Department of Energy, 12th and Pennsylvania, NW, Washington, DC 20461

171. John Hansen, Charles River Associates, 200 Clarendon Street, Boston, MASS 02116

172. C. Harris, Center for Management & Policy Research, 1625 "I" Street, NW Washington, DC 20006

173. J. Hausman, Economics Department, E-52, Massachusetts Institute of Technology, Cambridge, MASS 02139

174. W. W. Havens, Columbia University, 520 West 120th Street, New York, NY 10027

175. W. W. Hogan, Harvard University, 79 Boylston Street, Cambridge, MASS 02138

176. Mary Hutzler, Energy Information Administration, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

177. R. H. F. Jackson, Center for Applied Mathematics, U.S. Department of Commerce, National Bureau of Standards, Washington, DC 20234

178. C. W. Kilgore, Energy Information Administration, U.S. Department of Energy, 12th and Pennsylvania Avenue, NW Washington, DC 20461

179. D. Kresge, 53 Church Street, Cambridge, MASS 02138

180. G. M. Lady, Energy Information Administration, U.S. Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

181. Joel Lambert, National Bureau of Standards, Building 101, Washington, DC 20234

182. W. Langley, FJSRL, U.S. Air Force Academy, Colorado Springs, CO 80840

183. C. J. Lee, Department of Economics, Knox College, Galesburg, IL 61401

184. A. Linden, Jr., Energy Information Administration, U.S. Department of Energy, 2000 M Street, Washington, DC 20545

185. T. V. Long, II, University of Chicago, The Committee on Public Policy Studies, 1050 E. 59th Street, Chicago, IL 60637

186. H. McDaniel, Office of Energy Information Validation, U.S. Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

187. M. D. McKay, Los Alamos Scientific Laboratory, P.O. Box 1663, Los Alamos, NM 87545

188. D. L. McNichol, Energy Information Administration, U.S. Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

189. R. H. Males, Director, Energy Systems, Environment and Conservation Division, Electric Power Research Institute, 3412 Hillview Avenue, P.O. Box 10412, Palo Alto, CA 94303

190. R. A. Marshalla, Decision Focus, Inc., 5 Palo Alto Square, Suite 410, Palo Alto, CA 94303

191. J. S. Maybee, University of Colorado, Mathematics Department, Boulder, CO 90309

192. John Mitrisin, Energy Information Administration, U.S. Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

193. Thomas Mooney, Energy Information Administration, U.S. Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

194. G. H. Moore, Center for Energy Studies, University of Texas, Austin, TX 78712

195. T. H. Morlan, Energy Information Administration, U.S. Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

196. F. H. Murphy, Energy Information Administration, U.S. Deparment of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

197. E. L. Nelson, Energy Information Administration, U.S. Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

198. D. M. Nesbitt, Decision Focus, Inc., 5 Palo Alto Square, Suite 410, Palo Alto, CA 94304

199. David Nissen, Chase Manhattan Bank, 1 Chase Manhattan Plaza, New York, NY 10015

200. E. Oatman, Electric Power Research Institute, 3412 Hillview Avenue, P.O. Box 10412, Palo Alto, CA 94303

201. Richard P. O'Neill, Energy Information Administration, U.S. Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

202. Jerry Peabody, Energy Information Administration, U.S. Department of Energy, 12th and Pennsylvania Avenues, NW, Washington, DC 20461

203. John Pearson, Energy Information Administration, U.S. Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

204. R. Phillips, Decision Focus, Inc., 5 Palo Alto Square, Suite 410, Palo Alto, CA 94303

205. B. Poole, Energy Information Administration, U.S. Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

206. J. Rambo, Lawrence Livermore Laboratory, University of California, Livermore, CA 94550

207. Lillian Regelson, Energy Information Administration, U.S. Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

208. Richard Richels, Electric Power Research Institute, 3412 Hillview Avenue, P.O. Box 10412, Palo Alto, CA 94303

209. Fred S. Roberts, Rutgers University, Department of Mathematics, New Brunswick, NJ 08903

210. M. E. Rodekohr, Energy Information Administration, U.S. Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

211. D. J. Rose, Dept. of Nuclear Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139

212. L. Rubin, Electric Power Research Institute, 3412 Hillview Avenue, P.O. Box 10412, Palo Alto, CA 94034

213. Roy Shanker, Resource Planning Associates, 1901 "L" Street, NW, Washington, DC 20036

214. John B. Shewmaker, Energy Information Administration, U.S. Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

215. Scott Sitzer, Energy Information Administration, U.S. Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

216. C. Smith, Energy Information Validation, U.S. Department of Energy, 12th and Pennsylvania Avenues, NW, Washington, DC 20461

217. James Sweeney, Energy Modeling Forum, Stanford University, Stanford, CA 94305

218. Takashi Takayama, Energy Information Administration, U.S. Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

219. J. E. Todd, Energy Information Administration, U.S Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

220. Noel Uri, Energy Information Administration, U.S. Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

221. J. Weatherly, Institute of Gas Technology, 3424 S. State Street, Chicago, IL 60601

222. A. M. Weinberg, Institute for Energy Analysis, Oak Ridge Associated Universitities, Oak Ridge, TN 37830

223. P. Werbos, Office of Energy Information Validation, U.S. Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461

224. D. O. Wood, Energy Laboratory #-38, 418, Massachusetts Institute of Technology, Cambridge, MA 02139

225-228. L. Zutovsky, Energy Information Administration, U.S. Department of Energy, 12th and Pennsylvania Avenues, NW, Washington, DC 20461

229-255. Technical Information Center (TIC)