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Automated Sensitivity Analysis of CRESS (Commercial and Residential Energy Use and Emissions Simulation System)

L. D. Trowbridge

Fossil Energy Program

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ABSTRACT

A sensitivity analysis of CRESS (Argonne National Laboratory's Commercial and Residential Energy Use and Emissions Simulation System) has been carried out using an automated sensitivity analysis tool developed at Oak Ridge National Laboratory (ORNL). CRESS, using several linked computer models, projects U.S. commercial and residential sector contributions to the emission of five fossil energy-related atmospheric pollutants. These projections are derived from historical and projected economic and demographic parameters and derived energy use projections.

Sensitivity analyses of three of the key submodels in CRESS have been carried out with the aid of GRESS ("Gradient Enhanced Software System"), a tool which automates the direct method of sensitivity analysis. Previous reports in this series have discussed the analysis results for individual modules of the CRESS system. This report will summarize the individual analyses and examine the linkage of sensitivities through CRESS as a whole to examine the influence on emission projections of selected input projections and control parameters.

I. INTRODUCTION

CRESS, the Commercial and Residential Energy Use and Emissions Simulation System,[1] models the emissions of five atmospheric pollutants in the continental United States over the period 1980 to 2030. It was designed to provide the commercial and residential sector emission projections for a more comprehensive set of models sponsored by the National Acid Precipitation Assessment Program (NAPAP). This sensitivity study was undertaken with the support of the Department of Energy's Office of Planning and Environment and is supplementary to the Argonne National Laboratory (ANL) work on CRESS.

The fundamental task of CRESS is to translate projections of future economic, technological, and geographic parameters into projections of pollutant emissions. CRESS consists of a series of five computer programs which perform various components of this task. The five programs and their basic functions are:

PREP.FOR	Restructure input data sets
HOME2.FOR	Residential Sector Energy Use projections
CSEM2.FOR	Commercial Sector Energy Use projections
REGION.FOR	Disaggregate HOME2 and CSEM2 output by state
MODEL6.FOR	Project pollutant emissions from energy use and 1980 pollution data

The main computational work of the CRESS system is done in the HOME2, CSEM2 and MODEL6 modules. Sensitivity analyses have been conducted on these three modules separately. Earlier reports[2,3,4] detail the analysis of these three modules. This report will concern itself primarily with an overview of the behavior of the system as a whole, with relatively brief summaries only of the individual modules.

The intent of this work is to determine the responses of CRESS to its various input parameters. This should be of benefit in several ways. It will highlight which factors are of relatively more importance in determining the model's output, and which are of less importance. To the user of the model, this study should aid in the understanding of how the model is likely to respond to changes in input parameters; to the developers of the model, this may help determine whether the model functions as intended. In earlier work, the ready availability of response information aided in the detection and correction of problems in HOME2, one of the components of CRESS.[4]

I.1. CRESS Background

The CRESS system consists of 5 separate FORTRAN programs and 42 input data files containing on the order of 200,000 data elements. The system produces one permanent and 6 temporary output files. The full CRESS system can be conceptually divided into 5 separate modules, each consistting of a single program and its associated input and output files. For the purposes of using the automated sensitivity analysis system (named GRESS)[5] developed by Oak Ridge National Laboratory (ORNL), this separation was necessary.

Automated coupling of sensitivities between program modules is under development, but at present must be done manually. The process of linking sensitivities across modules was done in a mechanized, if not automated, fashion using results previously obtained via GRESS from the three primary modules of CRESS and reported in Refs. 2 through 4.

This paper will focus on the response of the CRESS system as a whole to the various projections which drive the system's emission results. Responses of the individual modules (HOME2, CSEM2 and MODEL6) will be linked to provide the overall CRESS response to these driver projections.

For example, sensitivities of energy use projections generated by CSEM2 and HOME2 to input projections of disposable income are coupled with MODEL6's sensitivities of emissions to energy use in order to compute the response of emissions to income.

CRESS and its component modules can be characterized as statistical models. That is, functional forms are postulated to characterize the various relationships among quantities of interest, and statistical fitting techniques were used with historical data to determine calibration parameters for those functional forms. The result is a system of equations that provides in some sense the best "fit" of history to the equations used, but does not necessarily represent a causal model. The historical data sets used may be interdependent, as are, for example, regional income and population. Within the framework of CRESS, however, a sensitivity analysis will only examine and reveal those responses which formally exist in an algebraic sense in the code. Regional population and income projections, being exogenous to CRESS, are independent as far as CRESS or a sensitivity analysis of CRESS is concerned.

A sensitivity coefficient S of a result Q with respect to a parameter P is normalized to the base values Qo and Po, namely:

$$S = \frac{dQ/Qo}{dP/Po} \qquad (1)$$

The sensitivity coefficient is thus dimensionless. This is a convenient form to study variables whose values change essentially by multiplication or exponentiation, as is generally the case in CRESS. The sensitivity thus should be interpreted as meaning: "A change of 1% in P will result in a change of S% in Q." The GRESS-calculated results are, however, analytic derivatives. No change in the parameter P is actually made during the calculation of the sensitivity, nor does the result Q differ from the standard model result. Consequently, multiple sensitivities can be calculated in a single run using GRESS, in contrast to indirect (i.e. perturbation) methods.

Input items chosen were those elements intended to drive the model (i.e. those that can be reasonably be expected to change from one CRESS run to be next). These parameters exist in arrays of substantial size. For example, fuel price projections used by HOME2 and CSEM2 contain 1836 components, one for each of 9 fuels in each of 4 regions for each of 51 years. In order to limit the analysis to a tractable number, a limited number of sample responses have been calculated for each module by aggregating various combinations of input parameters. Aggregation of the response of a group of input parameters will examine the response of the model output to a proportional change in that entire aggregate group. That is, the sensitivity will be that response which would occur if each selected parameter were multiplied by the same factor, although using GRESS no actual perturbation actually takes place.

A useful variation of this technique is used to examine the short-term and long-term responses of the model. To examine the short-term response of the model to a parameter, sensitivities are determined with respect to the parameter's value during a single time period. The resulting sensitivities emulate the response of the model to a "spike" or "square-wave" perturbation in the parameter. The corresponding long-term behavior can be obtained by examining the sensitivity with respect to the values of the parameter for all periods after a certain date. The calculated sensitivities in this case emulate the response to a "shock" or "step-function" perturbation to the parameter. These techniques are instructive when examining sensitivity of the model to time-projections of, for example, fuel price or population.

I.2. GRESS

GRESS ("Gradient Enhanced Software System")[5] is a tool for automating the direct method of sensitivity analysis for FORTRAN programs. It is used as a precompiler on source code to produce an enhanced source code and library which has the capability of propagating (via the chain rule of differentiation) partial derivatives with respect to any real parameter. This enhancement to the original code allows the calculation of the sensitivity of any variable with respect to any other without (in principle) detailed examination or knowledge of the intermediate processing the code may perform. Multiple sensitivities may be calculated using this tool (limited by computer memory and run time), in contrast to perturbation methods, which generally permit only a single variable to be varied per run. Calculated sensitivities from GRESS are for the particular solution point only; development of a detailed response surface would require re-run of the subject program with altered input values. A re-run with input assumptions which differ only in data files, however, does not require recompilation of the model through GRESS. The existing enhanced code can be run with altered inputs to generate altered results and altered sensitivities.

GRESS as presently formulated is compatible with most commonly-used features of FORTRAN-77. Automated propagation of sensitivities between series of programs (such as the modules of the CRESS system) is not available at this writing, but is under development. Propagation of sensitivities through CRESS was therefore done manually (albeit in a "mechanized," if not automated, fashion, via standardized output structures read into a spreadsheet).

The CRESS programs were developed and run at ANL on an IBM 3033 system. While IBM 3033's are available at ORNL, for logistic reasons (cost, turnaround time, and availability of the most recent version of GRESS), the runs at ORNL were conducted on the Scientific and Technical Computing system, which contains a VAX 8600 on which this work was done. Compatibility problems with either the IBM-VAX translation or with GRESS proved to be minor and are discussed individually for each module in Refs. 2 through 4.

The procedure for utilizing GRESS on an existing model generally requires modification of the model's source code to solve any incompatibility problems that may exist, precompiling the model through GRESS, and then conducting a limited verification of the GRESS-enhanced version. The verification step involves two procedures. The first is to confirm that the output results of the GRESS-enhanced version of the program are the same as those of the original model. The second verification procedure requires performing a limited sensitivity study on the original model using a parameter perturbation technique, and comparing the resulting response to that calculated using the GRESS-enhanced model. This process presented no extraordinary problems with any of the modules; the details of verification for each of the CRESS modules are covered in Refs. 2 through 4.

Aside from the modification and recompilation required, there is typically a CPU-time penalty associated with running a GRESS-enhanced program, i.e. the enhanced version CPU time is some multiple of the time required for the original code. In the three modules analyzed in this study, these penalties ranged from a low of x3 for MODEL6 to x12 for CSEM2 to x32 for HOME2.

Typical factors for other programs have ranged from x10 to x30. In addition to this initial verification, a number of parallel perturbation analyses were carried out during the course of this work to confirm GRESS results, particularly in the early phase of the work (on HOME2) when counter-intuitive results were obtained. In all cases, the sensitivities calculated via the perturbation runs were consistent with the GRESS results.

II. EMISSIONS MODULE (MODEL6)

This section will discuss selected sensitivities in the final CRESS module, MODEL6.FOR, which converts energy usage and other geographic projections into forecasts of pollutant emissions.

II.1. Model Description

MODEL6 consists of two parallel models, one for projecting VOC (volatile organic compound) emissions, and another for projecting emissions of four other energy-related atmospheric pollutants, SO_2, NOx, CO and TSP (total suspended particulates). Projections of emission levels are made using recent historical data on economic activity and pollution levels, and projections of future activity and changes in pollution factors. These two equations will be referred to in this paper as "Q-functions."

SOx, NOx, CO, and TSP emissions are projected with the formula:

$$Q = C * (B*(1 - A) + A*(1 - R)^t + A*E*(B - (1 - R)^t)) \qquad (2)$$

where the parameters, internal variable array names, and their definitions are:

Q = TPYSO2, TPYNOX, etc. : tons of pollutant/yr
C = TPYSO2, TPYNOX, etc. : tons of pollutant/yr in 1980
A = GROWTH : fraction of new equipment/activity subject to new emission factors
E = ERATIO : ratio of pollution factors (new:old)
R = FRACRR : annual replacement rate for old equipment/activity
B = driver variable (based on RESEGY, CMIEGY and DRIVAR)
t = years since 1980

Complementing the above equation are several logic checks which impose boundary conditions on the applicability of the equation. The variables Q and C are read from the POINT.DAT and AREA.DAT files, which contain the NAPAP data base on point and area emission sources. Each entry in these files is categorized according to its source classification and state. Each such category is associated with values for the parameters **A**, **E**, and **R**, read from other data files. The source category will likewise determine which of 18 parameters the driver variable will be based upon. These parameters are derived from internal variables in arrays named RESEGY, CMIEGY, and DRIVAR. Most are fuel usage projections, but a few are geographic in nature (forest acreage; total and rural population).

These driver parameters are the only data elements used by MODEL6 which derive from the first 4 modules of CRESS. The sensitivities of emission projections to these variables provides the connection to the commercial and residential energy use modules, CSEM2 and HOME2.

The driver variable **B** is defined as the ratio of the parameter value in time **t** to its value in 1980:

$$B = \frac{\text{Driver}(t)}{\text{Driver}(1980)} \qquad (3)$$

The above formula in essence says that pollution will change at the same rate as the selected driver variable, with appropriate corrections made for improvements in equipment and emission regulations. This assumed relationship between pollution and driver variable is not necessarily intended to be either comprehensive or causal. Pollution due to a particular type of activity will be driven by a single driver variable, even though obvious (or subtle) relationships may exist between that driver variable and other driver variables. The model authors have simply chosen what they deemed to be the most appropriate available datum on which to base projections.

A particular model result will be formally sensitive only to its own driver variable. There may be a host of relationships implicit in the value of a particular driver variable that will not be evident in this sensitivity analysis on MODEL6. For example, pollution due to residential use of natural gas is driven (quite reasonably) by projections of residential usage of natural gas. Gas usage certainly is related to population (another driver variable), but this relationship will not be evident from this sensitivity analysis. Some of these implicit relationship appear in the sensitivities derived from CSEM2 and HOME2, but others are implicit in economic and geographic projections imported into the CRESS system as a whole, and will not appear in this analysis.

VOC emissions are treated conceptually in the same manner as the other pollutants, but using a different equation:

$$Q = A * (1/B) * (D*E + C) \tag{4}$$

where the internal variable array names and meanings are:

Q = TPYVOC : tons of pollutant/yr
A = TPYVOC : tons of pollutant/yr in 1980
B = VOCBYR : 1980 emission factor
C = VOCOLD : projected emission factor for existing and replacement sources
E = VOCNEW : projected emission factor for new sources
D = driver variable (based on DRIVAR, RESEGY, and CMIEGY)

Some differences in definition in this equation should be noted. The driver variable is, as before, based on an appropriate fuel use or other parameter, but is defined as:

$$D = \frac{\text{Driver}(t) - \text{Driver}(1980)}{\text{Driver}(1980)} \qquad (5)$$

Secondly, the parameter **C** encompasses the estimates of replacements (and possible improvement) of 1980 equipment which were at least partially calculated using **R**, **t**, **E** and **A** in the SOx equation.

The parameters used in the above two equations are read from a number of input files. The names of the files and the associated variable names from which they are derived are listed in Table II.1.

Table II.1: Input File List for MODEL6.FOR

File Name	Variable	Description
VOC1980.DAT	VOCBYR	VOC Emission factors by
VOC1985.DAT	VOCOLD	source for old
VOC1990.DAT	"	equipment/activities
VOC1995.DAT	"	
VOC2000.DAT	"	
VOC2010.DAT	"	
VOC2020.DAT	"	
VOC2030.DAT	"	
AREA.DAT	TPYxxx	NAPAP 1980 emission
POINT.DAT	"	source data base
VOCDATA1.NTM	RESEGY;CMIEGY	Driver
VOCDATA2.NTM	DRIVAR	variables
SOXFRR.DAT	FRACRR	SOx,NOx,CO,TSP
SOXNCP.DAT	GROWTH	parameters
SNCPFACT.DAT	ERATIO	
VCN1985.DAT	VOCNEW	VOC Emission factors by
VCN1990.DAT	"	source for new
VCN1995.DAT	"	equipment/activities
VCN2000.DAT	"	
VCN2010.DAT	"	
VCN2020.DAT	"	
VCN2030.DAT	"	

The basic function which MODEL6 performs is to read each of the 33,000 non-zero source terms in the NAPAP data base, project pollution via the appropriate Q-function for that source in each model period, and add the result to appropriate subtotals (which categorize pollution by sector, aggregated source categories, pollutant, state, region, and national total). This output is written to a single file, RESULT.TAB.

II.2. Emissions Module Sensitivity Results

Two approaches were taken in Ref. 3 to the sensitivity analyses of MODEL6. The first approach examined analytical sensitivities of the Q-functions to their dependent variables. The second approach used GRESS to compute sensitivities for three classes of input parameters at various levels of aggregation. The first class of input parameters consisted of those specific to MODEL6 itself, such as predicted emission factors and equipment attrition rates. As these parameters are not used in CRESS prior to the MODEL6 program module, linkage with sensitivities from other CRESS modules is not pertinent to this class.

The second and third classes study aspects of the sensitivity of emission projections to the economic or geographic driver variables and source groupings. The driver variables provide the linkage to CSEM2 and HOME2, and they will be the focus of this report. Sensitivities to the pollutant sources disaggregated by source grouping closely resemble the driver variable sensitivities, and will not be discussed here. The reader is referred to Ref. 3 for details of the MODEL6-specific sensitivity analyses.

II.2.A. Non-Driver Parameters.

The SOx model (used for all pollutants except VOC) contains several parameters of potential interest. The three that have been examined in detail in Ref. 3 are FRACRR, ERATIO, and

GROWTH [the **R**, **E**, and **A** in the SOx Q-function, Eq. (1)]. The cumulative sensitivities of total national emissions (for each of the four pollutants in each period) with respect to all elements of these parameter arrays have been computed using the parameter aggregation technique. The results are listed in Table II.2.

The computed sensitivities of emissions to all these parameters proved to be rather small in most cases. For example, sensitivities to the variable ERATIO (ratio of emission factors of activity/equipment: new to old) were small (<0.03) except in the case of NOx emissions, where it is as high as 0.29 in 2030. An examination of the file SNCPFACT, which contains the source data for the ERATIO array, reveals that only a small fraction of the source categories is projected to have reduced emission factors in the future. These represent pollution attributed to subsets of natural gas usage and of commercial coal and oil usage. These fuel categories are the most important drivers of NOx projections, but are of lesser importance in driving other pollution projections.

The method of calculating normalized sensitivities combined with the data element values in the current data set for MODEL6 conceals the potential importance of these parameters. The method used in the input data sets to "switch off" use of a new emission factor, namely setting **A** to zero, renders the results insensitive to **E** and **R** for most of the entries. For only a very few source categories are actual reductions in emission factors indicated by the data. Thus the sensitivity

$$\frac{\partial Q}{\partial E} = \sum_{\text{Sources}} CA(B - F) \qquad (6)$$

Table II.2. Sensitivity of Emissions to Non-Driver Parameters.

Sensitivities of National Pollution Totals with respect to aggregation parameters for all FRACRR (fractional replacement rate), ERATIO ("new" to "old" pollution factor ratio), and GROWTH (fraction of new activity subject to new regulations).

ERATIO* results are the result of modifying entries for which "A=0, E=1" to "A=1, E=1" in order to highlight sensitivity to pollution ratio E, even when it didn't change from 1980 rate.

Parameter: (Q Fn:)	FRACRR (R)	ERATIO (E)	ERATIO* (E*)	GROWTH (A)
SOx Emissions				
1980	--	--	--	--
1985	-1.14E-03	5.79E-03	1.06E-01	-3.99E-03
1990	-3.23E-03	1.02E-02	2.34E-01	-5.79E-03
1995	-4.07E-03	1.54E-02	3.35E-01	-7.97E-03
2000	-4.89E-03	1.81E-02	3.86E-01	-9.17E-03
2010	-6.54E-03	2.06E-02	4.38E-01	-1.04E-02
2020	-8.19E-03	2.13E-02	4.66E-01	-1.08E-02
2030	-9.29E-03	2.24E-02	5.02E-01	-1.14E-02
NOx Emissions				
1980	--	--	--	--
1985	-4.85E-03	4.90E-02	8.54E-02	-8.24E-03
1990	-8.63E-03	1.00E-01	1.87E-01	-1.69E-02
1995	-1.12E-02	1.36E-01	2.62E-01	-2.28E-02
2000	-1.34E-02	1.63E-01	3.09E-01	-2.73E-02
2010	-1.66E-02	2.05E-01	3.69E-01	-3.45E-02
2020	-1.84E-02	2.46E-01	4.18E-01	-4.20E-02
2030	-1.87E-02	2.88E-01	4.67E-01	-4.95E-02

Parameter: (Q Fn:)	FRACRR (R)	ERATIO (E)	ERATIO* (E*)	GROWTH (A)
CO Emissions				
1980	--	--	--	--
1985	-8.42E-05	1.08E-03	4.85E-02	-1.42E-04
1990	-1.57E-04	2.21E-03	8.33E-02	-3.07E-04
1995	-2.10E-04	3.15E-03	1.11E-01	-4.23E-04
2000	-2.48E-04	3.73E-03	1.36E-01	-5.03E-04
2010	-2.92E-04	4.36E-03	1.85E-01	-6.06E-04
2020	-3.08E-04	4.86E-03	2.18E-01	-7.10E-04
2030	-3.08E-04	5.45E-03	2.40E-01	-8.25E-04
TSP Emissions				
1980	--	--	--	--
1985	-3.38E-04	1.10E-03	4.75E-02	-1.19E-03
1990	-1.31E-03	2.26E-03	8.49E-02	-1.69E-03
1995	-1.75E-03	3.48E-03	1.16E-01	-2.51E-03
2000	-2.09E-03	4.15E-03	1.42E-01	-2.88E-03
2010	-2.53E-03	4.72E-03	1.89E-01	-2.99E-03
2020	-2.77E-03	5.09E-03	2.21E-01	-2.89E-03
2030	-2.82E-03	5.64E-03	2.43E-01	-2.94E-03

will be very small, as most terms in the summation have the value of **A** set to zero. A modification was made to MODEL6 to investigate the effect of this pattern of data. For those source categories which would ordinarily use a value of **A=0** in combination with **E=1**, the value of **A** was altered to be equal to one. Inspection of the Eq. (2) shows that either combination should yield the same result; the calculated sensitivities, however, are significantly different. The original and altered sensitivity results for total emissions with respect to ERATIO are listed in Table II.2. For SOx, CO, and TSP emissions, the sensitivities all have increased by an order of magnitude; the NOx sensitivity also increased, but was fairly large already. All the ERATIO sensitivities grow with time to be in the realm of 0.1 to 0.5. This indicates that, contrary to the initial sensitivity calculations, the emission factor ratio will be fairly important if more complete emission factor data becomes available.

The VOC model is structured somewhat differently, and thus its controlling parameters have a different meaning from those in the SOx model. The formulation of the Q-function for VOC emissions makes it difficult to examine the corresponding VOC model sensitivity of emissions to changes in pollution factors, since equipment containing both changed and unchanged emission factors is combined outside of CRESS into the array VOCOLD. An examination of several of the VOCxxxx and VCNxxxx files suggests that most of the pollution factors contained in the present data are not projected to change. The reader is referred to Ref. 3 for a discussion of sensitivities of these parameters.

II.2.B. Sensitivities to Driver Variables. Each category of pollution sources projects future changes in emission levels through use of a driver variable. It is explicitly assumed that the activity which results in emission from that source will change in a manner directly proportional to the selected driver variable. Actual emission levels depend on both the activity and the other factors enumerated above. The driver variables are derived from parameters CMIEGY (an array of commercial fuel usage projections dimensioned with 49 states, 8 periods, and 7 fuels), RESEGY (an array similar to CMIEGY, but for residential sources), and DRIVAR (an array of geographic projections for 49 states, 8 periods, and 4 indices). The four indices of DRIVAR are total population, rural population, forest acreage, and gasoline sales. The precise categories the various driver variables represent are listed in Table II.3 as column headings. These driver variable values comprise the only information passed to MODEL6 from the previous modules of CRESS.

The sensitivity for a particular driver parameter is, due to the linear nature of its use in the Q-functions, proportional to the contribution made to total emission by sources driven by that parameter. Sensitivities calculated here are to the elements of the arrays RESEGY, CMIEGY and DRIVAR rather than to the derived driver variables **B** in Eq. (2) and **D** in Eq. (3). For the SOx Q-function, the normalized sensitivity of total emissions to the driver **Dn** for a particular source **n** is:

$$\frac{\partial Q}{\partial D_n}\ \frac{D_n}{Q} = \frac{\sum\limits_{\text{Source(n)}} C\frac{D_n}{D_n('80)}\left[1-A(1-E)\right]}{\sum\limits_{\text{Sources}} C\frac{D}{D('80)}\left[1-A(1-E)\right] + F_o A(1-E)} \qquad (7)$$

For nearly all sources, the term **A(1-E)** in the current data set is zero, so the normalized sensitivity is approximately equal to the fractional share of the pollution driven by source **n**, namely:

Table II.3. Sensitivities of Emissions to Driver Variables: sensitivities which are identically equal to zero are shown as dashes.

VARIABLE:	DRIVAR				RESEGY							CMIEGY						
index:	(1) Gasoline Sales	(2) Total Pop.	(3) Rural Pop.	(4) Forest Area	(1) Coal	(2) Resid. Oil	(3) Distil. Oil	(4) Nat. Gas	(5) LPG	(6) Wood	(7) Electr.	(1) Coal	(2) Resid. Oil	(3) Distil. Oil	(4) Nat. Gas	(5) LPG	(6) Wood	(7) Electr.
SOx Emissions																		
1980	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1985	--	0.0280	0.0102	0.0088	0.0447	--	0.1350	1.1E-03	--	9.1E-04	--	0.1960	0.4320	0.1180	1.8E-03	8.1E-05	--	--
1990	--	0.0267	0.0096	0.0079	0.0354	--	0.1230	1.0E-03	--	8.3E-04	--	0.1670	0.4700	0.1290	1.7E-03	7.4E-05	--	--
1995	--	0.0264	0.0093	0.0074	0.0292	--	0.1030	9.1E-04	--	7.8E-04	--	0.1490	0.5110	0.1380	1.6E-03	7.0E-05	--	--
2000	--	0.0277	0.0096	0.0075	0.0259	--	0.0866	8.6E-04	--	8.2E-04	--	0.1420	0.5330	0.1420	1.5E-03	7.2E-05	--	--
2010	--	0.0329	0.0111	0.0082	0.0223	--	0.0647	8.5E-04	--	1.0E-03	--	0.1410	0.5510	0.1450	1.5E-03	8.1E-05	--	--
2020	--	0.0401	0.0135	0.0096	0.0206	--	0.0532	9.0E-04	--	1.3E-03	--	0.1490	0.5480	0.1430	1.4E-03	9.7E-05	--	--
2030	--	0.0470	0.0159	0.0109	0.0186	--	0.0469	9.8E-04	--	1.5E-03	--	0.1540	0.5430	0.1420	1.4E-03	1.1E-04	--	--
NOx Emissions																		
1980	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1985	--	0.0392	0.0635	0.2180	0.0029	--	0.0740	0.2100	--	0.0082	--	0.0494	0.1090	0.0589	0.1170	6.7E-05	--	--
1990	--	0.0391	0.0635	0.2090	0.0024	--	0.0716	0.1960	--	0.0081	--	0.0451	0.1280	0.0687	0.1160	6.3E-05	--	--
1995	--	0.0399	0.0651	0.2080	0.0021	--	0.0635	0.1850	--	0.0081	--	0.0424	0.1450	0.0772	0.1160	6.1E-05	--	--
2000	--	0.0418	0.0683	0.2120	0.0019	--	0.0542	0.1780	--	0.0086	--	0.0412	0.1530	0.0807	0.1150	6.1E-05	--	--
2010	--	0.0471	0.0776	0.2300	0.0016	--	0.0397	0.1710	--	0.0105	--	0.0404	0.1530	0.0799	0.1110	6.4E-05	--	--
2020	--	0.0537	0.0883	0.2500	0.0014	--	0.0306	0.1700	--	0.0122	--	0.0399	0.1410	0.0734	0.1010	6.8E-05	--	--
2030	--	0.0588	0.0968	0.2660	0.0012	--	0.0255	0.1730	--	0.0130	--	0.0387	0.1310	0.0680	0.0922	7.1E-05	--	--
CO Emissions																		
1980	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1985	--	0.1160	0.0918	0.6100	0.0078	--	1.8E-03	0.0036	--	0.1270	--	0.0014	0.0012	0.0013	0.0027	1.6E-05	--	--
1990	--	0.1200	0.0943	0.6030	0.0068	--	1.8E-03	0.0035	--	0.1290	--	0.0013	0.0015	0.0016	0.0028	1.5E-05	--	--
1995	--	0.1240	0.0967	0.5980	0.0059	--	1.6E-03	0.0033	--	0.1290	--	0.0012	0.0017	0.0018	0.0029	1.5E-05	--	--
2000	--	0.1260	0.0983	0.5930	0.0052	--	1.3E-03	0.0031	--	0.1320	--	0.0011	0.0017	0.0018	0.0028	1.5E-05	--	--
2010	--	0.1300	0.1010	0.5780	0.0039	--	8.5E-04	0.0027	--	0.1450	--	0.0010	0.0015	0.0016	0.0025	1.5E-05	--	--
2020	--	0.1330	0.1030	0.5670	0.0031	--	5.9E-04	0.0024	--	0.1530	--	0.0009	0.0013	0.0013	0.0021	1.5E-05	--	--
2030	--	0.1360	0.1060	0.5640	0.0024	--	4.6E-04	0.0023	--	0.1520	--	0.0008	0.0011	0.0011	0.0018	1.6E-05	--	--

Table II.3. (cont'd)

VARIABLE:	DRIVAR				RESEGY							CMIEGY						
Index:	(1) Gasoline Sales	(2) Total Pop.	(3) Rural Pop.	(4) Forest Area	(1) Coal	(2) Resid. Oil	(3) Distil. Oil	(4) Nat. Gas	(5) LPG	(6) Wood	(7) Electr.	(1) Coal	(2) Resid. Oil	(3) Distil. Oil	(4) Nat. Gas	(5) LPG	(6) Wood	(7) Electr.
TSP Emissions																		
1980	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1985	--	0.1210	0.1320	0.5250	0.0066	--	0.0054	0.0033	--	0.1090	--	0.0205	0.0266	0.0061	0.0062	1.6E-05	--	--
1990	--	0.1240	0.1350	0.5170	0.0057	--	0.0054	0.0031	--	0.1100	--	0.0191	0.0276	0.0072	0.0063	1.6E-05	--	--
1995	--	0.1270	0.1380	0.5110	0.0049	--	0.0048	0.0029	--	0.1100	--	0.0178	0.0307	0.0079	0.0063	1.6E-05	--	--
2000	--	0.1300	0.1410	0.5070	0.0043	--	0.0039	0.0028	--	0.1130	--	0.0167	0.0309	0.0079	0.0060	1.6E-05	--	--
2010	--	0.1340	0.1450	0.4980	0.0033	--	0.0026	0.0024	--	0.1250	--	0.0148	0.0276	0.0070	0.0051	1.5E-05	--	--
2020	--	0.1380	0.1500	0.4920	0.0026	--	0.0018	0.0022	--	0.1320	--	0.0132	0.0231	0.0058	0.0042	1.6E-05	--	--
2030	--	0.1420	0.1540	0.4910	0.0021	--	0.0014	0.0021	--	0.1320	--	0.0120	0.0200	0.0050	0.0035	1.6E-05	--	--
VOC Emissions																		
1980	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1985	0.0678	0.6430	0.1450	0.1210	1.0E-03	--	2.8E-04	1.3E-03	--	1.4E-03	--	1.7E-04	2.4E-04	2.6E-04	1.1E-03	5.8E-06	--	--
1990	0.0536	0.6610	0.1490	0.1200	8.8E-04	--	2.8E-04	1.3E-03	--	1.4E-03	--	1.6E-04	2.9E-04	3.1E-04	1.1E-03	5.5E-06	--	--
1995	0.0508	0.6680	0.1500	0.1170	7.6E-04	--	2.5E-04	1.2E-03	--	1.4E-03	--	1.4E-04	3.2E-04	3.4E-04	1.1E-03	5.3E-06	--	--
2000	0.0514	0.6720	0.1500	0.1140	6.5E-04	--	2.0E-04	1.1E-03	--	1.4E-03	--	1.3E-04	3.3E-04	3.4E-04	1.1E-03	5.2E-06	--	--
2010	0.0524	0.6760	0.1510	0.1100	4.9E-04	--	1.3E-04	9.2E-04	--	1.5E-03	--	1.2E-04	2.9E-04	3.0E-04	9.6E-04	5.0E-06	--	--
2020	0.0507	0.6810	0.1520	0.1060	3.7E-04	--	9.0E-05	8.1E-04	--	1.5E-03	--	1.0E-04	2.3E-04	2.5E-04	7.8E-04	4.9E-06	--	--
2030	0.0516	0.6830	0.1520	0.1030	2.9E-04	--	6.9E-05	7.6E-04	--	1.5E-03	--	9.0E-05	2.0E-04	2.1E-04	6.6E-04	4.9E-06	--	--

$$\frac{\partial Q}{\partial D_n} \frac{D_n}{Q} \approx \frac{\sum_{Source(n)} CD_n/D_n('80)}{\sum_{Sources} CD/D('80)} \quad . \tag{8}$$

The VOC module uses driver parameters differently from the SOx module, as has been described previously, but the intent and effect is similar. The aggregation parameter technique was used on the driver variables to examine combined sensitivities to emissions at the national level. Thus 18 sensitivities were calculated (7 for each of the RESEGY and CMIEGY fuel types and 4 for the DRIVAR variables) for each of the 5 pollutants in each of the 7 post-1980 model periods.

The sensitivity of the national emission totals to the driver variables are listed in Table II.3. In Table II.3, sensitivities which were found to be equal to zero are portrayed with dashes (--). Categories displaying zero sensitivity arose for a number of reasons. Some categories of fuel use simply never were referred to by any of the pollution categories; other categories of fuel showed no use of that fuel. Most of the non-zero driver parameters had at least a moderate influence on one or more pollutants (i.e. above a few percent) with the exception of commercial LPG use. Its maximum sensitivity to any pollutant total was of the order of 10^{-4}.

A general observation that can be made is that the emission projections do not change very much over time. This seems to be inherent in the data (both the driver projections and in the relatively unchanging nature of other parameters, such as pollution factors).

SOx emission projections are driven largely by commercial oil and coal usage. Residential oil usage also contributes moderately to SOx projections; other variables make only relatively small contributions. NOx emissions are driven by a more diverse mixture of parameters, with approximately equal contributions from commercial energy use, residential energy use, and geographic parameters.

CO and TSP emissions exhibit similar patterns of sensitivity, being driven primarily by geographic variables (mainly forest acreage), with a moderate contribution from residential wood usage, and only small contributions from other sources. VOC emissions are driven almost exclusively by geographic projections, the most important of which is total population. It is the only pollutant to utilize the gasoline sales projections as a driver, and this contributes only minimally to total emissions (ca. 5%).

In summary, the driver variables in MODEL6 are the only information imported to MODEL6 from the earlier modules of CRESS. Sensitivities of emissions to driver variables approximate the shares of emission driven by a particular driver parameter. These sensitivities will be used in propagating sensitivity of parameters in HOME2 and CSEM2 through to emission projections made by MODEL6.

III. HOME2 - RESIDENTIAL SECTOR ENERGY USE MODULE

This section will discuss sensitivities in the residential sector energy use module, HOME2, on a stand-alone basis.

III.1. Model Description

HOME2, a model of the energy use within the U.S. residential sector, was adapted from HOME, a model developed and used by the Energy Information Administration (Ref. 7). HOME was designed to provide intermediate-term (ca 10-year) projections for residential sector energy use and related data for such publications as the Annual Energy Outlook.[9] The ANL adaptation of HOME extends the time horizon to 2030, and makes some minor structural changes to accommodate the needs of CRESS.

HOME is driven by historically determined statistical relationships among a number of input parameters and data sets. The input data include projections of disposable income, housing additions, and fuel prices. Historical data was used to statistically derive values for parameters relating the input projections to internally generated projections of residential housing stock, fuel conversions, and fuel consumption. The details of the HOME design can be found in Ref. 7.

A comprehensive sensitivity analysis of HOME2 is reported in Ref. 4. The sensitivity analyses reported there focused on both the exogenous projections which are intended to drive the model, namely the fuel prices, disposable income, and housing starts, and on the various forecasting coefficients which control and calibrate the model. This summary will discuss parameters in the former category, as these represent the exogenous projections intended to drive CRESS as a whole. These parameters are listed in Table III.1.

Table III.1. HOME2 Parameters: Parameters discussed in this summary at varying levels of aggregation. ("Variable" indicates the array name in the HOME2 code; "Description" also includes the implicit or explicit dimensions of the variable.)

File Name	Variable	Description
COEFS.HDD	QHDD	Heating Degree Days (4 Regions)
	CGWTH	Coal Use Decline Time Constant
HOUSE.DAT	HDRT	Housing decay rates (4 Regions x 4 Vintages x 2 Classes x 5 decades)
RESEXOG.NTM	PRC	Fuel Price (4 Regions x 6 Fuels x 51 years)
	HINC	Regional Disposable Income (5 Regions x 51 years)
	HCON	Housing Starts (5 Regions x 2 Classes x 51 years)

The sensitivity analysis of the original (June 1986) version of HOME2 uncovered a number of anomalous response patterns which in turn led to discovery of some errors in the program. HOME2 was revised by ANL to produce the current (May 1987) version of HOME2, on which the discussion in this report centers.

The anomalous behavior of the earlier versions of HOME derived from two programming errors. One resulted in an overestimate of housing construction. The other resulted in the inadvertent magnification of the intended response of space heating energy use to household income and to climate (i.e. average heating-degree-days). The current version of HOME2 has rectified the construction and income problem. The heating-degree-day error remains, but is more an aesthetic problem than a real one. Future heating-degree-day projections are not subject to user alteration (short of some minor reprogramming), and consequently no perturbation of the current values can take place while using CRESS. The only adverse effect of this problem is a potential (but constant) error in the residential energy use results due to the projections for heating-degree-days not being the true long-term averages. For a more detailed discussion of this matter, the reader is referred to Ref. 4.

III.2. <u>HOME2 Sensitivity Results</u>

The class of parameters which are examined in this section are the exogenous projections designed to drive energy use, and which are likely candidates for alteration in running different scenarios. These projections include housing construction parameters, disposable income, fuel prices, and climate. Most projections contain values for each of four U.S. regions (Northeast, North Central, South, and West) in each year from 1980 to 2030.

For purposes of this study, these parameters will be aggregated over all regions to give average national responses.

The "results" of HOME2 for purposes of this study are taken to be those energy use values which are read into the CRESS emission module, MODEL6, and used as driver variables for its emission calculations. MODEL6 uses and calculates emissions for 5-year intervals from 1980 (the base year) through 2000, then 10-year intervals through 2030.

The normalized sensitivities computed from the baseline scenario for both HOME2 and CSEM2 are listed in Tables III.2 through III.8. Each category of energy use is shown as a column heading; the table titles describes the particular parameter. Entries for which the calculated sensitivity was identically zero are left blank; entire categories which

Table III.2. Sensitivity of Energy Use to Electricity Price. (Upper section shows effect of a short-term price excursion in the year 1990 only; lower section shows effect of a permanent change in price beginning in 1990. Sensitivities which are identically equal to zero are left blank. Residential energy use module results are shown on the left; commercial results on the right.)

ELECTRICITY PRICE - 1990 Only

	Electr.	Gas	Oil	LPG	Wood	Electr.	Gas	Resid. Oil	Distil. Oil
	HOME2					CSEM2			
1980									
1985									
1990	-0.0685	0.0025	0.0018	7.3E-11		-0.0359	0.0031	0.0022	0.0024
1995	-0.0230	0.0023	0.0016	1.0E-10	0.0389	-0.0300	0.0028	0.0019	0.0021
2000	-0.0082	0.0022	0.0016	-7.5E-11	0.0255	-0.0250	0.0026	0.0017	0.0019
2010	-0.0017	0.0022	0.0017	-2.1E-10	0.0271	-0.0174	0.0023	0.0014	0.0015
2020	-0.0010	0.0021	0.0019	-2.0E-10	0.0010	-0.0121	0.0020	0.0012	0.0013
2030	-0.0008	0.0020	0.0020	-2.1E-10	-5.0E-06	-0.0084	0.0018	0.0011	0.0012

ELECTRICITY PRICE - 1990...2030

	Electr.	Gas	Oil	LPG	Wood	Electr.	Gas	Resid. Oil	Distil. Oil
	HOME2					CSEM2			
1980									
1985									
1990	-0.0685	0.0025	0.0018	7.3E-11		-0.0359	0.0031	0.0022	0.0024
1995	-0.2530	0.0136	0.0099	-4.3E-11	0.2968	-0.1975	0.0209	0.0138	0.0151
2000	-0.3136	0.0232	0.0171	1.3E-09	0.3362	-0.3310	0.0362	0.0228	0.0249
2010	-0.3435	0.0418	0.0331	7.8E-10	0.4453	-0.5324	0.0655	0.0382	0.0418
2020	-0.3509	0.0597	0.0524	-2.0E-09	0.0333	-0.6687	0.0865	0.0475	0.0520
2030	-0.3533	0.0753	0.0722	-1.0E-09	0.0075	-0.7599	0.1034	0.0539	0.0591

Table III.3. Sensitivity of Energy Use to Natural Gas Price.

NATURAL GAS PRICE - 1990 Only

	HOME2					CSEM2			
	Electr.	Gas	Oil	LPG	Wood	Electr.	Gas	Resid. Oil	Distil. Oil
1980									
1985									
1990	1.1E-03	-0.0998	0.0383	-1.8E-11		5.9E-04	-0.0563	0.0031	0.0034
1995	8.2E-04	-0.0357	0.0377	6.7E-11	0.0334	5.1E-04	-0.0473	0.0027	0.0029
2000	7.2E-04	-0.0152	0.0369	1.0E-10	0.0253	4.4E-04	-0.0397	0.0024	0.0026
2010	6.3E-04	-0.0060	0.0347	7.9E-11	0.0273	3.4E-04	-0.0281	0.0019	0.0021
2020	5.8E-04	-0.0039	0.0223	1.6E-11	0.0010	2.8E-04	-0.0201	0.0017	0.0019
2030	5.2E-04	-0.0032	0.0203	5.8E-11	6.2E-06	2.4E-04	-0.0146	0.0015	0.0017

NATURAL GAS PRICE - 1990...2030

	HOME2					CSEM2			
	Electr.	Gas	Oil	LPG	Wood	Electr.	Gas	Resid. Oil	Distil. Oil
1980									
1985									
1990	1.1E-03	-0.0998	0.0383	-1.8E-11		0.0006	-0.0563	0.0031	0.0034
1995	5.3E-03	-0.3644	0.2325	7.5E-11	0.2230	0.0038	-0.3141	0.0185	0.0203
2000	8.4E-03	-0.4483	0.4410	-9.0E-11	0.2803	0.0062	-0.5270	0.0296	0.0324
2010	1.4E-02	-0.4767	0.8842	-6.0E-10	0.4017	0.0099	-0.8524	0.0456	0.0500
2020	1.8E-02	-0.4704	0.9803	4.5E-10	0.0279	0.0121	-1.0707	0.0540	0.0591
2030	2.2E-02	-0.4864	1.3770	2.1E-09	0.0053	0.0136	-1.2207	0.0594	0.0650

Table III.4. Sensitivity of Energy Use to Oil Price.

OIL PRICE - 1990 Only

	HOME2 Electr.	HOME2 Gas	HOME2 Oil	HOME2 LPG	HOME2 Wood	CSEM2 Electr.	CSEM2 Gas	CSEM2 Resid. Oil	CSEM2 Distil. Oil
1980									
1985									
1990	2.2E-04	0.0065	-0.1775	3.6E-12		1.9E-04	0.0018	-0.0495	-0.0542
1995	1.2E-04	0.0057	-0.0830	-1.1E-10	0.0193	1.7E-04	0.0017	-0.0337	-0.0369
2000	9.7E-05	0.0049	-0.0516	-1.0E-10	0.0214	1.5E-04	0.0015	-0.0230	-0.0252
2010	9.3E-05	0.0035	-0.0367	-7.9E-11	0.0246	1.1E-04	0.0013	-0.0112	-0.0122
2020	9.8E-05	0.0020	-0.0231	-6.0E-11	8.8E-04	9.3E-05	0.0011	-0.0061	-0.0067
2030	1.0E-04	0.0015	-0.0211	-3.7E-11	5.2E-07	7.9E-05	0.0010	-0.0039	-0.0043

OIL PRICE - 1990...2030

	HOME2 Electr.	HOME2 Gas	HOME2 Oil	HOME2 LPG	HOME2 Wood	CSEM2 Electr.	CSEM2 Gas	CSEM2 Resid. Oil	CSEM2 Distil. Oil
1980									
1985									
1990	2.2E-04	0.0065	-0.1775	3.6E-12		1.9E-04	0.0018	-0.0495	-0.0542
1995	8.7E-04	0.0351	-0.7400	-6.1E-11	0.0926	1.2E-03	0.0121	-0.2498	-0.2736
2000	1.2E-03	0.0592	-1.0490	-1.9E-11	0.1749	2.0E-03	0.0201	-0.3793	-0.4155
2010	1.5E-03	0.0927	-1.4820	-4.4E-10	0.3089	3.2E-03	0.0330	-0.5128	-0.5617
2020	1.8E-03	0.0967	-1.5200	-3.1E-10	0.0136	3.9E-03	0.0407	-0.5565	-0.6096
2030	1.9E-03	0.1144	-1.8770	-5.8E-10	1.3E-04	4.3E-03	0.0460	-0.5689	-0.6232

Table III.5. Sensitivity of Energy Use to LPG and Kerosene Price.

	LPG PRICE - '90 Only		KEROSENE PRICE 1990 Only				
	LPG	Wood	Wood	Electr.	Gas	Resid. Oil	Distil. Oil
	------HOME2--------		HOME2	-----------CSEM2----------------			
1980							
1985							
1990	-0.0345			2.7E-05	2.0E-04	-4.5E-03	-5.0E-03
1995	0.8417	-2.1E-03	7.0E-04	2.3E-05	1.8E-04	-3.2E-03	-3.5E-03
2000	1.0680	-2.8E-03	6.5E-04	2.0E-05	1.7E-04	-2.3E-03	-2.5E-03
2010	0.9945	6.4E-04	7.3E-04	1.5E-05	1.4E-04	-1.2E-03	-1.3E-03
2020	0.8263	-1.0E-04	2.6E-05	1.2E-05	1.2E-04	-7.2E-04	-7.9E-04
2030	0.6942	-3.8E-05	2.2E-08	9.9E-06	1.1E-04	-4.9E-04	-5.4E-04

	LPG PRICE - '90...'30		KEROSENE PRICE 1990...2030				
	LPG	Wood	Wood	Electr.	Gas	Resid. Oil	Distil. Oil
	------HOME2--------		HOME2	-----------CSEM2----------------			
1980							
1985							
1990	-0.0345			2.7E-05	2.0E-04	-0.0045	-0.0050
1995	-0.1266	0.0179	3.9E-03	1.5E-04	1.1E-03	-0.0234	-0.0256
2000	-0.1639	0.0186	6.0E-03	2.3E-04	1.8E-03	-0.0362	-0.0396
2010	-0.1961	0.0209	9.8E-03	3.5E-04	2.9E-03	-0.0505	-0.0554
2020	-0.2108	0.0015	4.8E-04	3.9E-04	3.4E-03	-0.0550	-0.0602
2030	-0.2201	0.0003	2.1E-05	4.0E-04	3.6E-03	-0.0554	-0.0607

Table III.6. Sensitivity of Energy Use to General Fuel Prices.

GENERAL ENERGY PRICE - 1990 Only

	HOME2 Electr.	HOME2 Gas	HOME2 Oil	HOME2 LPG	HOME2 Wood	CSEM2 Electr.	CSEM2 Gas	CSEM2 Resid. Oil	CSEM2 Distil. Oil
1980									
1985									
1990	-0.0672	-0.0907	-0.1373	-0.0345		-0.0352	-0.0513	-0.0442	-0.0484
1995	-0.0221	-0.0277	-0.0437	0.8417	0.0902	-0.0293	-0.0428	-0.0291	-0.0319
2000	-0.0074	-0.0081	-0.0131	1.0680	0.0701	-0.0244	-0.0356	-0.0189	-0.0207
2010	-1.0E-03	-3.6E-04	-0.0003	0.9945	0.0803	-0.0169	-0.0246	-0.0078	-0.0086
2020	-3.2E-04	2.8E-04	0.0011	0.8263	0.0028	-0.0117	-0.0170	-0.0032	-0.0035
2030	-2.2E-04	2.8E-04	0.0013	0.6942	-3.6E-05	-0.0081	-0.0117	-0.0013	-0.0015

GENERAL ENERGY PRICE - 1990...2030

	HOME2 Electr.	HOME2 Gas	HOME2 Oil	HOME2 LPG	HOME2 Wood	CSEM2 Electr.	CSEM2 Gas	CSEM2 Resid. Oil	CSEM2 Distil. Oil
1980									
1985									
1990	-0.0672	-0.0907	-0.1373	-0.0345		-0.0352	-0.0513	-0.0442	-0.0484
1995	-0.2469	-0.3156	-0.4975	-0.1266	0.6342	-0.1925	-0.2810	-0.2175	-0.2382
2000	-0.3040	-0.3659	-0.5905	-0.1639	0.8161	-0.3229	-0.4707	-0.3269	-0.3582
2010	-0.3282	-0.3422	-0.5649	-0.1961	1.1870	-0.5193	-0.7539	-0.4290	-0.4699
2020	-0.3310	-0.3140	-0.4876	-0.2108	0.0767	-0.6527	-0.9435	-0.4551	-0.4985
2030	-0.3296	-0.2966	-0.4271	-0.2201	0.0133	-0.7419	-1.0713	-0.4556	-0.4991

Table III.7. Sensitivity of Energy Use to Housing Starts, Housing Attrition, and Population Projections.

HOUSING STARTS - All Years

	Electr.	Gas	Oil	LPG	Wood
	HOME2				
1980					
1985	0.0918	0.0362	0.0172	0.0581	0.0036
1990	0.2036	0.0930	0.0475	0.1404	0.0138
1995	0.2958	0.1490	0.0832	0.2153	0.0213
2000	0.3684	0.2008	0.1237	0.2811	0.0259
2010	0.4955	0.3058	0.2325	0.4110	0.0365
2020	0.6022	0.4053	0.3904	0.5367	0.0021
2030	0.6764	0.4883	0.5648	0.6362	0.0002

HOUSING STARTS - 1990 only

	Electr.	Gas	Oil	LPG	Wood
	HOME2				
1980					
1985					
1990					
1995	0.0226	0.0116	0.0066	0.0165	0.0013
2000	0.0206	0.0113	0.0070	0.0161	0.0015
2010	0.0177	0.0112	0.0083	0.0154	0.0019
2020	0.0154	0.0109	0.0099	0.0147	0.0001
2030	0.0133	0.0102	0.0109	0.0135	0.0000

HOUSING DECAY RATE

	Electr.	Gas	Oil	LPG	Wood
	HOME2				
1980					
1985	-0.0182	-0.0213	-0.0240	-0.0222	0.0003
1990	-0.0412	-0.0538	-0.0643	-0.0532	0.0013
1995	-0.0779	-0.1148	-0.1468	-0.1049	0.0044
2000	-0.1067	-0.1671	-0.2267	-0.1496	0.0078
2010	-0.1590	-0.2649	-0.3906	-0.2335	0.0156
2020	-0.2084	-0.3469	-0.4949	-0.3124	0.0011
2030	-0.2547	-0.4087	-0.6208	-0.3766	0.0002

POPULATION - 1990...2030

	Electr.	Gas	Resid. Oil	Distil. Oil
	CSEM2			
1980				
1985				
1990	1.1788	0.6826	0.5478	0.6001
1995	1.1667	0.7137	0.5557	0.6087
2000	1.1463	0.7365	0.5635	0.6172
2010	1.0873	0.7682	0.5754	0.6303
2020	1.0113	0.7685	0.5733	0.6280
2030	0.9249	0.7476	0.5605	0.6140

Table III.8. Sensitivity of Energy Use Climate, Minor Fuel Decline, and Income Projections.

CLIMATE (1983 Heating-Degree-Days) / MINOR FUEL DECLINE PARAMETERS

	Electr.	Gas	Oil	LPG	Wood	Coal	LPG	Coal
	HOME2					HOME2	CSEM2	
1980								
1985	0.2085	1.1030	1.3510	0.8491	-0.0747	-0.0938	-0.0256	-0.0306
1990	0.4133	1.9010	2.3240	0.9664	-0.2815	-0.2109	-0.0671	-0.0809
1995	0.5211	2.1500	2.6100	0.9881	-0.3789	-0.3281	-0.1070	-0.1304
2000	0.5861	2.2140	2.6330	0.9530	-0.4280	-0.4453	-0.1453	-0.1788
2010	0.6718	2.2030	2.4470	0.8156	-0.5392	-0.6797	-0.2164	-0.2728
2020	0.7297	2.2010	2.1790	0.6713	-0.0256	-0.9140	-0.2798	-0.3626
2030	0.7756	2.2150	1.9370	0.5599	-0.0020	-1.1480	-0.3345	-0.4479

DISPOSABLE INCOME

	Electr.	Nat. Gas	Distil. Oil	LPG	Wood	Electr.	Nat. Gas	Resid. Oil	Distil. Oil
	HOME2					CSEM2			
1980									
1985									
1990	0.0172	0.0144	0.0213	6.9E-05		0.7412	0.5648	0.2724	0.2984
1995	0.0643	0.0549	0.0792	2.6E-04	3.3E-03	0.7365	0.5780	0.2684	0.2941
2000	0.0809	0.0703	0.0972	3.8E-04	6.7E-03	0.7380	0.5901	0.2641	0.2893
2010	0.0894	0.0816	0.1013	5.8E-04	1.3E-02	0.7530	0.6155	0.2555	0.2799
2020	0.0915	0.0877	0.0966	7.5E-04	6.3E-04	0.7773	0.6406	0.2504	0.2743
2030	0.0929	0.0929	0.0876	8.8E-04	2.1E-05	0.8091	0.6685	0.2494	0.2732

are insensitive to a particular parameter are not included in the table (e.g. coal use, which is computed in different sections of HOME2 and CSEM2, is not sensitive to any fuel price, and is not listed in these tables). Each section of the tables indicates the module (HOME2 or CSEM2) from which the sensitivities were derived. In many cases, a table will contain sections indicating both short-term and long-term responses. In general, the value of a variable in the year 1990 was taken as the parameter to illustrate response to short-term variations. To illustrate response to long-term variations in a variable, its values for the period 1990-2030 were aggregated, as discussed in Chapter I. Table III.2 illustrates all of these features: The sensitivity of residential natural gas use in the year 2000 to perturbation to electricity price in the year 1990 only (i.e. the response to a short-term increase) is 0.0022 (column 2, upper left section of Table III.2). The corresponding long-term response -- i.e. to a permanent incremental increase in electricity price starting in 1990 -- is some 10 times higher at 0.0232 (column 2, lower left section of the same table).

III.2.A. Fuel Price Sensitivities. Six fuel prices are read into HOME2 each year for each of the four regions: electricity, natural gas, distillate oil, LPG, coal, and kerosene. The coal price, however, is not actually used by the program: energy use is not sensitive to its price.

Price response in HOME2 is intentionally lagged to reflect the slow rate of housing and capital stock replacement. Price sensitivities therefore are examined both for short-term and long-term response to sample price excursions which begin in 1990. In all cases shown here, price response has been aggregated across all regions.

For the major fuels (oil, natural gas, and electricity) the short-term price sensitivity is fairly small (on the order of 0.07 to 0.18), but persists for many years. The long-term response of major fuels to fuel prices (lower section of Tables III.2 through III.4) slowly grows to reach substantial values by 2030, on the order of -0.4 for gas and electricity, and -1.9 for oil. The largest effect of price of a particular fuel is to the use of that fuel, as one would expect. In each case, a modest amount of fuel switching is indicated by the positive response of other fuels, in addition to a net energy use conservation.[4] The model contains no overt cross-price elasticities, but accomplishes the indicated fuel switching by fuel conversions.

LPG use (Table III.5) rebounds fairly drastically from the pseudo-perturbation to its 1990 price, i.e. a temporary LPG price increase in 1990 decrease 1990 LPG use slightly, but greatly increases LPG use in later years. This behavior was verified by a perturbation run. LPG is relatively unimportant in CRESS (residential LPG use is ignored as a driver in MODEL6 -- its only influence on emissions is through its effect on wood use), so this question wasn't pursued. Long-term LPG price sensitivities behaved in a more intuitive manner, with the magnitude of the sensitivity growing to -0.22 by 2030.

Kerosene price has only a very small effect on energy use, as it is not directly included in any output categories of HOME2. Its only influence is on wood use (Table III.5).

Table III.6 displays the sensitivity of fuel use to the price of all fuels, i.e. the response of the model to a general price spike in 1990 (upper section) or to a permanent price increase in 1990 (lower section).

In this table, all fuel prices effectively increase by the same proportion, so all price ratios will remain the same, and fuel switching based on relative price changes should be eliminated. The remaining response is the inherent price-induced fuel conservation. LPG again rebounds in response to a short-term price excursion. The major fuels, however, respond in a manner similar to their response to an increase in their own price. The responses are, however, slightly weaker than in the single-fuel-price-excursion cases above.

Wood is treated differently from the other fuels in HOME2. Wood is considered to have no inherent price, and its use responds to the average fuel use: its use increases when the average use of other fuels decreases. Within the model, there is an upper limit imposed on the annual use of wood. The sensitivity of wood to fuel prices decreases in the later periods of the model because wood use is approaching this limit, and the limit becomes the dominant factor in determining use.

Overall, the price responses of HOME2 reflect the intent and design, as reflected in the documentation.[1,7,10] Price response occurs fairly slowly, largely as a function the price lag parameter. The short-term response to a temporary price fluctuation is small (but persistent), while the long-term response to a continuing price increase is substantial.

III.2.B. Population. Unlike CSEM2 and MODEL6, population figures are not directly read into or used by HOME2. Implicitly, the housing construction rates and regional disposable income projections, which are exogenous to CRESS, depend on population. There is no formal algebraic relationship between population and energy use within HOME2, however.

III.2.C. **Housing Construction Parameters**. Housing stock is an important internal parameter of HOME2, in that most of the calculations estimate fuel use on a per-house basis. Regional and national use is later computed by multiplying by housing stock. Initial housing stocks are read from historical data, and exogenous projections of housing starts are read for each region from the file RESEXOG.NTM. Housing stocks are also subject to attrition via the parameter array HDRT (housing decay rate, with values around 2%/year). These two sets of projections (starts and decay rate) are the exogenous data determining housing stocks.

The sensitivity of energy use to housing starts is illustrated in Table III.7. The response of all regions and housing categories have been aggregated. Both the long-term response, computed by aggregating the effect of all values beyond the historical data, and the short-term response, that of the values for the year 1990, are shown. The long-term effect of a change in the rate of housing construction slowly grows to substantial values for the major fuels (on the order of 0.6). The influence of the housing start value for a single year, by contrast, is fairly small (sensitivity on the order of 0.02).

The housing decay rate projections are read into HOME2 by decade, rather than by year. There is thus no single-year analog to the short-term response discussed above for housing starts. The long-term response to an increase in magnitude in the housing decay rate is to slowly decrease major fuel use. Sensitivities, displayed in Table III.7, grow by the year 2030 to range from -0.3 for electricity use to -0.6 for oil use.

III.2.D. Heating-Degree-Days. Heating-degree-days are used in a manner similar to fuel price and income to estimate space heat energy use per house. Like income, projections of future climate are used with an elasticity array (BHDD) to project climate-response. The projected values of heating-degree-days for years past 1983, however, are constant: the 1983 values are used for all future years. The intended long-term climate response is unintentionally lagged, and is magnified by a factor of 5 due to an error in the price response lag formulation.[4] Table III.8 displays the sensitivity of energy use to all annual heating- degree-day projections in and after 1984.

While post-1984 data values are present in one of the HOME2 input files, they are not actually read into the program. Thus, without reprogramming HOME2, a user cannot perturb the future projections of heating-degree-days in a way that will modify the CRESS output. That is, while the sensitivity of energy use to heating-degree-day perturbations is 5 times what it should be, no such perturbations are possible with the current version of CRESS. The error will, however, magnify the difference between CRESS results using 1983 data and the result CRESS would obtain if it used the true (but unknown) values for future heating-degree-day needs. A "quick fix" to this could be to use the long-term average value for the final (1983) datum, rather than the specific value for 1983.

III.2.E. Disposable Income. Disposable income is used in a manner similar to fuel price to estimate energy use per house. In the original version of HOME, income response was inadvertently magnified by the price lag parameter, as had been discussed above. In HOME2, this has been corrected. The income response, like the price response, is lagged.

Table III.8 illustrates the effect on fuel use of a permanent change in disposable income beginning in the year 1990. When the sensitivities are aggregated across all building types and regions, the response to income of fuel use is of moderate magnitude and fairly uniform among the major fuel categories, all values being about 0.09; LPG and wood use respond only minimally to income.

III.2.F. Minor Fuels -- Coal. Both HOME2 and CSEM2 handle certain minor constituents of their fuel mix in a much simplified manner. This is illustrated by the treatment of coal in HOME2. The parameter CGWTH is the only variable that affects coal use, which is projected via an exponential formula:

$$Q(t) = Q('80) * \exp(CGWTH * t) \quad . \qquad (9)$$

The value of CGWTH is about -0.02, and thus the sensitivity of utilization is negative to a magnitude increase in this parameter, growing linearly in time, as shown in Table III.8.

IV. CSEM2 -- COMMERCIAL SECTOR ENERGY USE MODULE

This chapter will discuss the commercial sector energy use module and will review sensitivity results[2] pertinent to this study.

IV.1. Model Description

CSEM2 was adapted from CSEM, a model developed and used by the Energy Information Administration.[6] CSEM was designed to provide intermediate-term (ca 10-year) projections for commercial sector energy use and related data for such publications as the Annual Energy Outlook.[9] The ANL adaptation of CSEM extends the time horizon to 2030, and makes some minor structural changes to accommodate the needs of CRESS.

CSEM2 produces two types of output. One type consists of projections of fuel use by region, fuel, and year; the other type is a projection of population by region and year. The population projections, however, are simply read from one file and written to another unaltered (except for a truncation in the 5th significant digit). Only the energy use projections are actually calculated by CSEM2, and these are the results examined in this section.

CSEM is driven by historically determined statistical relationships among a number of input parameters and data sets. The input data include projections of population, disposable income, and fuel prices. Historical data were used to statistically derive values for parameters relating the input projections to internally generated projections of commercial floor space, fuel choices, and fuel consumption. The details of the CSEM design can be found in Ref. 6.

The majority of parameters examined are read from input files, but a few are contained directly within the source code. The variables examined in this study are listed in Table IV.1.

Table IV.1. CSEM2 Parameters. (Parameters discussed in this section at varying levels of aggregation. "Variable" indicates the array name in the source code; "Description" also includes the implicit or explicit dimensions of the variable array.)

File Name	Variable	Description	
		Fuel prices	
COMEXOG:	PEL	Elec	(4 Regions x 51 Years)
	PNG	Gas	
	PDS	Dist Oil	
	PRL	Resid Oil	
	PKS	Kerosene	
	POP4	Population	(4 Reg x 51 Years)
	DPI4	Disposable Income	(4 Reg x 51 Years)
Internal to CSEM2 Code		Growth/Decline Rate	
	GRWMG	Gasoline	(4 Regions)
	GRWLG	LPG	
	GRWCL	Coal	

IV.2. CSEM2 Sensitivity Results

A stand-alone sensitivity analysis of CSEM2 was carried out and previously reported.[2] Results of that study which are pertinent to the linkage in CRESS will be reviewed here. The class of parameters which will be reviewed are the exogenous projections of population, disposable income, and prices for 5 fuels. These parameters are discussed in more detail in Ref. 2. Also included in Ref. 2, but not discussed in this report, are analyses of the effects of a number of other parameters which will not be discussed here. These are mainly model control and calibration parameters, such and price and income elasticities, price response lag parameters, and floor space forecasting coefficients. These intrinsic control parameters are generally the result of statistical fitting of historical data, and as such are not subject to change from one CRESS scenario to the next.

Each price, income, or population projection, read from the file COMEXOG.NTM, contains values for each of four US regions (Northeast, North Central, South, and West) in each year from 1980 to 2030. The responses reviewed here, however, are aggregated over all regions. As MODEL6 uses and prints results for only 8 specific years during the 1980 to 2030 time interval, only these sensitivities will be displayed in this report. The sensitivities of the appropriate CSEM2 outputs with respect to CSEM2 input parameters are listed with the corresponding HOME2 sensitivities in Tables III.2 through III.8, above.

IV.2.A. Fuel Price. Price response in CSEM2 is intentionally lagged to reflect the slow rate of capital stock replacement. Price sensitivities therefore are examined both for short-term and long-term responsive-responsiveness by the method described in Chapter I for sample price sions beginning in 1990.

The upper sections of Tables III.2 through III.6 display the sensitivity of fuel use to the price of fuels in 1990 (i.e. these figures show the response of the model to a short-term price excursion in 1990). The lower sections of these tables display the response to a permanent price change beginning in 1990.

In CSEM2, only the major fuel categories, oil (composed of distillate, residual, and kerosene), natural gas, and electricity are influenced by fuel prices. In all cases, the short-term sensitivity is quite small (on the order of -0.05 to -0.1), but persists for many years. The long-term response grows slowly to substantial values (ranging from -0.6 to -1.2). The largest effect of price of a particular fuel is to the use of that fuel, as one would expect. In each case, a modest amount of fuel switching is indicated by the positive response of other fuels. The model contains no overt cross-price elasticities, but accomplishes the indicated fuel switching by fuel conversions and fuel choice in newly-constructed buildings. The kerosene price has only a very small influence on any category of energy use, and LPG price has no influence at all.

Table III.6 displays the sensitivity of fuel use to the price of all fuels, i.e. the response of the model to a general price change in 1990. In this chart, all fuel prices effectively increase by the same proportional amount. Thus, all price ratios will remain the same and fuel switching determined on the basis of relative prices should be eliminated. The remaining response is the inherent fuel conservation. Again, the short-term response is small but persistent, as before; the long-term response is similar to, but slightly weaker than, the "own-fuel" responses (e.g. the response of gas use to gas price).

Overall, the price responses of CSEM2 reflect the intent and design, as reflected in the documentation.[6] Price response occurs very slowly, largely as a function of building stock replacement. The short-term response to a temporary price fluctuation is thus small (but persistent), while the long-term response to a continuing price increase is substantial.

IV.2.B. Population. Table III.7 displays the sensitivity of energy use to post-1989 population. The sensitivity of total fuel use to population is about 1.0, which seems quite reasonable. The sensitivities of individual fuels straddle this value, gas being lower at around 0.7 and oil and electricity being somewhat above one. Unlike price response, the population response of the model is immediate, and its magnitude does not vary a great deal over time, although there is a considerable variation in the response when examined on a regional or fuel-category basis.

IV.2.C. Disposable Income. Disposable income is used in a manner identical to population to estimate floor stock. As with population, the influence of an income change is immediate. The sensitivities of national fuel use to disposable income are listed in Table III.8. When the sensitivities are aggregated across all building types and regions, the response to income of fuel use is significant in magnitude and fairly uniform from one fuel to another, all values being within the range 0.6 to 0.8. The response of fuel use to a change in a particular year of either income or population is immediate: new demand for commercial services (as determined by increased population or income) is met by the necessary building stock additions in a single computational period (i.e. within the year). Fuel use per unit area is calculated separately, and the two results (area and use per unit area) are combined to produce the model's results, commercial energy use.

IV.2.D. Minor Fuel Decline Parameters. CSEM2 tracks eight sources of energy, but only five, electricity, gas, and oil (which includes contribubutions from residual, distillate, and kerosene), are treated in the comprehensive manner described and analyzed above. Three other fuels, coal, gasoline, and LPG, which make only a very minor contribution to total commercial energy use, are treated in a much more circumscribed manner. The use of these fuels is projected on a region-by-region basis by a simple exponential decline function, similar to the treatment for coal in HOME2 (Chapter III, above).

The use of these minor fuels is thus sensitive only to time and the decline parameter (variable arrays GRWCL, GRWMG, and GRWLG in the FORTRAN source code). Sensitivities of fuel use to the coal and LPG decline parameters, aggregated over all regions, are listed in Table III.8. Most of their values are negative, and consequently sensitivities (to a magnitude increase) are negative. Gasoline use is an output from CSEM2, but is ignored in the processing in the regionalization module, REGION, and is never read into MODEL6.

V. SENSITIVITY LINKAGE

The three modules of CRESS have been extensively examined using an automated application of the direct method of sensitivity analysis. The results of the direct method are analytical values for the gradients or sensitivities of model results with respect to their inputs. Within a program, GRESS automatically propagates the gradients via the chain rule of differentiation. The same method can be manually applied to link sensitivities between modules. CRESS consists of a series of modules, each of which can be treated as (complicated) function of its input parameters. Considering for the moment only the three major modules, CSEM2, HOME2 and MODEL6, and putting aside the question of the influence of the other two modules of CRESS, these functions can be written as:

CSEM2	:	C(Pc),	
HOME2	:	H(Ph),	and
MODEL6	:	M(Pm,H,C) .	

where the value of **C** depends only on a set of exogenous parameters **Pc**, **H** depends only on a set of exogenous parameters **Ph**, and **M** depends on both an exogenous set of parameters **Pm** and on the functions **C** and **H**. The stand-alone sensitivity analyses of HOME2, CSEM2 and MODEL6 provide the normalized sensitivities:

$$\frac{\partial C}{\partial PC} \quad , \quad \frac{\partial H}{\partial Ph} \quad , \text{ and } \frac{\partial M}{\partial Pm} \tag{10}$$

The majority of the driver variables of MODEL6 (the arrays RESEGY and CMIEGY) represent the values of **H** and **C**; their sensitivities were also computed , so that

$$\frac{\partial M}{\partial H} \text{ and } \frac{\partial M}{\partial C} \tag{11}$$

are also available. The overall sensitivity of a result of CRESS (which is to say a result, **M**, of MODEL6) with respect to a parameter, **P**, is

$$\frac{dM}{dP} = \frac{\partial M}{\partial P} + \frac{\partial M}{\partial H}\frac{\partial H}{\partial P} + \frac{\partial M}{\partial C}\frac{\partial C}{\partial P} \qquad (12)$$

where **P** is a member of one or more of the sets **Pm**, **Ph**, and **Pc**. The above equation expresses the means for linking sensitivities within the three primary modules of CRESS.

This method is embodied in the sample linkage calculation shown in Table V.1. This table shows the detailed calculation of the sensitivity of SOx emissions to a long-term oil price change beginning in 1990. The columns in the table are the MODEL6 driver variables. The upper block of data comprises the sensitivities of SOx emissions to the driver variables from MODEL6 (see Table II.3), namely $\partial M/\partial P$, $\partial M/\partial H$, and $\partial M/\partial C$. The center block contains the sensitivities derived from CSEM2 and HOME, namely $\partial H/\partial P$ and $\partial C/\partial P$. The lower block contains the product of the corresponding members of the upper and center blocks, (e.g. $\partial H/\partial P \cdot \partial M/\partial H$). The overall sensitivity of SOx emissions in a given year is the sum of all entries in that year's row in the lower block. The entries that are most significant in determining SOx's response to a parameter are those with the largest sensitivity coefficient. In this example, the price of oil influences SOx emissions not too surprisingly through its inhibiting influence on the use of oil. Commercial residual oil exerts the strongest influence, being about three times larger than the influence of distillate oil from either the commercial or residential sector.

Some general warnings are in order regarding interpretation of sensitivity results. The first is that relationships may exist between

Table V.1. Sample Calculation of Linked Sensitivity Results. (Propagation of sensitivities for a long-term oil price change through HOME2, CSEM2, and MODEL6. The upper block shows the MODEL6 sensitivities to driver variables (mainly fuel use; the middle block gives the sensitivities of HOME2 and CSEM2 energy use to the oil price change beginning in 1990; the lower block contains the product of corresponding terms. The overall sensitivity is the row sum of the lower block.)

MODEL6 Variable:		DRIVAR				RESEGY							CMIEGY						
	Index:	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
		Gasoline Sales SOx Emissions	Total Pop.	Rural Pop.	Forest Area	Coal	Resid. Oil	Distil. Oil	Nat. Gas	LPG	Wood	Electr.	Coal	Resid. Oil	Distil. Oil	Nat. Gas	LPG	Wood	Electr.
dE/dU	1980	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
from	1985	--	0.0280	0.0102	0.0088	0.0447	--	0.1350	1.1E-03	--	9.1E-04	--	0.1960	0.4320	0.1180	1.8E-03	8.1E-05	--	--
MODEL6	1990	--	0.0267	0.0096	0.0079	0.0354	--	0.1230	1.0E-03	--	8.3E-04	--	0.1670	0.4700	0.1290	1.7E-03	7.4E-05	--	--
	1995	--	0.0264	0.0093	0.0074	0.0292	--	0.1030	9.1E-04	--	7.8E-04	--	0.1490	0.5110	0.1380	1.6E-03	7.0E-05	--	--
	2000	--	0.0277	0.0096	0.0075	0.0259	--	0.0866	8.6E-04	--	8.2E-04	--	0.1420	0.5330	0.1420	1.5E-03	7.2E-05	--	--
	2010	--	0.0329	0.0111	0.0082	0.0223	--	0.0647	8.5E-04	--	1.0E-03	--	0.1410	0.5510	0.1450	1.5E-03	8.1E-05	--	--
	2020	--	0.0401	0.0135	0.0096	0.0206	--	0.0532	9.0E-04	--	1.3E-03	--	0.1490	0.5480	0.1430	1.4E-03	9.7E-05	--	--
	2030	--	0.0470	0.0159	0.0109	0.0186	--	0.0469	9.8E-04	--	1.5E-03	--	0.1540	0.5430	0.1420	1.4E-03	1.1E-04	--	--
						Residential Sector (HOME2) Sensitivities							Commercial Sector (CSEM2) Sensitivities						
dU/dPrm	1980	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
from	1985	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
HOME &	1990	--	--	--	--	--	--	-0.1775	0.0065	4E-12	--	2.2E-04	--	-0.0495	-0.0542	0.0018	--	--	1.9E-04
CSEM	1995	--	--	--	--	--	--	-0.7400	0.0351	-6E-11	0.0926	8.7E-04	--	-0.2498	-0.2736	0.0121	--	--	1.2E-03
	2000	--	--	--	--	--	--	-1.0490	0.0592	-2E-11	0.1749	1.2E-03	--	-0.3793	-0.4155	0.0201	--	--	2.0E-03
	2010	--	--	--	--	--	--	-1.4820	0.0927	-4E-10	0.3089	1.5E-03	--	-0.5128	-0.5617	0.0330	--	--	3.2E-03
	2020	--	--	--	--	--	--	-1.5200	0.0967	-3E-10	0.0136	1.8E-03	--	-0.5565	-0.6096	0.0407	--	--	3.9E-03
	2030	--	--	--	--	--	--	-1.8770	0.1144	-6E-10	0.0001	1.9E-03	--	-0.5689	-0.6232	0.0460	--	--	4.3E-03
dE/dPrm	1980	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
overall	1985	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	1990	--	--	--	--	--	--	-0.0218	6.7E-06	--	--	--	--	-0.0233	-0.0070	3.1E-06	--	--	--
	1995	--	--	--	--	--	--	-0.0762	3.2E-05	--	7.2E-05	--	--	-0.1276	-0.0378	1.9E-05	--	--	--
	2000	--	--	--	--	--	--	-0.0908	5.1E-05	--	1.4E-04	--	--	-0.2022	-0.0590	3.1E-05	--	--	--
	2010	--	--	--	--	--	--	-0.0959	7.9E-05	--	3.2E-04	--	--	-0.2825	-0.0814	4.9E-05	--	--	--
	2020	--	--	--	--	--	--	-0.0809	8.7E-05	--	1.8E-05	--	--	-0.3050	-0.0872	5.9E-05	--	--	--
	2030	--	--	--	--	--	--	-0.0880	1.1E-04	--	1.9E-07	--	--	-0.3089	-0.0885	6.4E-05	--	--	--

exogenous parameters which will not be evident in any of the sensitivity analyses.

For example, two of the parameter sets consist of projections of regional disposable income and regional population. While these are certainly not independent of one another, within the framework of CRESS they are considered to be independent. The sensitivity results will show only the formal sensitivity which exists within the framework of CRESS, and, in the absence of additional information, will not reveal implicit relationships among the exogenous parameters. The second caveat is that the sensitivity results computed apply, strictly speaking, only to the "solution point" used (i.e. to the specific combination of input and output values). In a model like CRESS, which is designed from fundamentally linear (or log-linear) equations, this is often not a serious limitation: the sensitivity values calculated for the reference case will be at least approximately valid over a fairly wide range of input parameter values. Non-linearities do exist, however (e.g. limits on equipment conversion; wood use limits).

V.1. Parameters Examined

The exogenous parameter sets which are intended to drive CRESS and which will be examined are the following:

Fuel Prices (Electricity, Gas, Residual Oil, Distillate Oil, Kerosene, and LPG)
Population
Disposable Income
Housing Starts
Climate (Heating-degree-days)

In addition to the above, several projections are used internally within MODEL6 which have been covered in the discussion of that module.

Two such projections are driver variables: forest acreage and gasoline sales. Forest acreage is assumed to be a constant throughout time. Gasoline sales influence only VOC emissions. Additional projections in MODEL6 deal with the evolution of emission factors through time. These have been discussed above in the Chapter on MODEL6, and more extensively in Ref. 3. Finally, minor fuel exponential decline factors will be examined, as they are the only parameters influencing use of one of the "dirtier" fuels, coal.

V.2. INPUT.PREP and REGION

Two modules of CRESS have not undergone sensitivity analysis, and for purposes of this discussion will be ignored. A brief discussion of the probable effects of these modules is, however, in order.

INPUT.PREP is the first module of CRESS. It is used mainly to restructure the exogenous data to suit the needs of CSEM2, HOME2, and REGION, and to convert data to common units. For example, fuel price data at 5-year intervals is interpolated to produce projections at 1-year intervals. A fairly detailed examination of INPUT.PREP suggested that analysis of that module would not be a useful exercise and that the same insight into the behavior of CRESS can be obtained by beginning with INPUT.PREP's output, rather than its input.

REGION processes output data from INPUT.PREP, HOME2, and CSEM2, restructuring it to accommodate the needs of MODEL6. Its function is primarily to reorganize and disaggregate the regional data from four major divisions of the U.S.A. to the state level and to a different (10-region) structure. It does this by apportioning fuel use based of differences in state fuel prices, population, and employment levels. In the present analysis of CRESS, emissions are examined on a national, not regional or state, level. REGION is designed to allocate shares of the total fuel use without altering the total use. To a good approximation, REGION's processing should not significantly change the overall emission sensitivities. This is only an approximation, however, as it is conceivably possible for REGION to shift fuel use within a region toward or away from states with differing emissions standards, and thus to alter overall emissions while keeping total fuel use constant. For purposes of the following discussion, however, REGION's processing is ignored: sensitivities of fuel use aggregated to the national level from CSEM2 and HOME2 are used directly with sensitivities from MODEL6 to calculate overall sensitivities.

V.3. CRESS Sensitivity Results

Sensitivities of emissions to the various economic and demographic projections which drive CRESS have been calculated using Eq. (12). In all cases, a significant degree of aggregation has taken place across various categories of, for example, building type, energy end-use, region, and time. Each set of sensitivities is discussed below.

V.3.A. Fuel Prices. There are six fuels for which prices are used in CSEM2 or HOME2, and the commercial sector in general has slightly lower prices than the residential sector for fuels common to both. The energy sources for which prices are used are residual oil, distillate oil, kerosene, liquid petroleum gas, natural gas, and electricity. In the discussion that follows, residential and commercial sector use of identical fuels will be combined. This assumes that prices for these fuels would change by the same proportional amount in each sector in a perturbation.

For example, if the price of distillate oil were to increase 1% from the base case projection in the commercial sector, then it is assumed to increase by 1% in the residential sector as well. In addition, the prices of residual and distil-late oil will be similarly combined.

Several of the price projections do not have a direct connection to emissions. These sources are electricity, liquid gas, and kerosene. No emissions are attributed to use of electricity within the residential and commercial sectors. Residential sector use of liquid petroleum gas (LPG) is driven by its price, but the resulting LPG projection for the residential sector is not used by MODEL6.[3] LPG projections from the commercial sector are used by MODEL6, but the LPG price is not used by CSEM2 to make that projection. Kerosene use is subtracted from oil (as a constant fraction of total oil use) in both the commercial and residential sectors. Each of these fuels will, however, have an indirect effect on emissions through their influence upon the use of other fuels. For example, an increase in electricity price causes electric use to decrease and other fuel use to increase.

V.3.A.1. Fuel Prices - Short-Term Effects. The short term effect of fuel prices is illustrated by calculating the sensitivity of emissions to the price of a fuel in a single year, 1990. The resulting sensitivities depict the effect of a temporary price "spike" in 1990.

The effect of a short-term change in electricity price is illustrated in Fig. 1. The sensitivity of emissions for all five pollutants is very small: on the order of 0.002 to 0.003 for SOx and NOx, 0.005 for CO and TSP, and less than 0.0001 for VOC emissions. The influence of electricity price on CO and TSP emissions occurs mainly via residential wood use. Its

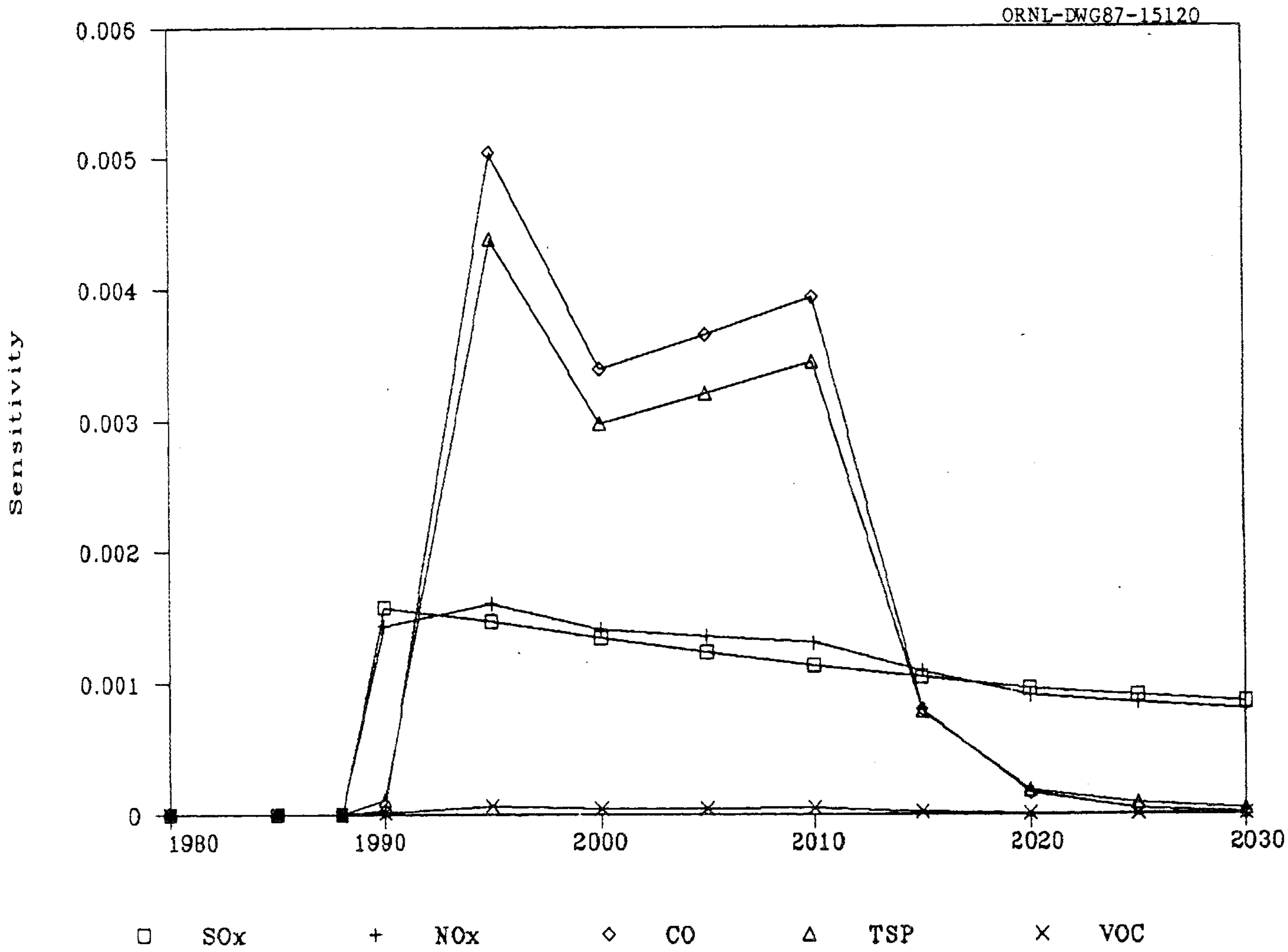

Fig. 1. Sensitivity of emissions to 1990 price of electricity.

influence on SOx and NOx emissions occurs primarily through influence on oil use.

The effect of a short-term increase in natural gas price is illustrated in Fig. 2. The influence on emissions is larger than for electricity, but still small (sensitivity magnitudes are less than 0.03). NOx emissions decrease in response to decreased use of natural gas. SOx emissions increase primarily due to increased oil use, and CO and TSP emissions increase with increased wood use. VOC emissions are quite insensitive to gas price.

SOx emissions decrease in response to an oil price increase (Fig. 3). The sensitivity in 1990 to oil price in 1990 is -0.05, and declines eventually to a tenth of that value. NOx emissions also decline, but are less responsive than oil. TSP and CO emissions' sensitivities are much lower and change sign in time with the varying relative influence of increased wood use and decreased oil use.

LPG price sensitivities (Fig. 4) are quite small: none are as high in magnitude as 0.0004, and this derives solely from the influence in HOME2 on wood use. As discussed above, the direct effects of LPG price were eliminated in CSEM2 and MODEL6.

Kerosene prices exert a very small influence on SOx and NOx emissions (ca. -0.00028 in 1990) due mainly on its influence on commercial oil use. Sensitivities of other emissions are one to three orders of magnitude less (Fig. 5). Kerosene use is not actually part of the fuel use considered in MODEL6. REGION eliminates kerosene use (as a fixed proportion of "Oil") as it processes the output of HOME2 and CSEM2. Its price does, however, exert the small influences indicated via effects on other fuel categories.

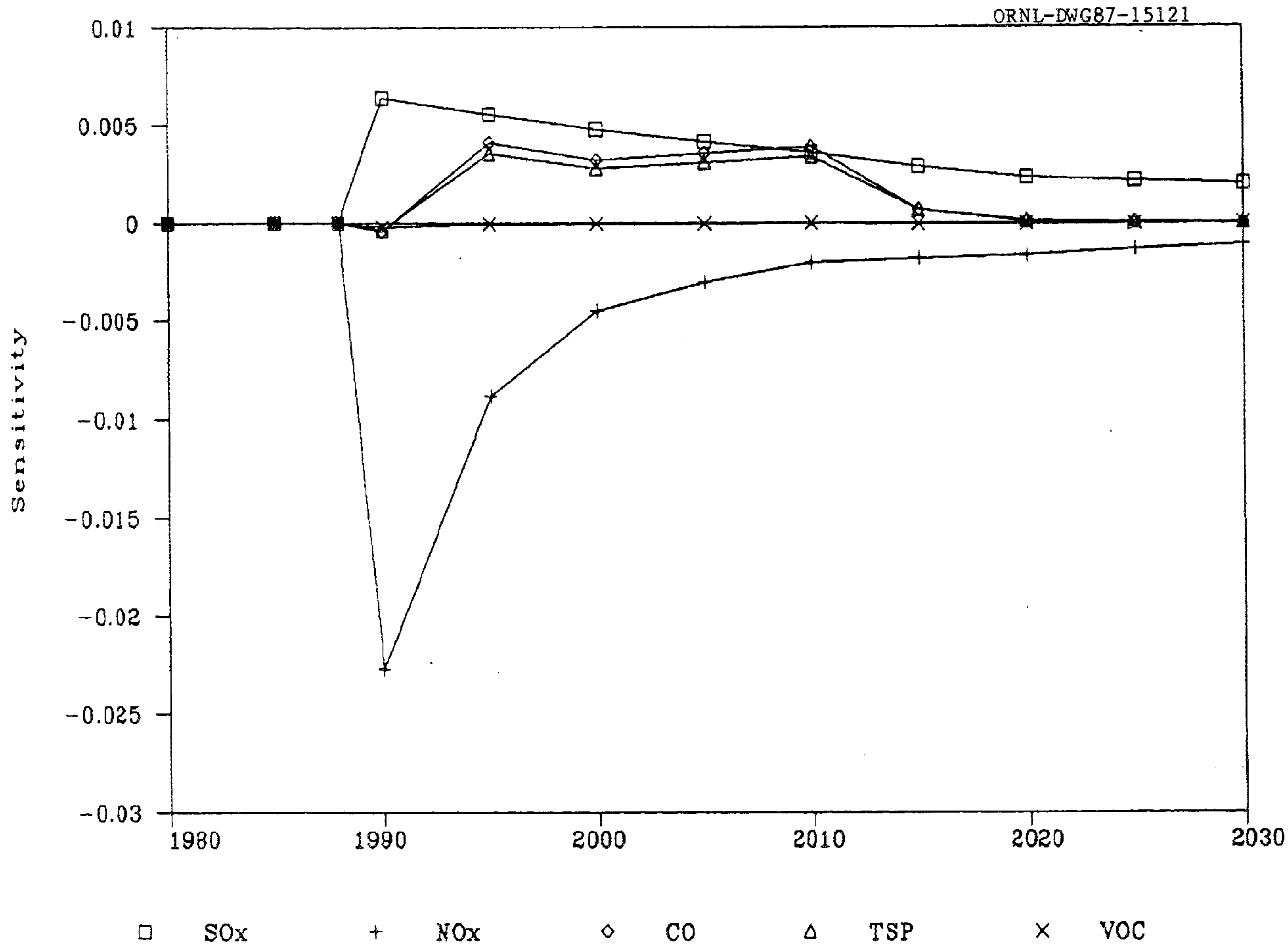

Fig. 2. Sensitivity of emissions to 1990 price of natural gas.

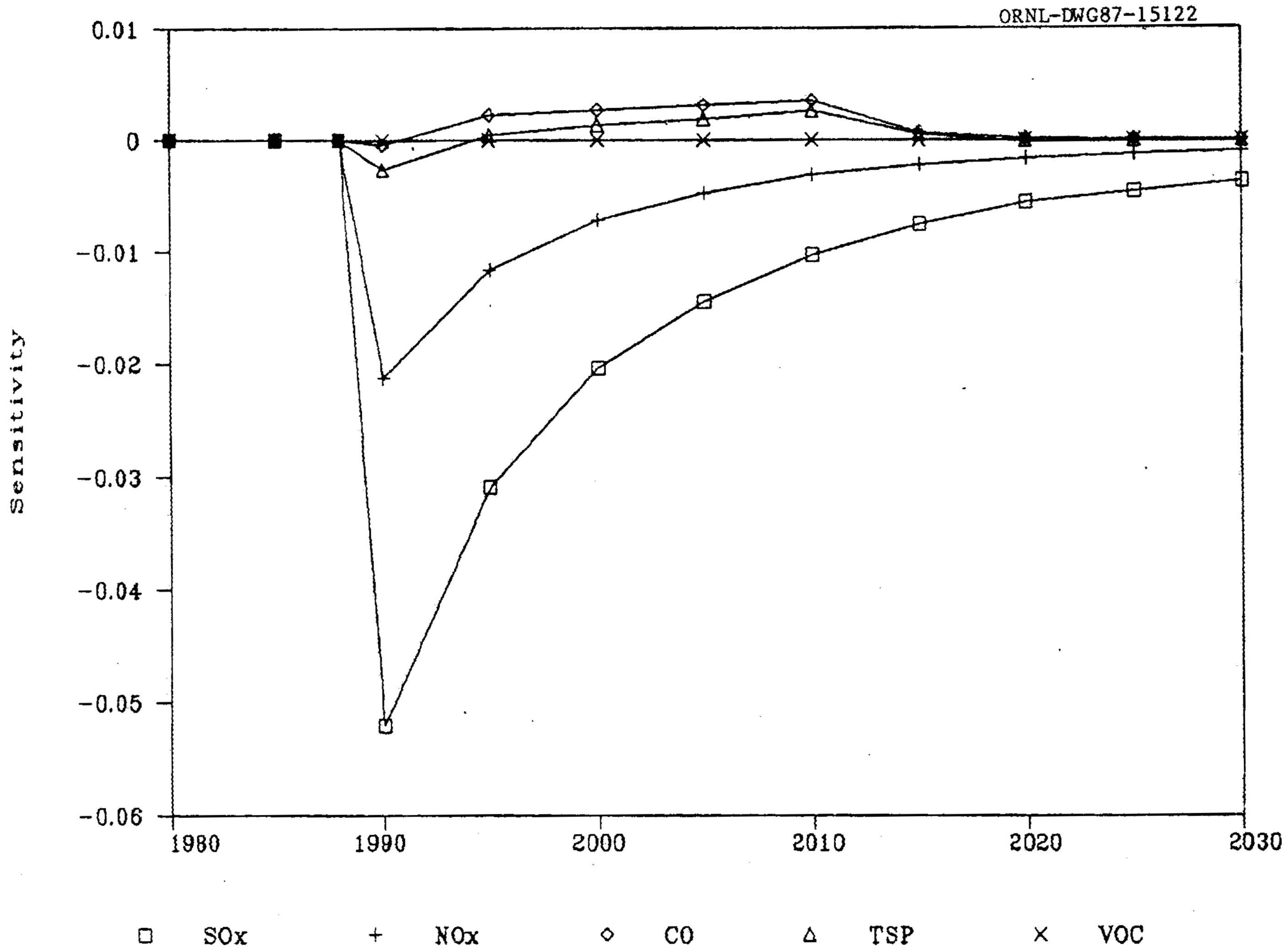

Fig. 3. Sensitivity of emissions to 1990 price of oil, including contributions from distillate and residual.

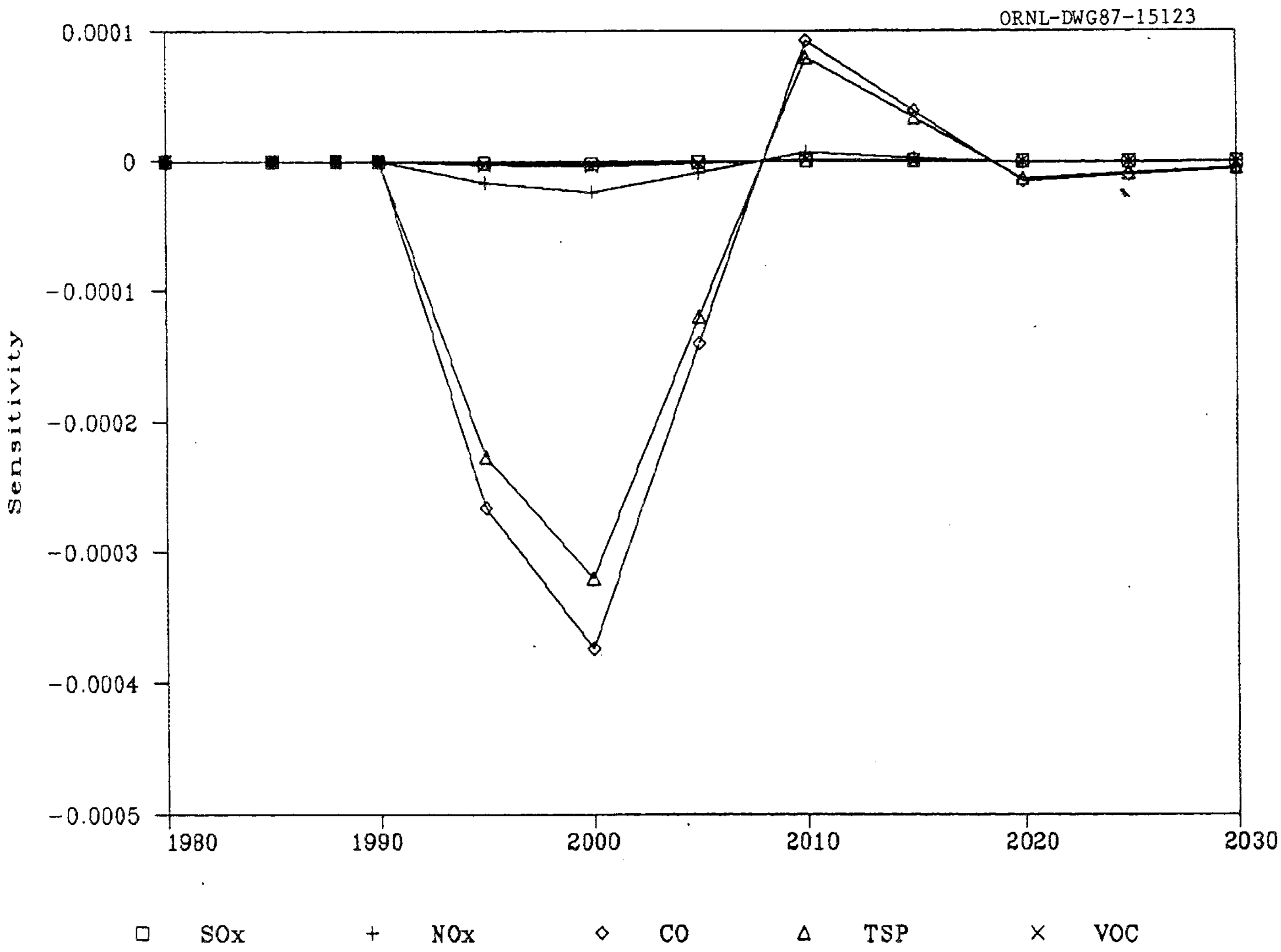

Fig. 4. Sensitivity of emissions to 1990 price of LPG.

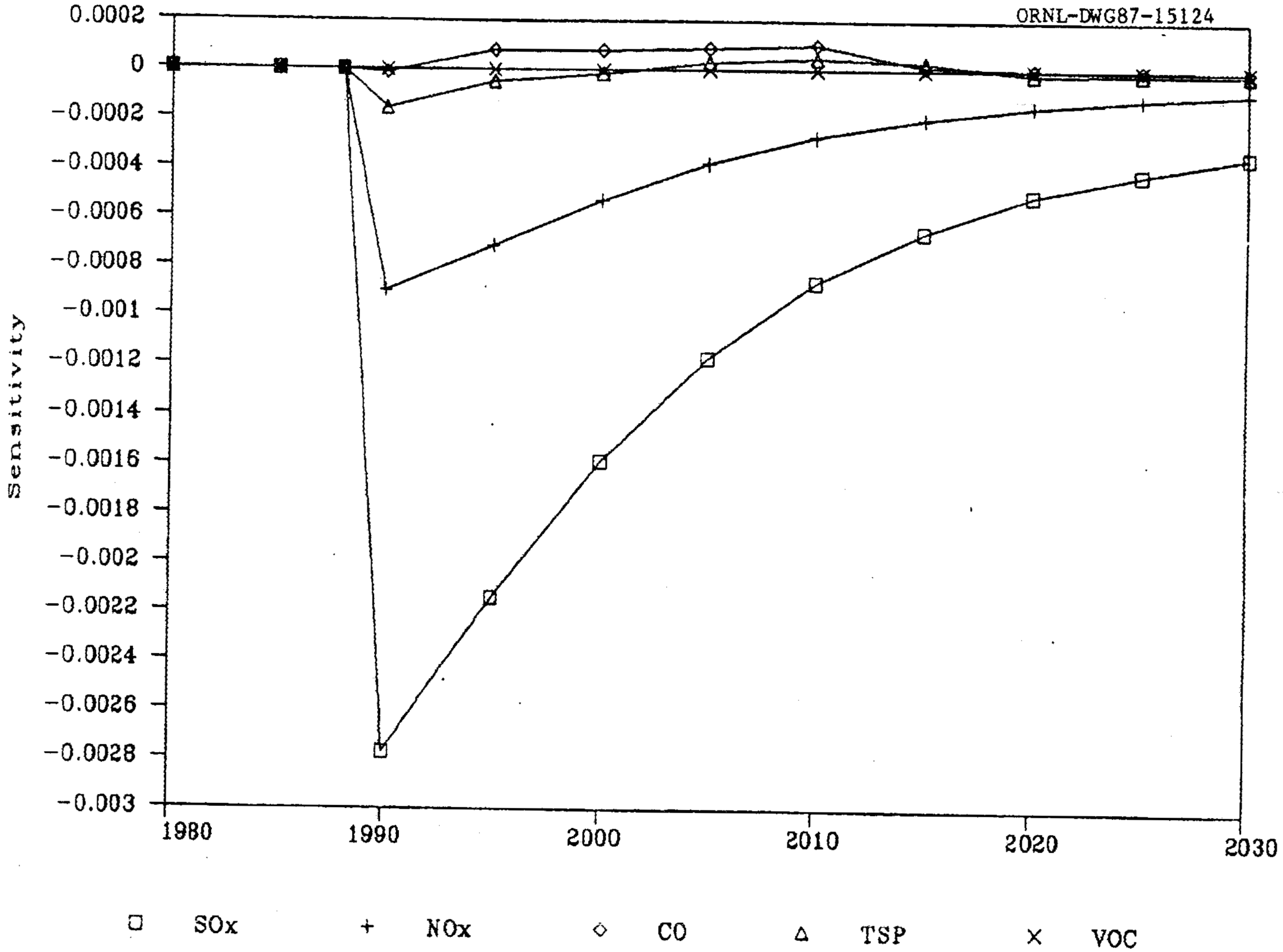

Fig. 5. Sensitivity of emissions to 1990 price of kerosene.

Figure 6 illustrates the response of CRESS to a general fuel price spike in 1990, i.e. an increase in all fuel prices by the same proportion. NOx and SOx emissions are reduced by similar amounts. SOx reductions are due mainly to a decrease in oil use, while NOx reductions derive primarily from diminished natural gas use. The response of TSP and CO emissions are due to competing reductions in use of major fuels and increased wood use.

V.3.A.2. Long-Term Price Effects. The influence of long term (i.e. permanent) price changes are illustrated by examining the influence of all prices in and after 1990. Sensitivity of emissions under these circumstances depict the effect of a permanent proportional price increase in that year.

The effect of a long term change in electricity price is illustrated in Fig. 7. Emissions for all five pollutants increase by a small amount in response to increased electricity price. SOx and NOx sensitivities slowly grow to reach values around 0.04, while CO and TSP sensitivities reach somewhat higher values earlier, then diminish. VOC emissions are much less sensitive to electricity price. The influence of electricity price on CO and TSP emissions occurs mainly via residential wood use. Its influence on SOx emissions occurs primarily through influence on oil use, largely in the commercial sector, while NOx emission is influenced largely through residential natural gas use.

The effect of a long term increase in natural gas price is illustrated in Fig. 8. The influence on emissions is larger than for electricity. NOx emissions decrease with the sensitivity approaching -0.14 by 2030. For NOx, decreased use of natural gas dominates increases in other fuels. SOx emissions increase primarily due to increased oil use, with a

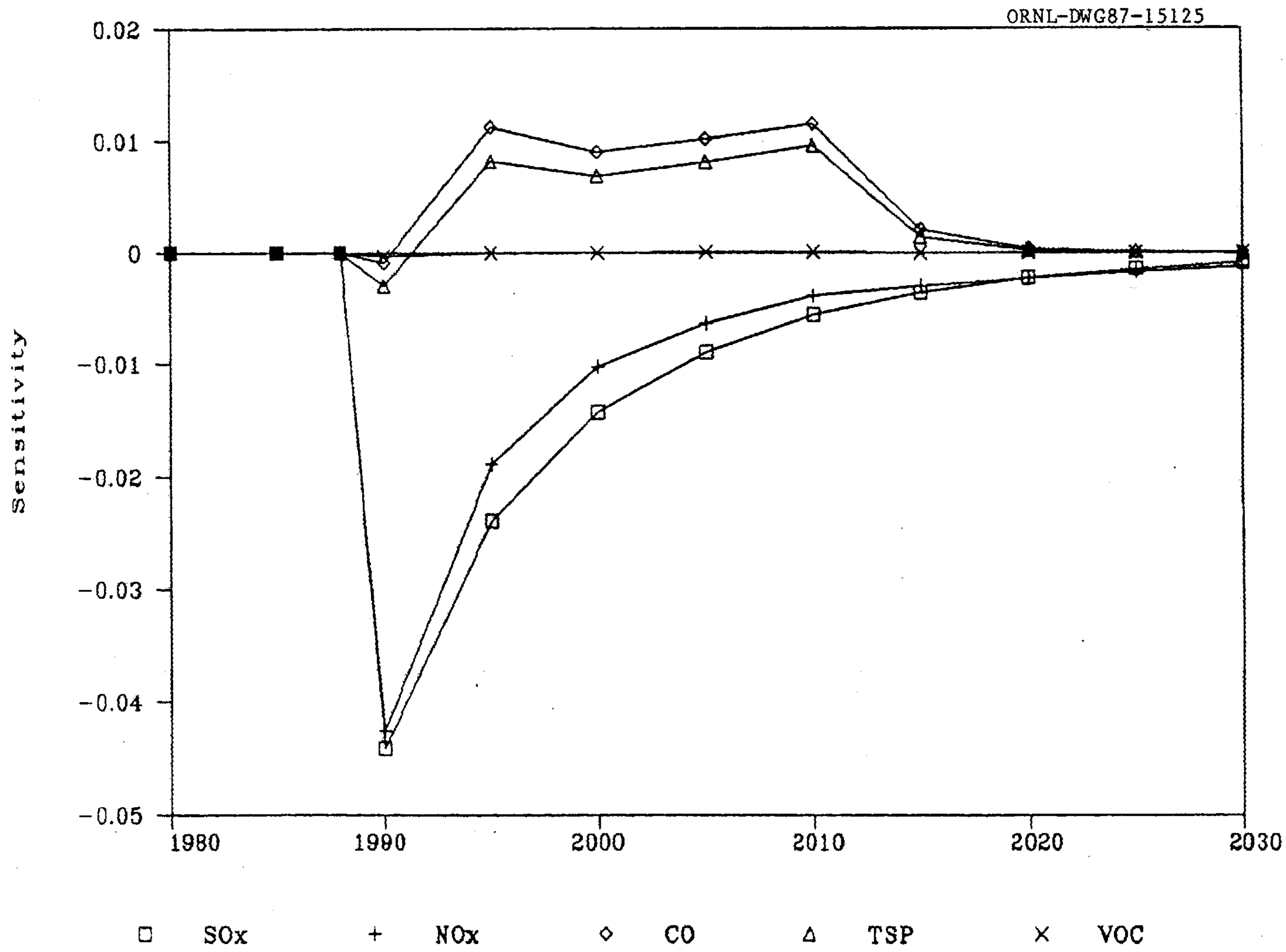

Fig. 6. Sensitivity of emissions to 1990 price of all fuels, i.e. to general price change.

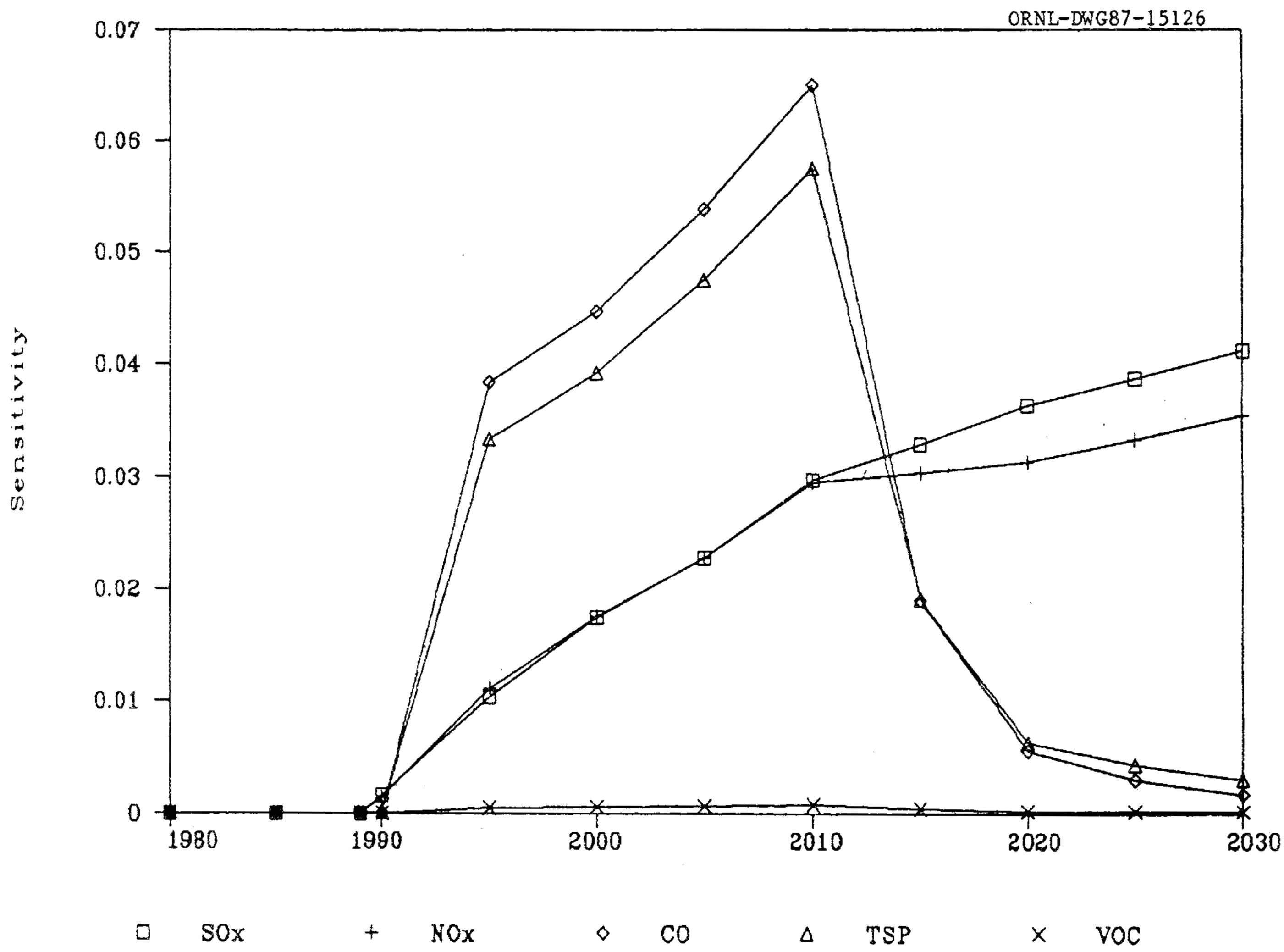

Fig. 7. Sensitivity of emissions to post-1989 price of electricity.

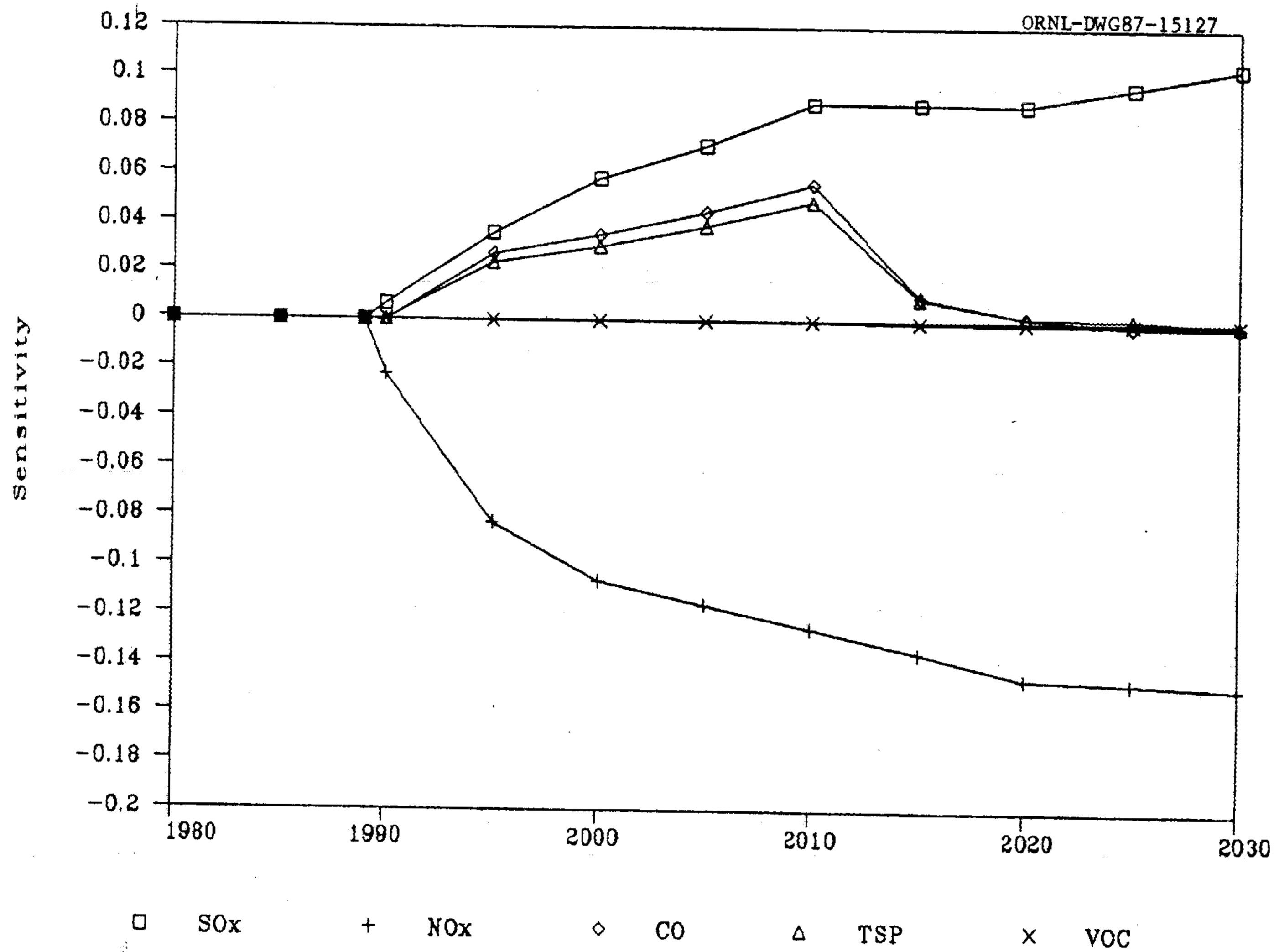

Fig. 8. Sensitivity of emissions to post-1989 price of natural gas.

sensitivity eventually approaching +0.1. CO and TSP emissions increase due to increased wood use. VOC emissions diminish very slightly in response to increased gas prices.

SOx emissions decrease markedly in response to an increase in oil price (Fig. 9). The sensitivity of SOx emissions grows to near -0.5 by 2010 largely as a function of a decline in oil use. NOx emissions also decline, but are less responsive than SOx, with decreases in NOx emissions from declining oil use dominating increased emissions from increased gas use. TSP and CO emissions are relatively insensitive to oil price due to competing opposite effects from oil and wood.

LPG price influences primarily CO and TSP emissions, with sensitivities peaking at about 0.003 in 2000 (Fig. 10). As previously discussed, LPG price influence derives solely from its effect in HOME2 on wood use.

Kerosene price exerts a small influence on SOx emissions (-0.04 by 2010) due mainly on its influence on commercial oil use. NOx emissions are influenced to a lesser degree and sensitivities of other emissions are one to three orders of magnitude less (Fig. 11). As discussed above, kerosene price exerts its small influence indirectly, via effects on other fuel categories.

Figure 12 illustrates the response of CRESS to a general fuel price shock in and after 1990, i.e. a permanent increase in all fuel prices by the same proportion. Under these circumstances, fuel price ratios remain the same. Calculations which result in fuel switching (e.g. by changing fuel use choices in newly constructed buildings) in HOME2 and CSEM2 generally use price ratios to determine the extent of change. Thus, in this calculation, there will be no such fuel switching, and the remaining

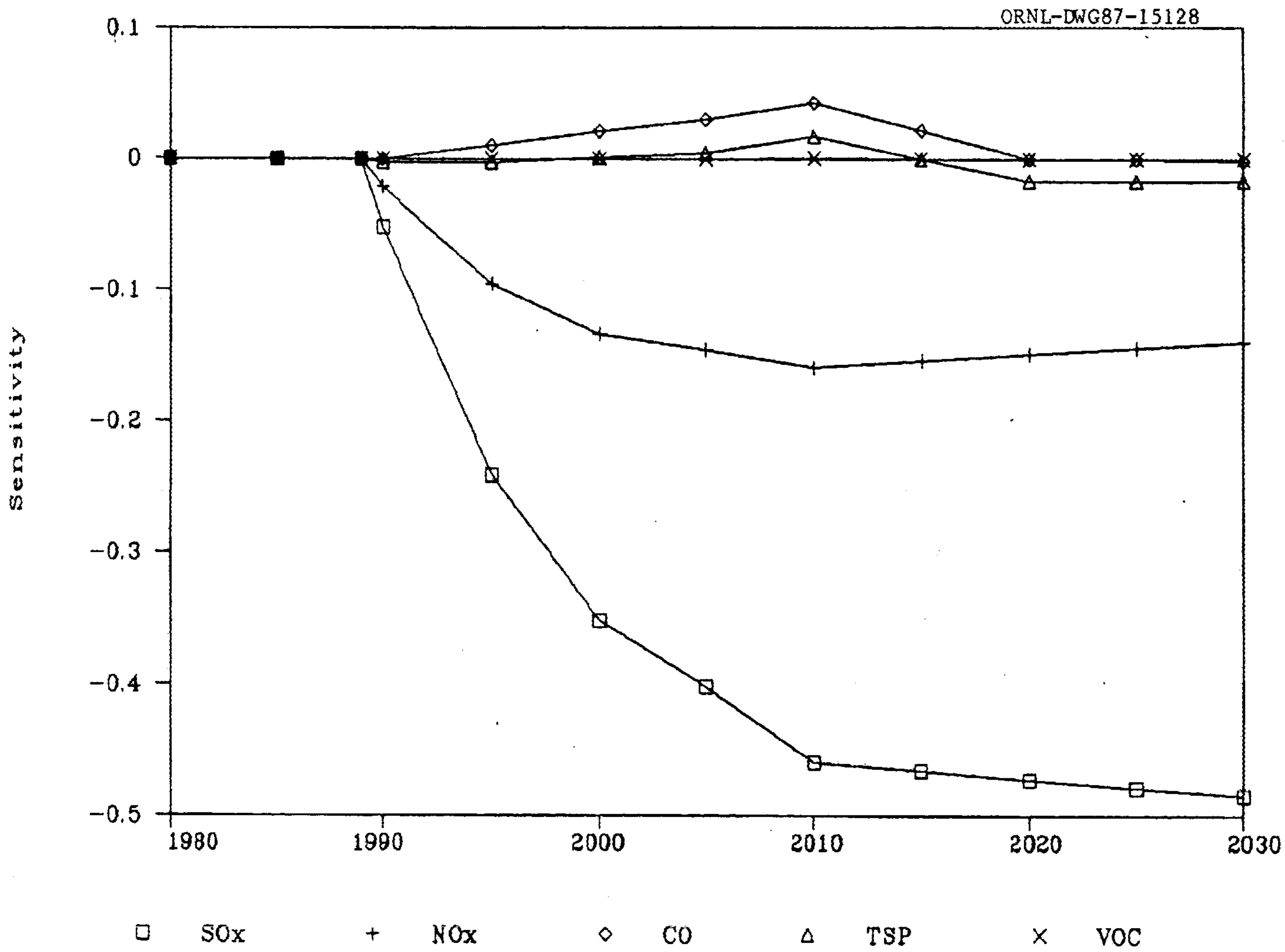

Fig. 9. Sensitivity of emissions to post-1989 price of oil, including contributions from distillate and residual oil.

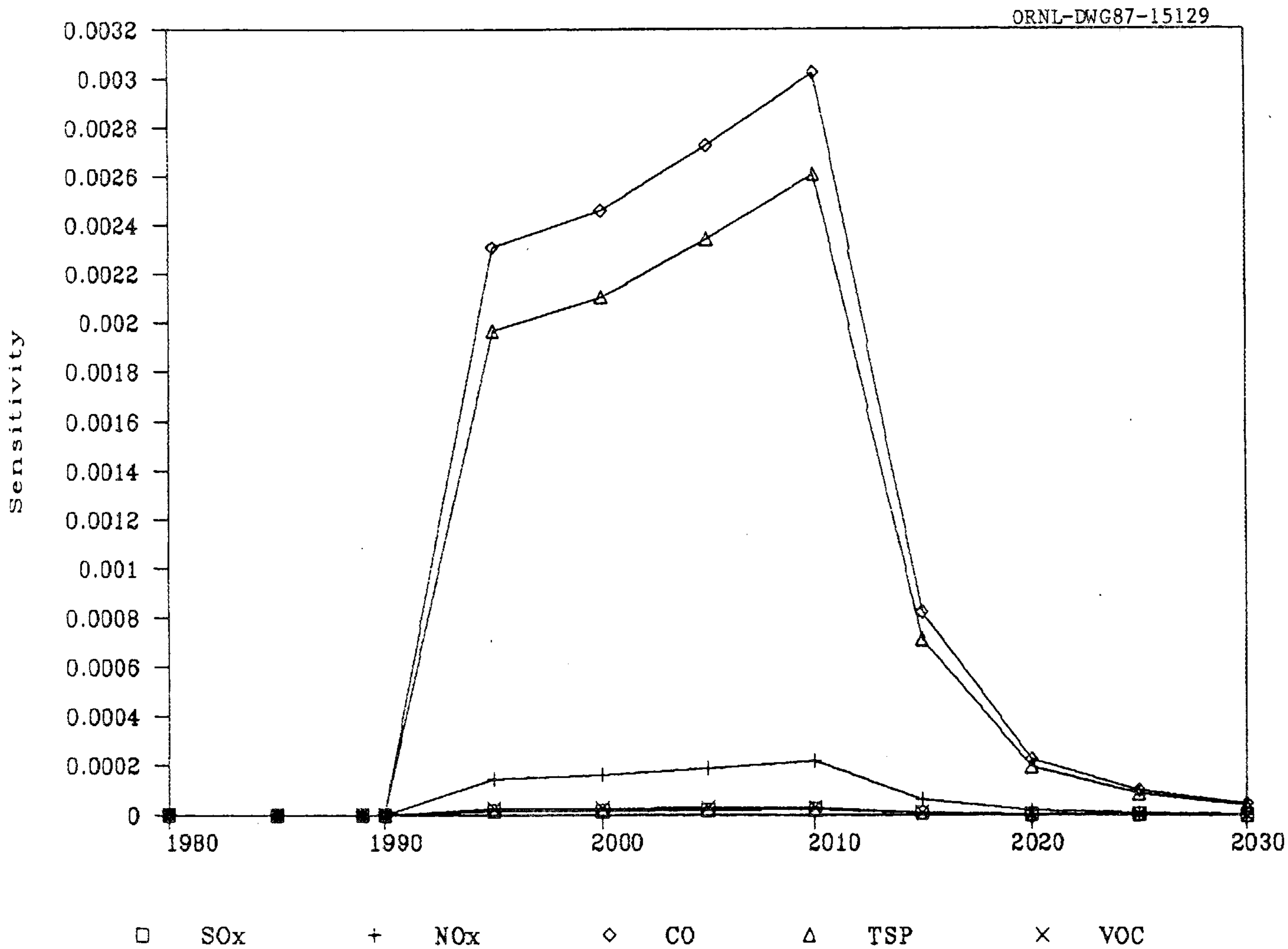

Fig. 10. Sensitivity of emissions to post-1989 price of LPG.

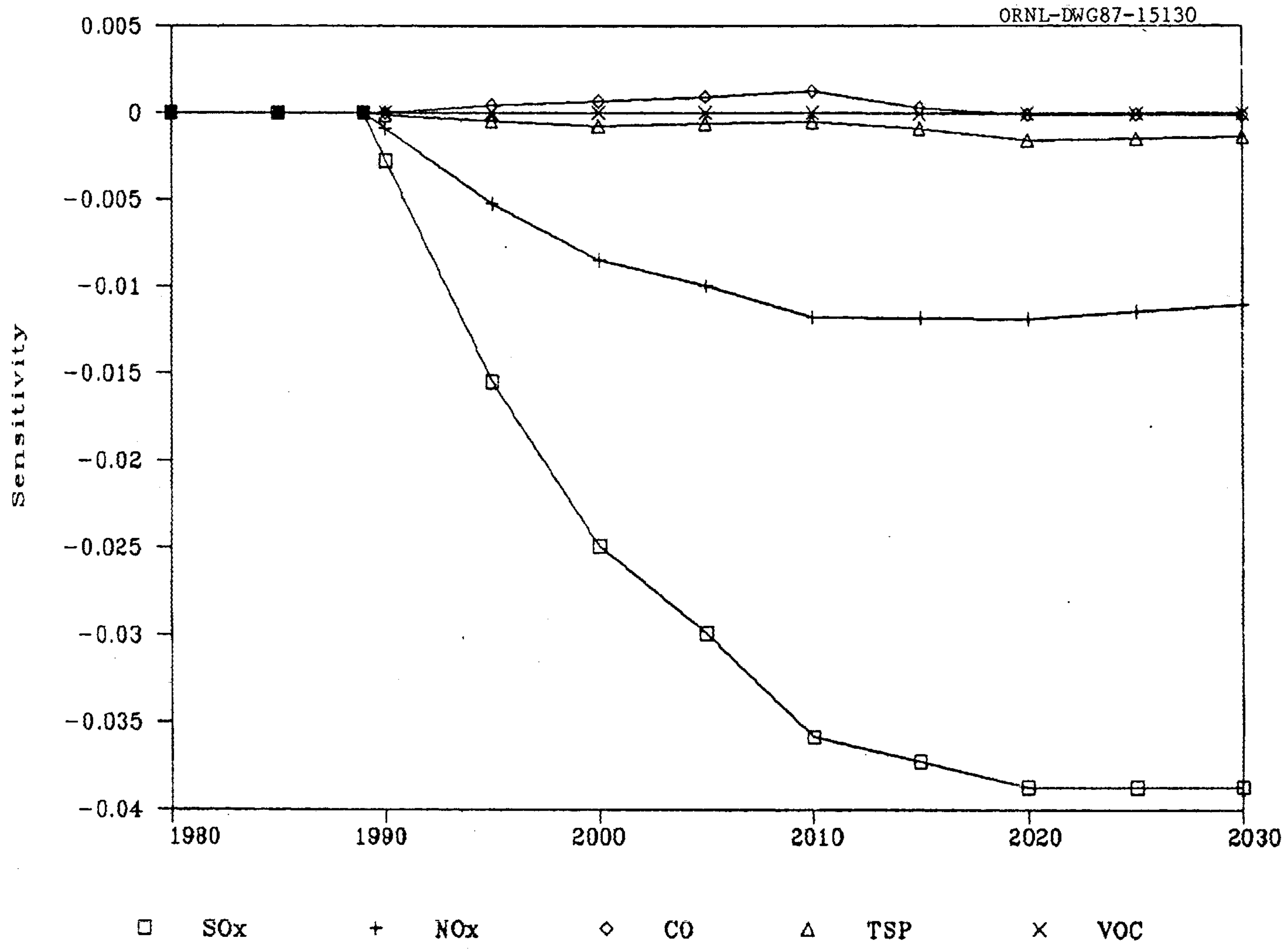

Fig. 11. Sensitivity of emissions to post-1989 price of kerosene.

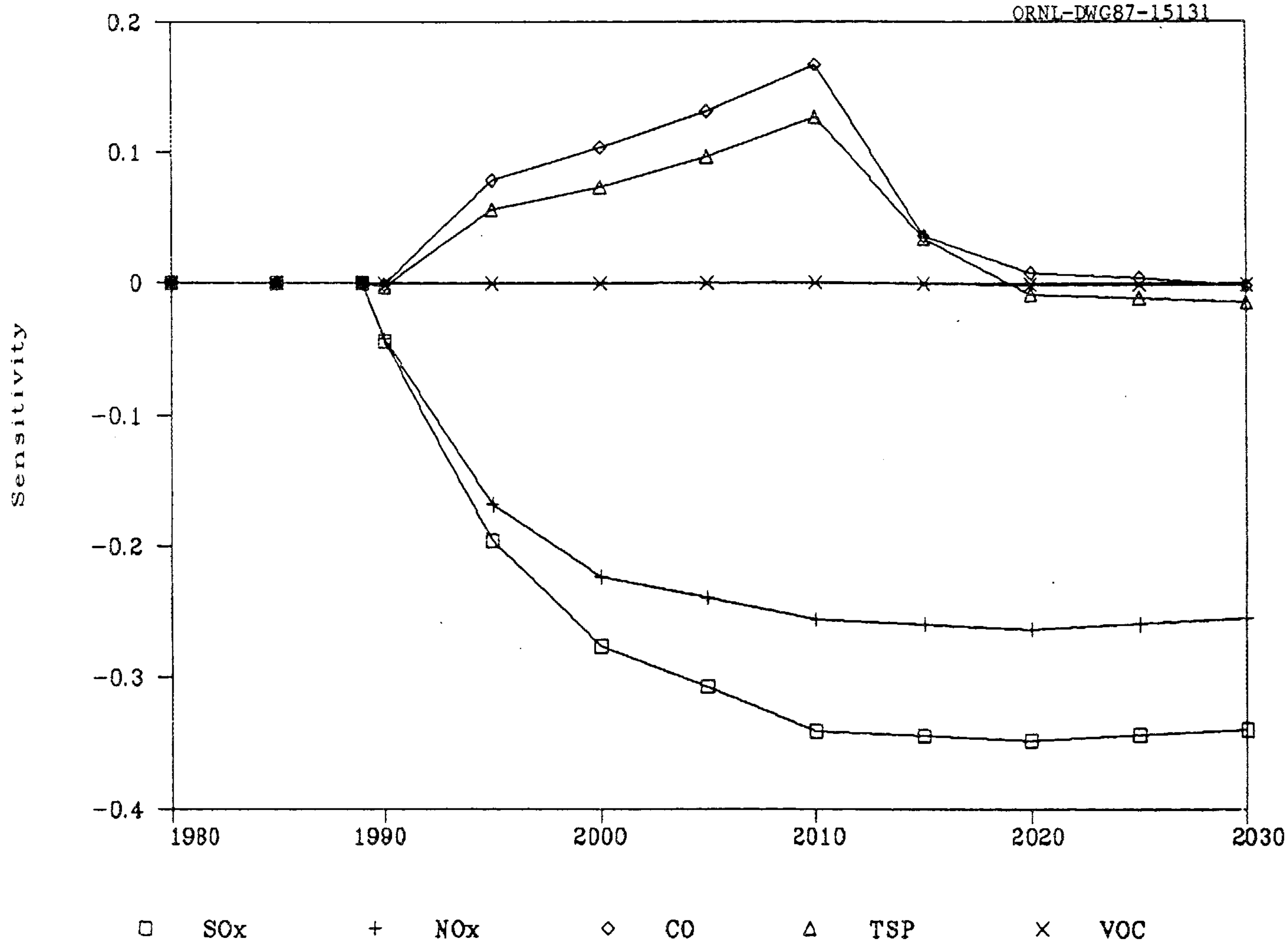

Fig. 12. Sensitivity of emissions to post-1989 price of all fuels, i.e. to a general price change.

sensitivities represent price-induced conservation. The only exception to this is residential wood use, which changes in response to general fuel use and price.

Under a general and permanent fuel price increase, NOx and SOx emissions are reduced by similar amounts (sensitivities of the order of -0.3 by 2010). SOx reductions are due mainly to decrease in oil use, while NOx reductions derive primarily from diminished oil and natural gas use. TSP and CO emissions increase in the near term in response to increase wood use, later diminishing due to wood use saturation and increased competition from reductions in use of major fuels. VOC emissions are relatively insensitive to price, with sensitivities in the realm of 10^{-3} to 10^{-4}.

V.3.A.3. Prices - General Observations. Fuel prices in general do not have a dramatic influence on emissions, though in selected cases the sensitivity can be fairly large. Of the fuel prices considered by CRESS, oil has the most influence on SOx emissions. NOx emissions are influenced by a combination of oil and gas prices.

The sensitivity of VOC emissions is generally one to three orders of magnitude less than that for other pollutants. This is to be expected, as VOC emissions are driven primarily by geographic and demographic projections, and not by the fuel use projections imported from CSEM2 or HOME3. Prices influence CO and TSP emissions mainly via indirect influence on wood use. Wood is treated in a fairly simplified manner in HOME2 (and ignored in CSEM2). If CO and TSP pollutant figures from CRESS are considered important, a refined treatment of wood use might be a profitable area for investment of effort.

V.3.B. Minor Fuel Decline Parameters. In CSEM2 and HOME2, several minor fuels are not driven by exogenous economic or demographic projections, but are projected solely via an exponential decline or growth in time. These fuels are coal, and (in the commercial sector) LPG and motor gasoline (the latter being ignored in by MODEL6). While these fuels represent a minor component of energy use in these sectors, the projections, extrapolating an exponential over 50 years, are likely to be quite uncertain in the long term. Furthermore, though coal is a minor fuel, it is a relatively "dirty" one as well.

Figure 13 depicts the aggregated influence of all of these growth parameters. The effect on emissions is small but not insignificant. SOx is the pollutant most influenced, mainly by the coal parameters, with its sensitivity to a magnitude change in the fuel decline parameters steadily growing to near -0.1. NOx and others are influenced significantly less. While small, the influence of the growth parameters, particularly in the case of coal, is comparable to many of the price projections which are treated in a much more elaborate manner in CRESS.

V.3.C. Income. Figure 14 illustrates the effect of a permanent change in national disposable income in 1990. Income response is essentially immediate in CSEM2 but is lagged in HOME2. SOx emissions are most significantly affected by income, with a sensitivity of about 0.19. NOx is influenced to a lesser degree (sensitivity coefficient $\sim$0.14), and other pollutants much less so.

V.3.D. Population. Population is used both in CSEM2 and in MODEL6. In MODEL6 it is used both directly as a driver variable and indirectly in

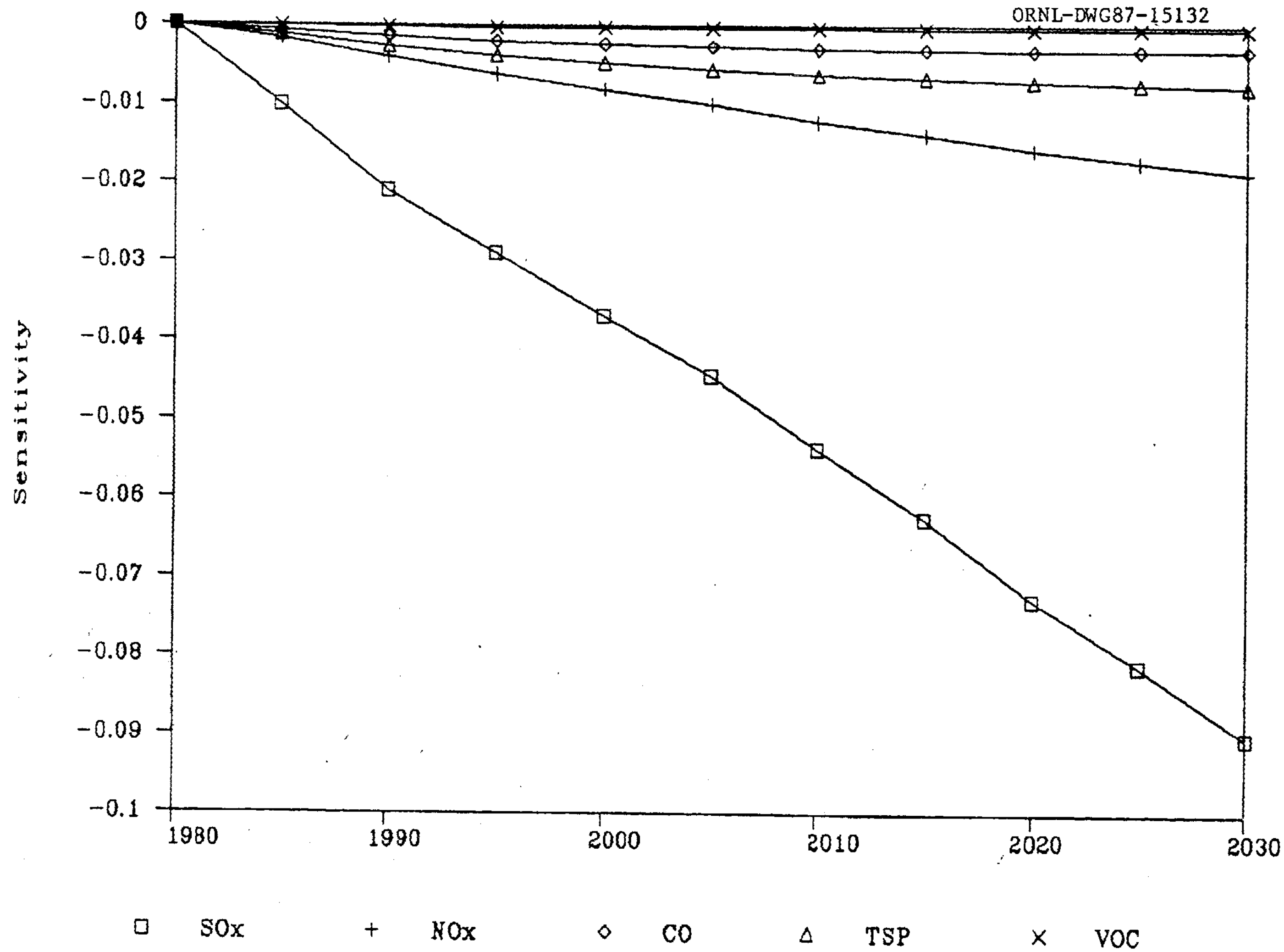

Fig. 13. Sensitivity of emissions to minor fuel decline parameters.

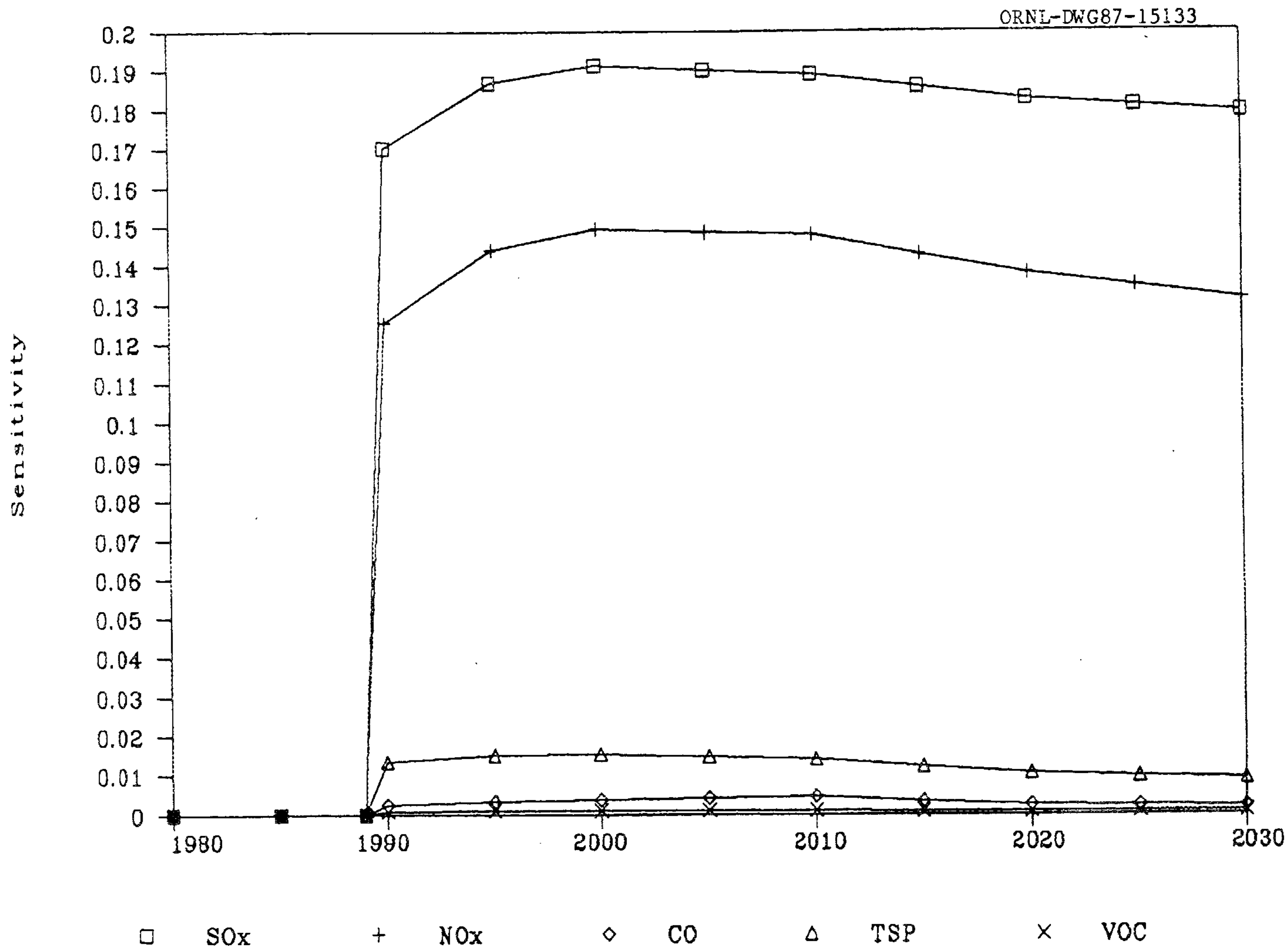

Fig. 14. Sensitivity of emissions to post-1989 national disposable income.

that a fixed fraction of population is assumed to be "rural". Population is not used by HOME2. Figure 15 depicts the response of emissions to population in and after 1990. Population has the largest influence on VOC emissions (sensitivity 0.8) which are driven primarily by rural and total population projections directly from within MODEL6. For the other pollutants, the sensitivities to population are between 0.2 and 0.4. CO and TSP sensitivities derive mainly from the direct influence of population within MODEL6, while the influence of population on SOx and NOx use is largely due to its effect on commercial oil and gas use, as computed in CSEM2.

V.3.E. Housing Stock Parameters. In the HOME2 model, housing stock computed internally by formula balancing existing stocks in 1980, future housing additions and housing attrition. Future annual housing starts (i.e. in units of houses per year) are obtained directly from an exogenous projection. Housing attrition rates (i.e. percent attrition per year) are similarly obtained from an exogenous projections (differentiated by decade). The sensitivities of CRESS emission projections were computed with respect to these exogenous projections rather than to housing stock per se. While the two variables are not directly comparable, they represent the exogenous data files which could be potentially altered by a user.

The design of CSEM2 does not provide a comparable set of parameters. While CSEM2 computes energy usage based on commercial building floor space, this floor space expands and contracts more or less instantaneously with demand for commercial services, as computed from regional disposable

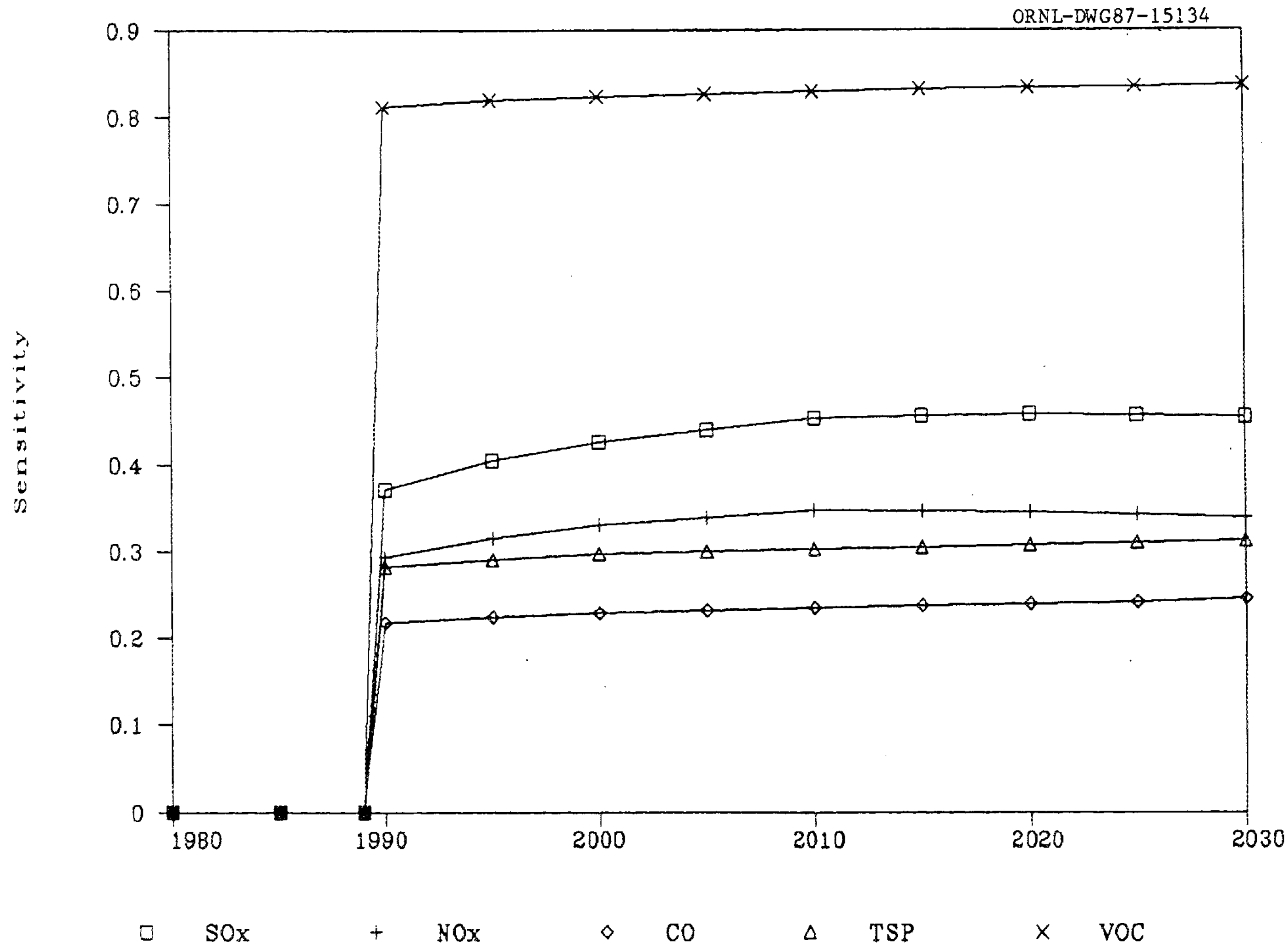

Fig. 15. Sensitivity of emissions to post-1989 population.

income and population. The housing stock parameter influences discussed here therefore come solely from HOME2.

Housing stock directly influences energy use in HOME2, and thus indirectly influences emissions in MODEL6. Housing starts increase housing stocks, and thus have a positive influence on emissions, as can be seen in Fig. 16. and Fig. 17. Starts for a single year, however, make only a small contribution to housing stocks, so it is not surprising that the influence of a single year's starts is small (0.0026 for NOx; 0.0008 for SOx; 0.0002 for CO and TSP, and much smaller for VOC). The influence of starts aggregated over all time periods (i.e. the effect of the rate of housing starts being higher in general than the current projection) is considerably higher, as can be seen in Fig. 17. By 2030, the sensitivity of NOx emissions to housing starts grows to about 0.1, and SOx grows to 0.025. CO and TSP, being mainly influenced by wood use, peak around 2010 at about 0.006 and decline in later years as wood use reaches "saturation".

Housing stocks decline per a rate (typically of the order of 2% per year) specified exogenously. There are separate rates for each vintage and class of dwelling in each of the 5 decades covered by HOME2, but for purposes of this analysis, the sensitivities have been aggregated to show the general influence of this data set. Figure 18 depicts the response to a proportional change in all values of the "housing decay rate. NOx and SOx emissions would decline moderately (S $\sim$-0.09 and -0.03 respectively). The response of VOC, CO and TSP emissions is much smaller.

V.3.F. Forest Acreage and Gasoline Sales. Two driver variable projections intrinsic to MODEL6 are gasoline sales and forest area. These

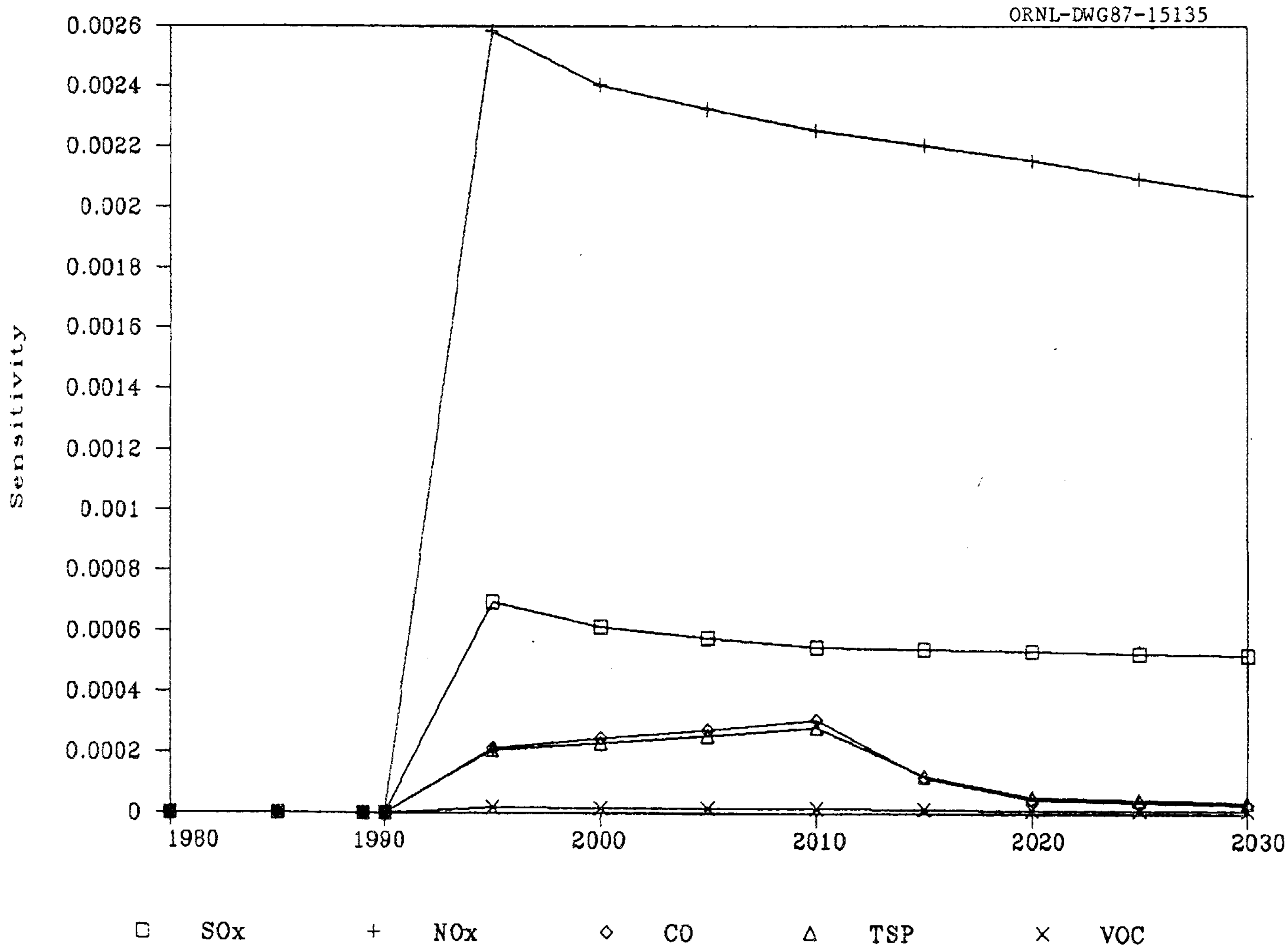

Fig. 16. Sensitivity of emissions to housing starts in 1990 only.

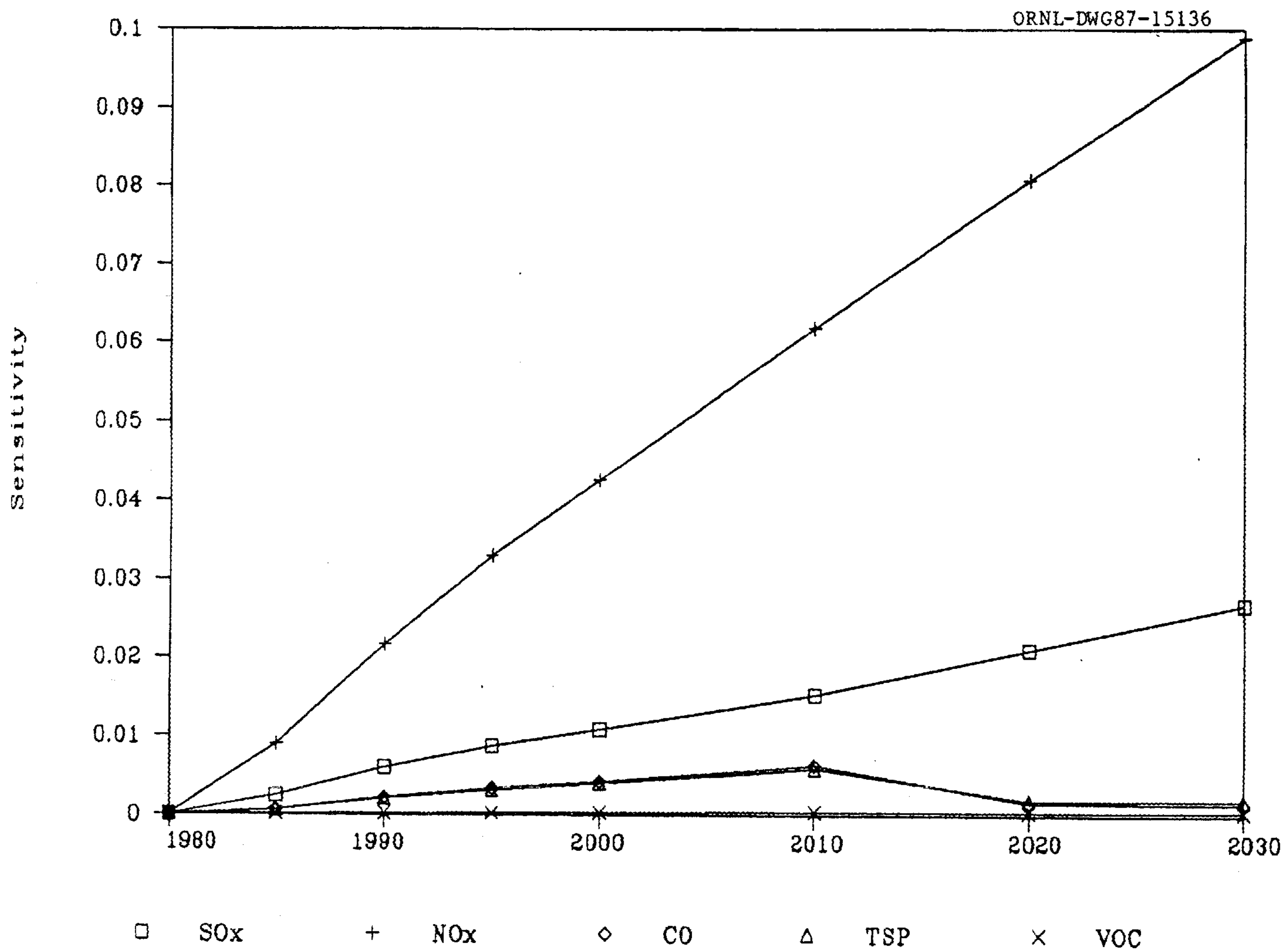

Fig. 17. Sensitivity of emissions to housing starts (all years).

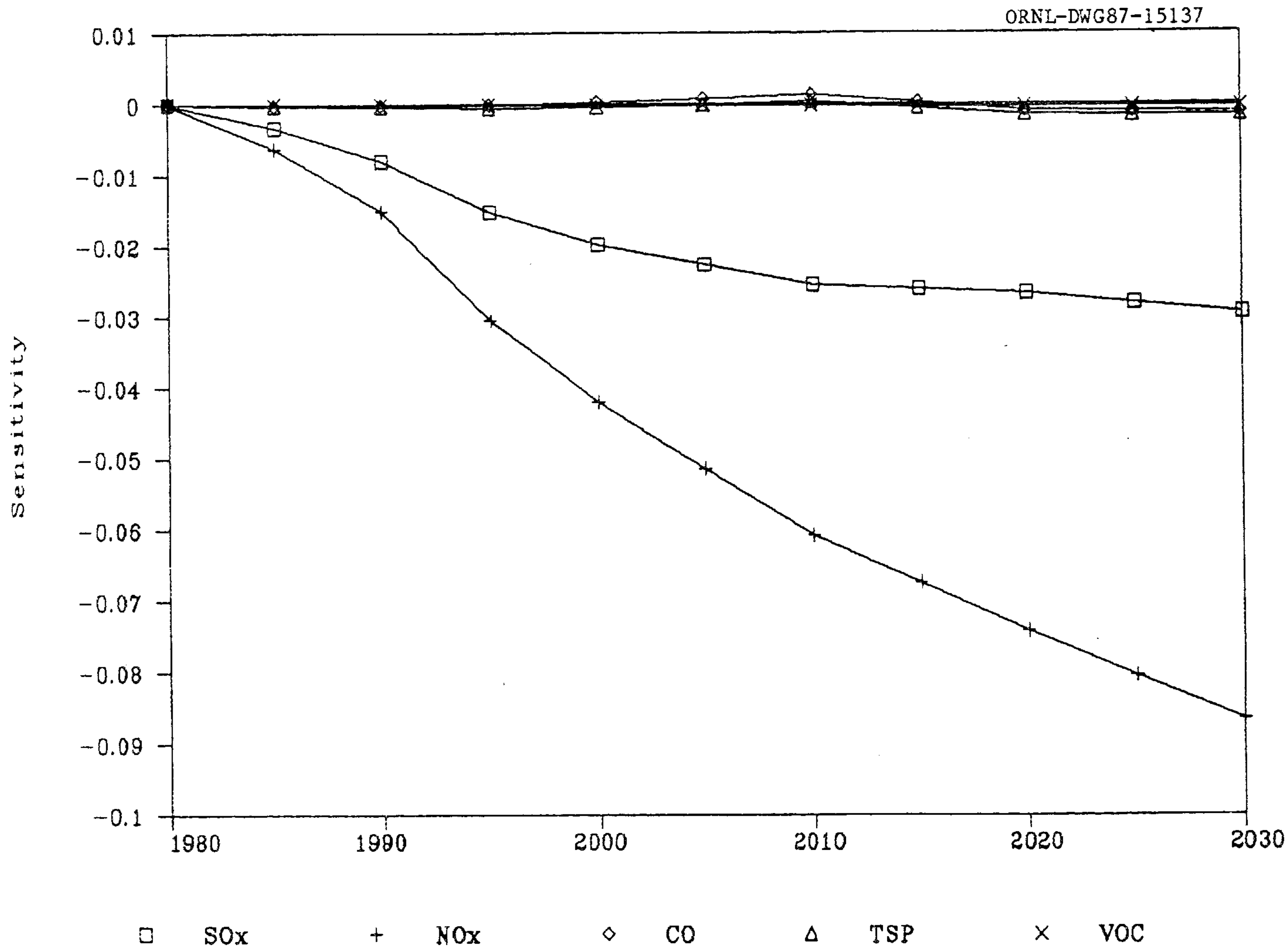

Fig. 18. Sensitivity of emissions to housing decay rate for all years.

have been covered in the analysis of MODEL6, but for purposes of comparison, it is useful to note here their relative influence on emissions.

The sensitivity to forest area (Fig. 19) is significant for CO and TSP emissions (0.6 and 0.5 respectively), and not inconsequential for NOx (at about 0.2) and VOC (0.1). SOx emissions are relatively insensitive to forest area. While assumed to be a constant throughout the future, forest area exerts an influence on some of the pollutant emission projections that is at least as large as projections handled in much greater detail. Forest area is coded into MODEL6 (rather than read from a data file), and thus not subject to casual user modification. The magnitudes of these sensitivities are, however, important in estimating the effect of the uncertainty in the assumed (constant) projection of forest area relative to the (unknown) true future forest area projection. For example, if forest area in 2000 is uncertain by, say 10% of its value, then the uncertainty from this cause in CRESS' projections for CO emissions will be uncertain by 6% of its value.

Gasoline sales influence only VOC emissions, and those to only a small degree (sensitivities are in the neighborhood of 0.05).

V.3.G. <u>Heating-Degree-Days</u>. HOME2 utilizes projections of regional heating degree days in a manner similar to projections of fuel price and disposable income. As has been discussed above, the response in HOME2 to heating-degree-days is inadvertently lagged and magnified over that intended, but this problem is somewhat hypothetical, as the heating degree day projections are not subject to casual modification in generating scenarios with CRESS.

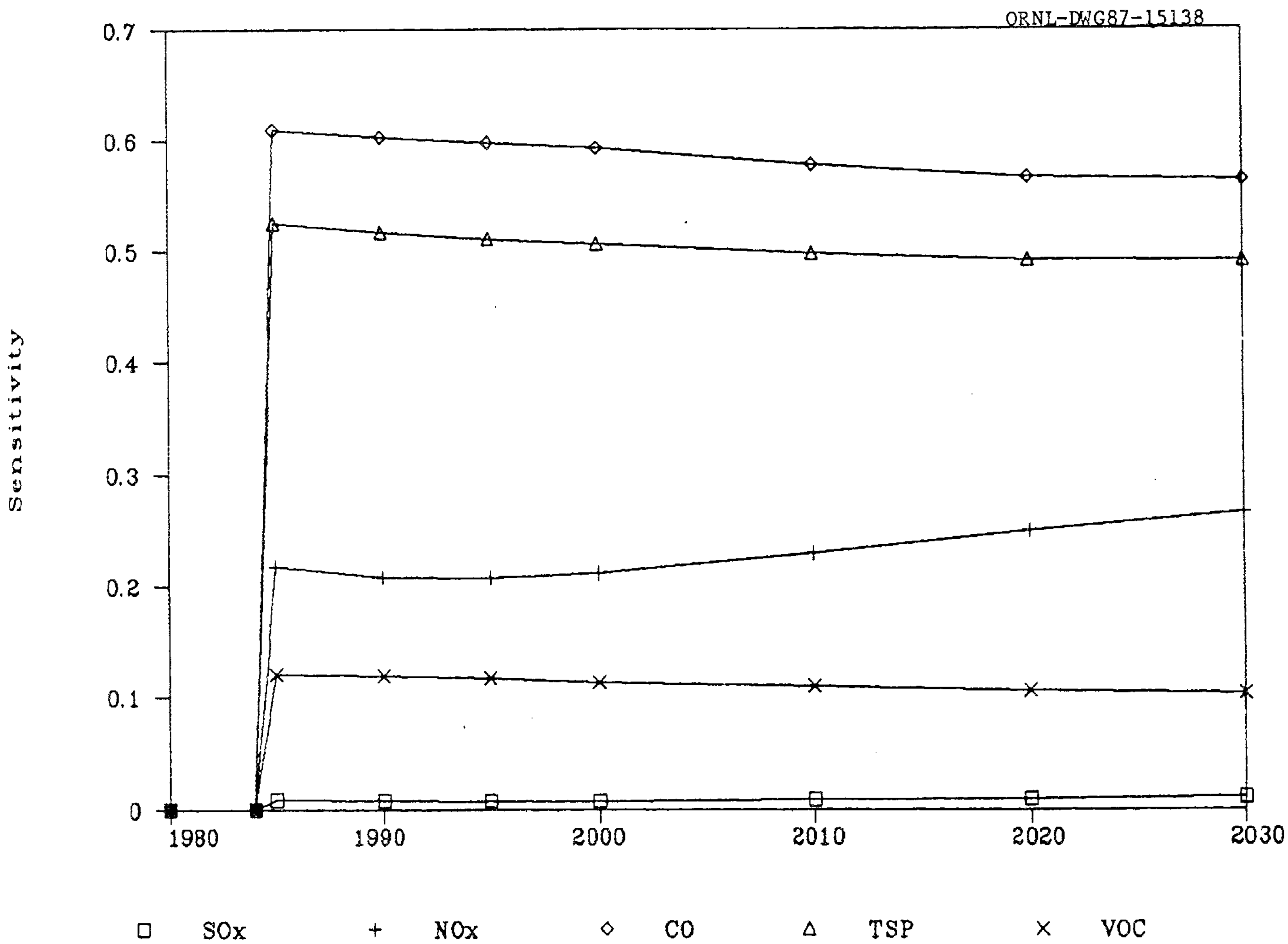

Fig. 19. Sensitivity of emissions to forest area (all years).

As illustrated in Fig. 20, NOx shows the largest response to a change in the long-term values for heating-degree-days (i.e. the 1983 values), on the order of 0.6. Sox is somewhat smaller at 0.3. Both increases result from general fuel use increases. CO and TSP, derived mainly from wood use, are less sensitive at -0.05. Their behavior results from a rare counter-intuitive side effect of the wood use formulation by which wood use responds to average household fuel use, moving in opposition to other fuel use trends.

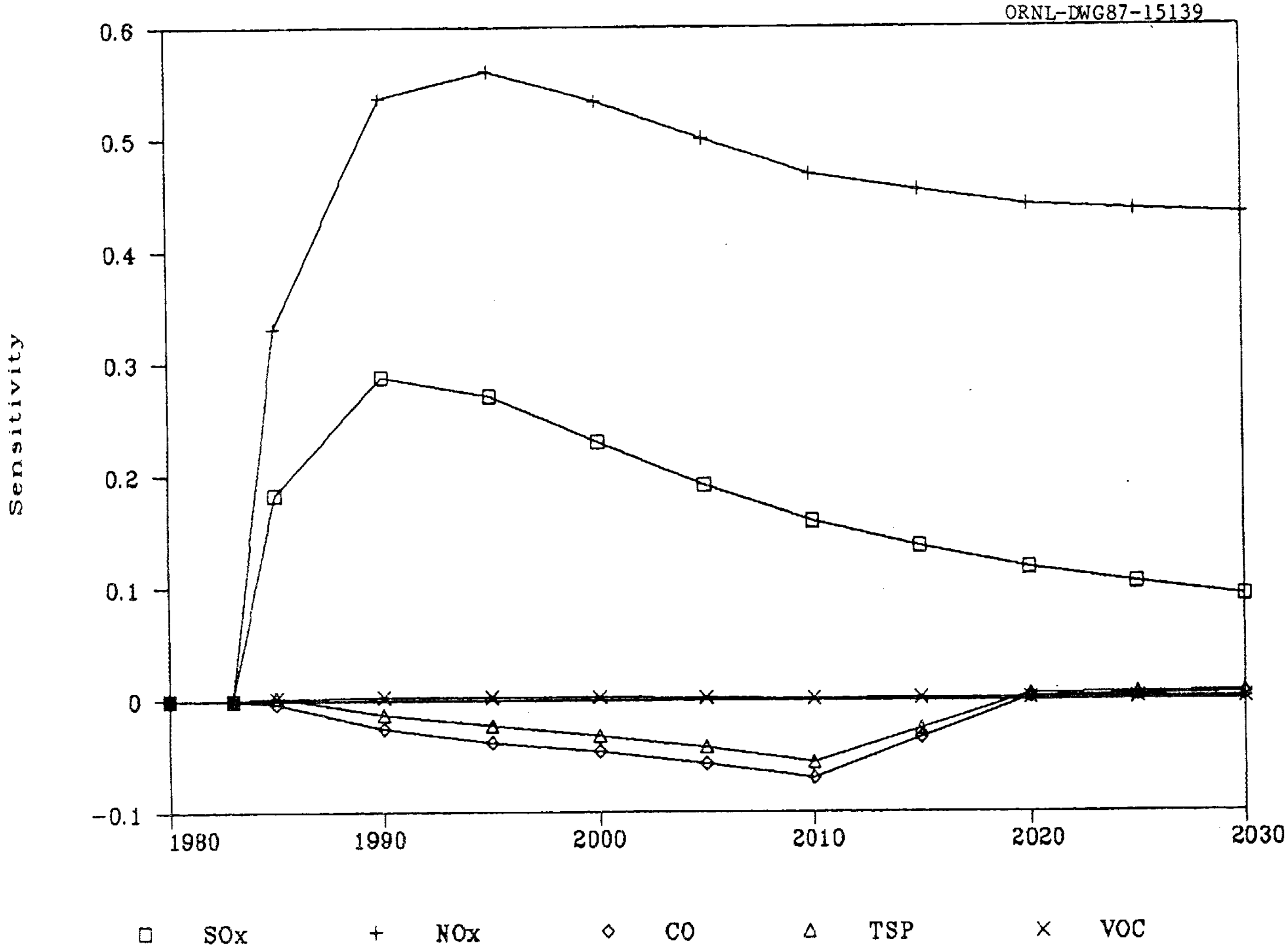

Fig. 20. Sensitivity of emissions to 1983 values for heating degree days (the 1983 value is used for the years 1893 to 2030.

VI. DISCUSSION AND CONCLUSIONS

Evaluation of sensitivity results is very much a subjective process. Factors which must be considered in assessing the importance of parameters include:

(a) The relative importance of specific results (e.g. is the 1990 value for SOx emissions more important than the 2030 value ?)

(b) The uncertainty in the value of the parameter (e.g. is the 2020 oil price projection "accurate" to within 50%?)

(c) The sensitivity of conclusions one draws from model results to the specific values of those results (e.g. how does the cost of mitigation vary with level of emissions).

This report has calculated sensitivities of emissions to the parameters that drive the CRESS system of models, but has not addressed any of the above considerations. The calculated sensitivities should act as a resource for users of CRESS to guide interpretation of the model's results.

Having given obeisance to the above considerations, we will now proceed to summarize the results of the CRESS sensitivity analysis by ignoring them. In the discussion and tables that follow, no particular preference is given to any parameter of result -- e.g. it is assumed that CO emissions in 2030 are potentially of as much importance as SOx emissions in 1990.

Table VI.1 lists the parameter sets which have been discussed, and, for each pollutant, its maximum sensitivity. This maximum may have occurred in any year; the reader is referred to the figures in Chapter V for the identity of the particular value which was the maximum. Besides the obvious driver parameters (e.g. prices; income; population), the list includes the modified sensitivity of the emission factor parameter from

Table VI.1. Maximum Sensitivities of Emissions to Driver Variables.

For each parameter, the sensitivity coefficient for with the highest magnitude in any time period is listed below. The parameters are those defined in the discussion and Figures. For example, "Electricity Price -- Short" gives the sensitivity of pollutant emissions to the price of electricity in the year 1990.

	SOx	NOx	CO	TSP	VOC
Electricity Price --Short	1.6E-03	1.6E-03	5.0E-03	4.4E-03	6.2E-05
Natural Gas Price --Short	6.4E-03	-2.3E-02	4.1E-03	3.6E-03	-1.8E-04
Oil Price --Short	-0.052	-0.021	3.5E-03	-2.7E-03	-7.0E-05
Kerosene Price --Short	-2.8E-03	-9.0E-04	1.0E-04	-1.6E-04	-2.6E-06
LPG Price --Short	-2.3E-06	-2.4E-05	-3.7E-04	-3.2E-04	-4.0E-06
General Fuel Price --Short	-0.044	-0.043	1.2E-02	9.6E-03	-2.4E-04
Electricity Price --Long	0.041	0.036	0.065	0.058	8.0E-04
Natural Gas Price --Long	0.104	-0.149	0.056	0.049	-1.1E-03
Oil Price --Long	-0.485	-0.159	0.042	0.017	-2.9E-04
LPG Price --Long	2.2E-05	2.2E-04	3.0E-03	2.6E-03	3.1E-05
Kerosene Price --Long	-0.039	-0.012	1.3E-03	-1.5E-03	-2.4E-05
General Fuel Price --Long	-0.348	-0.263	0.167	0.127	-1.2E-03
Minor Fuel Growth/Decline	-0.090	-0.019	-3.1E-03	-7.7E-03	-3.8E-04
Income	0.191	0.149	4.5E-03	1.5E-02	9.4E-04
Population	0.459	0.348	0.245	0.313	0.836
Housing Starts - 1990 only	7.0E-04	2.6E-03	3.1E-04	2.8E-04	1.7E-05
Housing Starts - All Years	0.027	0.099	6.3E-03	5.9E-03	4.1E-04
Housing Decay Rate	-0.030	-0.087	1.2E-03	-1.7E-03	-3.5E-04
Forest Acreage	0.011	0.266	0.610	0.525	0.121
Gasoline Sales	0	0	0	0	0.068
Heating Degree-Days	0.288	0.560	-0.070	-0.056	2.7E-03
Emission Factor Ratio	0.502	0.467	0.240	0.243	NA

MODEL6 (see Chapter II for discussion), and the minor fuel (i.e. mainly coal) exponential fuel decline parameter.

Table VI.2 lists the six parameters with the largest influence on each pollutant. The CO and TSP lists have been combined because the order of their most influential parameters was nearly identical. While the orders of the other lists vary, the same parameters appear in most of the lists. The emission factor ratio appears on all lists but that of VOC emissions, where it could not appear due to MODEL6's alternative treatment of emission factors[3] (see Chapter II). Population appears as an influential parameter in all lists, never being lower than third in any list. Heating-degree-days appears in all lists, and is the most influential parameter for NOx emissions. Recall, however, that it is not subject to ready alteration, its value is probably fairly well-known (relative to, say, oil prices in the year 2000), and that its response should be approximately 20% of that shown.

Fuel prices receive perhaps the most elaborate treatment of any of the projections driving CRESS. The effect of long-term general fuel price changes is the third or fourth most influential sensitivity in all the pollutant categories. Specific fuel prices appear in some of the lists. The price of oil has an important influence on SOx emission, with a sensitivity near -0.5. Short-term price excursions have only relatively small influences on emissions. While the sensitivity of emissions to fuel prices tends to be only moderate, it should be pointed out that projections of fuel prices are probably the more uncertain than other projections.

Table VI.2. Parameters with Greatest Influence on Pollutant Emissions.

For each pollutant, the six largest sensitivity coefficients are listed. CO and TSP are listed together, as the order of parameter importance is virtually the same for each (the last two elements of the TSP list, with nearly identical magnitudes, would be reversed).

	SOx
Emission Factor Ratio	0.502
Oil Price --Long	-0.485
Population	0.459
General Fuel Price --Long	-0.348
Heating Degree-Days	0.288
Income	0.191

	NOx
Heating Degree-Days	0.560
Emission Factor Ratio	0.467
Population	0.348
Forest Acreage	0.266
General Fuel Price --Long	-0.263
Oil Price --Long	-0.159

	VOC
Population	0.836
Forest Acreage	0.121
Gasoline Sales	0.068
Heating Degree-Days	2.7E-03
General Fuel Price --Long	-1.2E-03
Natural Gas Price --Long	-1.1E-03

	CO	TSP
Forest Acreage	0.610	0.525
Population	0.245	0.313
Emission Factor Ratio	0.240	0.243
General Fuel Price --Long	0.167	0.127
Heating Degree-Days	-0.070	-0.056
Electricity Price --Long	0.065	0.058

A number of the parameters appearing in Table VI.2 are ones that have been treated in a relatively simplified manner in CRESS. Forest acreage is the most influential parameter for three of the pollutant categories (VOC, CO, and TSP); in MODEL6, forest acreage is taken to be constant from 1980 to 2030. A significant portion of the influence of population derives from its direct use in MODEL6 as a driver variable. The heating-degree-day data has been previously mentioned. The emission factor treatment has been set up to be fairly detailed in MODEL6, but as yet, there is apparently little data projecting any future variation from current emission factor values.[3]

To this list might be added the exponential decline parameters for minor fuels, particularly coal. With a sensitivity of -0.09, it is the eighth most influential parameter for SOx emission. Projection of an exponential decline over 50 years is liable to result in a significant uncertainty in coal use in the later years of the model.

The parameters selected in this study were mainly those projections intended to drive the model, or variables resembling in some way driver projections. Most of these proved to have at least a moderate influence on emissions projections. One set of parameters which had only minimal influence were those related to housing stock. Both housing construction and housing attrition rates had only a modest influence on emissions, and furthermore, would tend to cancel each other's influence, under the plausible assumption that they are correlated.

A sensitivity analysis of CRESS has been carried out with the aid of an automated sensitivity analysis tool, GRESS. The automated analysis has assisted in examining and aggregating the extensive quantities of data processed by the model. A sensitivity analysis can't unaided verify the validity of a model or its input data. As such, this report is not a comprehensive review of CRESS, but should aid such a review by highlighting the responses to various input data sets. Ready access to a wide variety of responses in HOME2 (June '86 version), in fact, lead to detection and correction of errors in that version of CRESS's residential sector component and the generation of the present version. It is hoped that this analysis will aid the user's of CRESS in interpreting its results, and guide any future revision of the programs or data sets in the most fruitful direction.

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