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Sensitivity Analysis of the Commercial Energy Use Module of the "Commercial and Residential Energy Use and Emissions Simulation System" (CRESS)

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ABSTRACT

A sensitivity analysis of CSEM2, the commercial energy use component of Argonne National Laboratory's Commercial and Residential Energy Use and Emissions Simulation (CRESS) has been carried out using an automated sensitivity analysis tool developed at Oak Ridge National Laboratory. CSEM2 projects U.S. commercial sector energy use from a number of historical and projected economic and demographic parameters. The energy use projections from CSEM2 are used in later modules of CRESS to make projections of emissions for five fossil energy-related atmospheric pollutants. Sensitivities of commercial energy use projections to the various driver and control parameters are presented in this report.

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. An earlier report[2] details the analysis of the emission module. This report will concern itself with the commercial sector module, CSEM2. The purpose of this work is to determine the responses of CSEM2 to its various inputs and control parameters. This should be beneficial in several ways. It will highlight those factors which are of relatively more importance in determining the model's output, and those 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 behave; to the developers of the model, this may help determine whether the model functions as intended. The sensitivity values presented here are also of potential use in propagating sensitivity and possibly uncertainty through the CRESS system as a whole.

II. GRESS 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 consisting of a single program and its associated input and output files. For the purposes of using Oak Ridge National Laboratory's (ORNL) automated sensitivity analysis system (named GRESS -- an unfortunate coincidence of acronyms),[3] this separation is necessary. Automated coupling of sensitivities between program modules is under development, but at present must be done manually. This paper will discuss sensitivities in the commercial sector energy use module, CSEM2.FOR, on a stand-alone basis. The projections generated by CSEM2, along with parallel projections from the residential sector energy use module, HOME2, are used in the emission module to forecast pollutant emissions. Sensitivities derived from this study, in conjunction with similar results from HOME2, can be used to compute sensitivities of CRESS as a whole to its overall inputs.

The CRESS programs were 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. Both systems obstensibly operate the same version of FORTRAN, and no compatibility problems were encountered between the two implementations, as far as the CSEM2 module is concerned, other than the necessary alteration of the IBM JCL to the equivalent VAX DCL. The CRESS JCL was altered to preserve several intermediate data files which CSEM2 uses for input or output, and CRESS was run on the VAX 8600 for the "Reference" growth case (as opposed to the "High" and "Low" growth cases). The output of CSEM2 is written to a file named RESCOMMC.NTM, and consists of projections of annual energy use for 7 fuel categories in each of 4 regions for the period 1980 to 2030. This file is one of the temporary files discarded during normal operation on the IBM system, so the results of the VAX run could not conveniently be compared directly to the IBM runs at ANL. The overall CRESS output, however, was compared between the IBM and VAX versions, and agreed within the limitations of FORTRAN single precision accuracy, as described in Ref. 2.

CSEM2 was adapted from CSEM, a model developed and used by the Energy Information Administration.[4] 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.[5] The ANL adaptation of CSEM extends the time horizon to 2030, discards some unneeded output, and makes some minor structural changes to accommodate the needs of CRESS.

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. 4.

It is instructive to compare the CSEM2 fuel use projections with similar estimates from other sources. The 1985 NEPP study[6] lists projections for commercial sector energy use through 2010. The 1980 and 2010 estimates from NEPP are compared to the CSEM2 reference case, which was the basis of this sensitivity study, in Table 1. CSEM2 predicts somewhat more electricity use and correspondingly less natural gas use than does NEPP; the overall energy use estimated for 2010 is quite similar between NEPP and CSEM2.

Table 1. Comparison of CSEM2 output with 1985 NEPP commercial energy use projections[6]

	COMMERCIAL ENERGY USE (QUADS)			
	1980		2010	
	CSEM2	NEPP	CSEM2	NEPP
All	5.9	6.0	8.7	9.4
Liquids	1.3	1.3	1.4	1.4
Gas	2.7	2.7	2.6	3.3
Coal	.09	.1	.09	.1
Elec.	1.9	1.9	4.6	3.7
Renew.	NA	.0	NA	.9

The sensitivity analyses reported here focus on both the exogenous projections which are intended to drive the model, namely the fuel prices, disposable income, population, and the various forecasting coefficients which control and calibrate the model. It is recognized that the values of these forecasting coefficients are correlated, and that a recalibration which would alter the value of one parameter would also alter the values of many others. The same is no doubt true of the projections for fuel price, population and disposable income. Within the framework of the CSEM2 model itself and its existing data, a sensitivity analysis will only examine and reveal those responses which formally exist in an algebraic sense in the code.

CSEM2, like many econometric models, uses and projects the time evolution of variables of interest based on their ratios to base year values. For this reason, data arrays which represent the base year values for variables of interest were not examined.

The majority of parameters examined here are read from input files. A few are contained directly within the source code. The variables examined in this study are listed in Table 2.

Table 2. Listing of CSEM2 parameters for which sensitivities have been examined.

File Name	Variable	Description	
		Fuel prices	
COMEXOG:	PEL	Electr.	each:
	PNG	Gas	(4 Reg x 51 Years)
	PDS	Dist Oil	
	PRL	Resid Oil	
	PKS	Kerosene	
	POP4	Population	(4 Reg x 51 Years)
	DPI4	Disposable Income	(4 Reg x 51 Years)
FCOEFS:	FS	Floor space forecast coefficient (4 Regions x 6 Building Types x 2 parameters (Pop & Inc))	
TCOEFS:		Price Elasticity (6 Bldg Types)	
	PARMEL	Electricity	
	PARMNG	Gas	
	PARMFO	Oil	
Internal to Source Code		Growth/Decline Rate	
	GRWMG	Gasoline	(4 Regions)
	GRWLG	LPG	
	GRWCL	Coal	
	(Numeric)	Lag exponent for price response (3 fuels)	

II.1 Gress

GRESS ("Gradient Enhanced Software System"[3]) -- 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.

Aside from the modification and recompilation required, there is typically a CPU-time penalty associated with running a GRESS-enhanced program. In the case of CSEM2, the enhanced version required about 12 times as long to run as the original version. Typical factors for other programs are 10 to 30; the low factor in CSEM2 is due to the fact that it is not particularly computation-intensive.

GRESS as presently formulated is nearly compatible with FORTRAN-77 standards. A recent addition in this direction which aided the present study significantly is the ability to process arrays up to the FORTRAN-77 limit of 7 dimensions. 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.

Typically, the procedure for utilizing GRESS on an existing model 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.

Compatibility problems proved to be minor. Changes required to CSEM2 included reordering TYPE and COMMON statements (per a not-always-honored FORTRAN-77 standard) and replacing CHARACTER type declarations with similar length REAL declarations.

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. In this comparison, the results were not identical between the two versions, but none of the 1785 numbers output in the file RESCOMMC.NTM differed by more than 5.9 ppm from their original value, which is within round-off error for single precision in FORTRAN.

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. In this case, the parameter used for the perturbation analysis was FS(2,2,2), a forecast coefficient for North Central region institutional building floor space based on population. Normalized sensitivities of national and regional fuel use in 2030 to this parameter were calculated for each of 7 fuels using both GRESS and by imposing a +1% perturbation upon FS(2,2,2). The results, displayed in Table 3, show excellent agreement.

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; in all cases, the perturbation results were consistent with the GRESS results.

Table 3. Comparison of GRESS vs. perturbation sensitivities of fuel use to FS(2,2,2), forecase coefficient for estimating floor stock additions to building type 2 in region 2 based on regional population.

	Sensitivity (Q-USA)		Value	Sensitivity (Q(NCent)		Value
Fuel	GRESS	Perturbed	Q(USA)	GRESS	Perturbed	Q(NCent)
All	0.002310	0.0023172	9034.6621	0.011034	0.0110366	1891.3476
LPG	0	0	38.739563	0	0	12.755708
Gsln	0	0	84.066055	0	0	48.805462
Oil	0.001493	0.0015030	980.36718	0.015470	0.0155866	94.587242
Gas	0.002429	0.0024319	1860.4649	0.007064	0.0070639	639.64782
Coal	0	0	71.7883	0	0	26.66577
Elec	0.002482	0.0024786	5999.2358	0.013928	0.0139231	1068.8856

In addition to compatibility modifications, a modest amount of code must be added to the model to specify and extract the sensitivities of interest. The general techniques and requirements for doing this are discussed in Refs. 2 and 3 and will not be repeated here. Some discussion is in order, however, regarding specific tactics used extensively in this study.

In this study, the sensitivities (S) of a result (Q) with respect to a parameter (P) are normalized to their base values (Qo and Po), namely:

$$S = \frac{\partial Q/Qo}{\partial P/Po} \qquad (1)$$

The sensitivity is thus dimensionless. This is a convenient form to study variables whose values change essentially by multiplication or exponentiation, as is the case in CSEM2. 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 partial derivatives, and no change in the parameter (P) is actually made during the calculation of the sensitivity.

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 study. Since the time-evolution of energy use is the primary theme of CSEM2, all the sensitivities reported here have been calculated for each time period to exhibit the time-evolution of responses of the model.

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 the next), and also elements that are intended to control the model (i.e., internal parameters which calibrate the response of the functions used to make projections). Both classes of parameters exist in arrays of varying dimensions. For example, the variable FS (the Floor stock projection parameter) has 48 components, one for each of 6 building types in each of 4 regions as influenced by both regional population and disposable income.

The influence of any one member of such an array is likely to be quite small on national totals, and in perturbation analyses may be lost in the round-off error inherent in the single precision arithmetic used in CRESS. Because of the difficulty of comparing GRESS-generated sensitivities (calculated to single or double precision) in perturbation-generated sensitivities (which may contain significant round-off error), and again to create a tractable number of analyses for the study, most of the responses were calculated by use of aggregation parameters. In this technique, the computer code is modified to multiply each initial definition of a parameter which belongs to the aggregate group by an aggregation parameter which has been given a value of "1.0". Conceptually, for a parameter array, P, the following code would be added:

```
          A = 1.0
          DO 100 I=1,10
          P(I) = P(I)*A
    100   CONTINUE
```

The gradients and sensitivities of the final results are then taken with respect to the aggregation parameter. The effect is to determine the sensitivities of the results with respect to proportional changes in the magnitudes of the entire aggregate group.

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 the parameter P, it would be multiplied by A only in a single time period. The resulting sensitivities emulate the response of the model to a "pulse" or "square-wave" perturbation in P. The corresponding long-term behavior can be obtained by multiplying P by the aggregation parameter in all periods after a certain date. The calculated sensitivities in this case emulate the response to a "shock" or "step-function" perturbation to (P). These techniques are very useful in examining sensitivity of the model to time-projections of, for example, fuel price or population.

III. RESULTS

The first class of parameters which will be discussed are the exogenous projections of population, disposable income, and prices for 5 fuels. Each projection, read from the file COMEXOG.NTM, contains values for each of four U.S. regions (Northeast, North Central, South, and West) in each year from 1980 to 2030.

III.1 Fuel Price

Price response is intentionally lagged to reflect the slow rate of capital stock replacement. Price sensitivities therefore are examined both for short-term and long-term responsiveness to sample price excursions beginning in 1990 by the method described in the previous section. In all cases shown here, price response has been aggregated across all regions.

Figures 1 through 6 display the sensitivity of fuel use to the price of the indicated fuel in 1990 (i.e., these figures show the response of the model to a short-term price excursion in 1990). Figures 1 through 5 display the response to price of one of the 5 fuels for which prices are used within CSEM2 (distillate oil, residual oil, kerosene, natural gas, and electricity). In all cases, the sensitivity is quite small (on the order of -0.05 to -0.1), but persists for many years. The largest effect of price of a particular fuel is to the use of that fuel, as one would expect. Net conservation is reflected in the response of total fuel use (i.e., "All" in the figure keys). 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.

Figure 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. In this chart, all fuel prices effectively increase by the same proportional amount, so that all price ratios will remain the same, and fuel switching should be eliminated. The remaining response is the inherent fuel conservation. Again, the response is small but persistent, as before.

Long-term price response was examined by calculating sensitivity of use to all prices in or after 1990. Figures 7 through 12 thus display the equivalent of a response to a step increase in price in 1990. The response to individual fuel prices (Figs. 7-11) slowly grows to reach substantial values, on the order of -1 for gas, for example, by 2030. Distillate oil, residual oil, and kerosene have somewhat lower sensitivities individually, but this is because each comprises only a part of "oil", which is not distinguished by type in the output file. The sum of the three sensitivities is comparable to that for natural gas. The components of oil respond more quickly than do the other fuels due to their having a different value for their lag parameter.

Figure 12 displays the response of the model to a general price increase in 1990 (and thereafter). As in Fig. 6, this demonstrates the price-induced energy conservation predicted by the CSEM2.

Overall, the price responses of CSEM2 reflect the intent and design, as reflected in the documentation.[4] 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.

III.2. Population

Figures 13 and 14 display the sensitivity of energy use to post-1989 population. Unlike price response, the population response of the model is immediate, and its magnitude does not vary a great deal over time. There is a considerable variation in the response when examined on a regional or fuel-category basis. Figure 13 illustrates the regional variation. The sensitivity to population ranges from zero (for the Northeast region) to 2.5 for the South, with the West and North-central regions being about 0.4 and the USA as a whole having a sensitivity of about 1.0. This variation is the result of the data values in the array "FS".

FS is read from the file FCOEFS and dimensioned to contain values for (6 building types) x (4 regions) x (two indices -- population and income). Each value of FS is used in an equation which predicts the current floor stock (from which energy use is later estimated) as follows:

$$\frac{\text{FloorStock(Reg,Bldg,t)}}{\text{FloorStock(Reg,Bldg,t-1)}} = \left(\frac{\text{Pop(t)}}{\text{Pop(t-1)}}\right)^{\text{FS(Reg,Bldg,Pop)}} \times \text{(Income factor)} \qquad (2)$$

where the "income factor" represents a similar expression for disposable income. The FS values thus are the elasticities of the floor stock with respect to population. The values of these range from zero to over 10 (North Central hotels), with typical values being between 0.5 and 2.5. Most of the entries in the South lie between 2 and 3: hence its large response. The Northeast region has no entries (in effect making them equal to zero) which accounts for that region's insensitivity to population. The CSEM documentation[4] indicates that the values for the FS parameters (both population and income) were derived from a regression of historical data to the assumed equations, with values having counter-intuitive signs being set to zero. The values thus, in aggregate, represent the best statistical fit of the historical data to the model used, though in detail some of the values may seem counter-intuitive.

Figure 14 displays the response of fuel use, by fuel, to population, the results being aggregated over all regions. 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.

III.3 Disposable Income

Disposable income is used in a manner identical to population to estimate floor stock. It likewise shows marked regional differences in its influence on energy use projections. Figure 15 displays the sensitivity of total regional fuel use to post-'89 regional disposable income (i.e., the equivalent of the effect of a permanent income increase in 1990). As with population, the influence is immediate and permanent. The sensitivities range from a low (in the South) of around 0.25 to a high (in the Northeast) of about 1.0. Again, these sensitivities are directly due to the values of the FS array.

Figure 16 illustrates the effect on national fuel use of disposable income. 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 a year). The income/population sensitivities displayed in Figs. 13 through 16 are for a single model scenario. The calculations done were conducted only for the reference case population and income projections, which generally increase through time. What would happen if income or population declined faster than building attrition was not directly explored, but a cursory examination of the relevent section of the CSEM2 source code suggests that the response would not change from what has been determined here. That in effect implies that population and income changes, including large declines, influence only the newer vintage of buildings. For example, during a recession, the newer (post-'74) buildings would be taken out of service, and the attrition of the older stock would not change.

III.4 Floor Stock Forecast Coefficients

As discuss above, commercial floor space in a given year, building category, and region expands and contracts with population and income at a rate determined by the "FS" array, the floor stock forecast coefficients. Figures 17 through 22 examine the sensitivities of energy use to these values from several viewpoints.

The general influence of FS values can be seen in Fig. 17, which depicts regional fuel use sensitivity to regional population forecast coefficient, aggregated across all building classes. The sensitivity is zero through 1982, when historical data is used rather than projections. Thereafter, the sensitivity grows as the regional population grows, with the magnitude of the sensitivity proportional to the weighted average value of the FS parameters. In the Northeast, the FS parameters are all zero, so the normalized sensitivity is zero. The South, on the other hand, has the largest values for its FS population parameters, and consequently its sensitivity is large, exceeding 0.8 by 2030.

Figure 18 illustrates the effect on total fuel use of the floor stock/population coefficients for each building class, aggregated over all regions. The magnitudes reflect both the fuel use shares of each of the building classes (with retail, warehouse, and office classes dominating) as well as the magnitude of the forecast parameters. Figure 19 displays the sensitivities of the use of individual fuels to FS population parameters aggregated over all building types and regions. The overall influence grows in time to values ranging from 0.2 to 0.4.

The floor stock/income forecast coefficients' influence similarly grows with increasing disposable income. The overall sensitivity of fuel use to this parameter aggregated over all regions and building classes (Fig. 20) reaches 0.7 by 2030. Significant regional differences (shown in Fig. 21) in sensitivity are due mainly to the base values of the FS parameters which are significantly lower in the South than in other regions. Regional differences in income also influence this, but not to a great degree, as their values for the four regions do not vary greatly (on a logarithmic scale). In Fig. 22, building class response differences are illustrated: "office" and "retail" elements of FS(income) have the strongest influence on overall fuel use.

III.5 Price Elasticity and Lag Parameter

Price elasticity and lag parameters influence energy use per unit area of floor space via the equation:

$$\frac{U(t)}{U(t-1)} = \left(\frac{P(t)}{P(t-1)}\right)^{Es} \left(\frac{U(t-1)}{U(t-2)}\right)^{(1-Fl)} \qquad (3)$$

where U is energy use per unit area of floor space, P is fuel price, Es is short-run elasticity and Fl is a lag fraction. This equation will result in the short-term (one-period) response to a permanent price change being that given by Es, with the eventual long-run response to that price change being given by (Es/Fl).

The relation between the short-run elasticity, Es, directly used in the model and the long-run elasticity, El, which was derived from a statistical fit of historical data, and the assumed lag fraction value (0.035 for electricity and gas; 0.08 for oil) is defined by:

$$Es = Fl \times El$$

For electricity and natural gas, the short-run elasticity is further reduced by 10%. This additional reduction will also reduce the long-term responses by 10% from that which would apply if the statistically derived elasticities were directly used.

The small values of Fl account for the very slow response to price seen above (time constants for response to oil price of about 12 years and to other prices of about 30 years). Separate values of price elasticity and use are defined for each of the three fuels (oil, gas and electricity) in each of the building classes. The sensitivity of energy use (by fuel) to price elasticities, aggregated over building classes, is displayed in Fig. 23. The responses shown by the three curves reflect the trend in the change of fuel prices through time. Oil prices fall early in the reference scenario, but eventually rise, accounting for the change in sign of the oil sensitivity. There is little sensitivity of use to electricity price elasticity because electricity prices change little over the time horizon of the scenario examined. Oil and gas prices, in contrast, change significantly, and the plotted sensitivity reflects this. By 2030, the sensitivity of the results to price elasticity for oil and gas is significant, with values on the order of -1. There were no cross-price elasticities overtly contained in the model, and the price elasticity variables exhibited no (non-zero) cross-price sensitivities.

The lag fraction, defined by "Fl" above, is "hard-wired" into CSEM2, and is not designed to be either a data input element (as are, for example, price projections) or a calibration parameter (as are price elasticities). It does have a significant influence on the character of the model, and it was therefore examined. CSEM2 was modified to treat the lag exponents (Fl in Eq. 3, above, one for each of three fuels) as variables. The sensitivities of fuel use to each were examined and the results are plotted in Fig. 24. The sensitivity of a lag parameter reflects the change in use that would occur if the parameter Fl were larger in magnitude, i.e., if the model's time response were incrementally more rapid. In general, fuel prices rise, and thus more rapid response leads an earlier reduction in use. For electricity, the response is minimal because electricity prices change little. For oil and gas, the effect is more marked, with sensitivities reaching -0.3 and -0.6, respectively, by 2030.

III.6. Minor Fuel Decline Parameters

CSEM2 tracks eight sources of energy, but only five, electricity, gas, and oil (which includes contributions 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, namely

$$Use(t) = Use('80) \exp(G t)$$

The use of these minor fuels is thus sensitive only to time (t) and the parameter G (variable arrays GRWCL, GRWMG, and GRWLG in the FORTRAN source code). Sensitivities of fuel use to these decline parameters, G, aggregated over all regions, are displayed in Fig. 25. Most of the values of G are negative, and consequently sensitivities (to a magnitude change in G) are negative. G for gasoline in the North Central region, however, is positive. Eventually exponential growth in that one region dominates the decline in the other three regions, which accounts for the sign reversal of the gasoline sensitivity. Extending an exponential projection originally intended for a 10-year time horizon to one of 50 years will probably lead to unreasonable behavior in the internal regional detail of the model's projected minor fuel use. In aggregate, however, total fuel use will not be seriously affected by the slight contributions from these minor fuels. The values of the growth parameters are imbedded in the source code as data statements, and are not intended for or readily accessible to modification.

IV. DISCUSSION AND CONCLUSIONS

A sensitivity analysis of the CSEM2 component of CRESS has been carried out with the aid of an automated sensitivity analysis tool, GRESS. The automated analysis assists in examining and aggregating the extensive quantities of data processed by the model. A sensitivity analysis can not unaided verify the validity of a model or its input data. As such, this report is not a comprehensive review of CSEM2, but should aid such a review by highlighting the responses of CSEM2 to its various input and calibration parameters.

Within the framework of the model design, sensitivities computed have identified the important contributors to projected commercial fuel use, and in particular, have highlighted the time evolution of the responses to influential parameters.

Identification of the "most important" parameters in a model such as CSEM2 is somewhat subjective, depending strongly on what one considers to be the primary "result" of the model. This study has already been considerably restricted in that it examines only the reference economic growth case, and has aggregated most of the parameters that have been examined to some degree. The output of CSEM2 consists of projections of fuel use in six categories plus their total, and these categories (after apportioning by the regionalization module of CRESS, REGION.FOR) are read into the emissions module (MODEL6.FOR). The earlier examination of MODEL6[2] demonstrated that the separate fuel categories differ markedly in their influence on emissions. With these factors in mind, the results of interest here are national energy use projections, categorized by fuel type.

The parameters examined in this study can be categorized into extrinsic projections (fuel prices, population, and disposable income) and intrinsic parameters resulting from judgment or statistical fitting of model equations to historical data.

Of the projections driving the model, all can have significant influences on fuel use (i.e., sensitivities range from 0.5 to 1.3). Population tends to have the strongest influence and income a somewhat smaller effect. The effect of a change in a value of either projection in a given year occurs immediately. The response to such a change varies considerably across regions and building classes.

Long-term effects of permanent fuel price changes are also significant, with sensitivities (i.e., effectively the long-term elasticity) to a permanent price change eventually growing in magnitude to the order of minus one. Prices influence fuel use only for a subset of fuels. The fuels whose behavior is influenced are electricity, natural gas, and fuel oil. Motor gasoline, coal, and LPG are "immune" to prices: they are estimated by a simple (usually declining) exponential.

Of those fuels which are influenced by price, the responses all appear sensible and intuitive, though quite slow. A fuel price rise has a depressive effect on that fuel's usage, and smaller stimulative effect on substitutes. That is, there are both conservation effects and fuel switching effects. Price-induced fuel switching occurs mainly through a slow fuel chioce effect which occurs with attrition of equipment or buildings.

Short-term response is much smaller than long-term, as indicated by the model documentation. Thus, the response of the model to a temporary price change is not significant compared to the response to income or population.

Of the intrinsic parameters which are used to calibrate the behavior of CSEM2, the most important are the parameters which control use of the above income, population and price projections, namely the floor stock forecast coefficients and the price elasticities. In the scenario studied here, the price elasticities had the largest influence on fuel use (sensitivity ranging from -0.1 to -1.1), the income/floor stock parameters were of comparable influence (0.5 to 0.8) and the population/ floor stock parameters slightly lower (0.2 to 0.4). Because of the model design, the values of the sensitivities are strongly dependent on the ratio of the projection variable to its base year value [e.g., population (2030): population (1980)]. The order of importance listed here reflects this: disposable income and fuel prices are projected to increase more than population. In other scenarios, the order could thus change; all are important to the model results.

Other intrinsic parameters examined showed smaller, but significant influences on fuel use projections. The price response lag parameters' sensitivities ranged from -0.1 to -0.6, the spread being a reflection of the difference in anticipated price increases among the fuels considered. The minor fuel growth parameters exhibited sensitivities to their fuel category ranging from +0.1 to -0.4. The minor fuels comprise, however, only a very small fraction of total fuel use, so that their overall influence is minimal.

CSEM2, as a whole, appears to behave as its designers intended. While further aggregation (say, of all building classes) is always possible, no obviously profitable opportunities for simplification were highlighted by this analysis. The parameters examined all had at least a moderate influence on the projected fuel use.

Many potentially interesting and important relationships are implicit in the input data to CSEM2 and to CRESS as a whole and thus will not be revealed by this type of analysis. For example, national disposable income certainly is influenced by population. That relationship, however, will not appear in this analysis, or in the analysis of any other part of CRESS, because both population and disposable income projections are exogenous to CRESS. The influence of population that is explicitly modelled in CSEM2 can, however, be propagated through the emissions module[2] of CRESS to determine its explicit influence on CRESS' emission projections. It is intended that this will be done on completion of the analysis of the three major modules of CRESS (CSEM2, HOME2, and MODEL6), and documented in a later report.

ORNL-DWG 87-6015

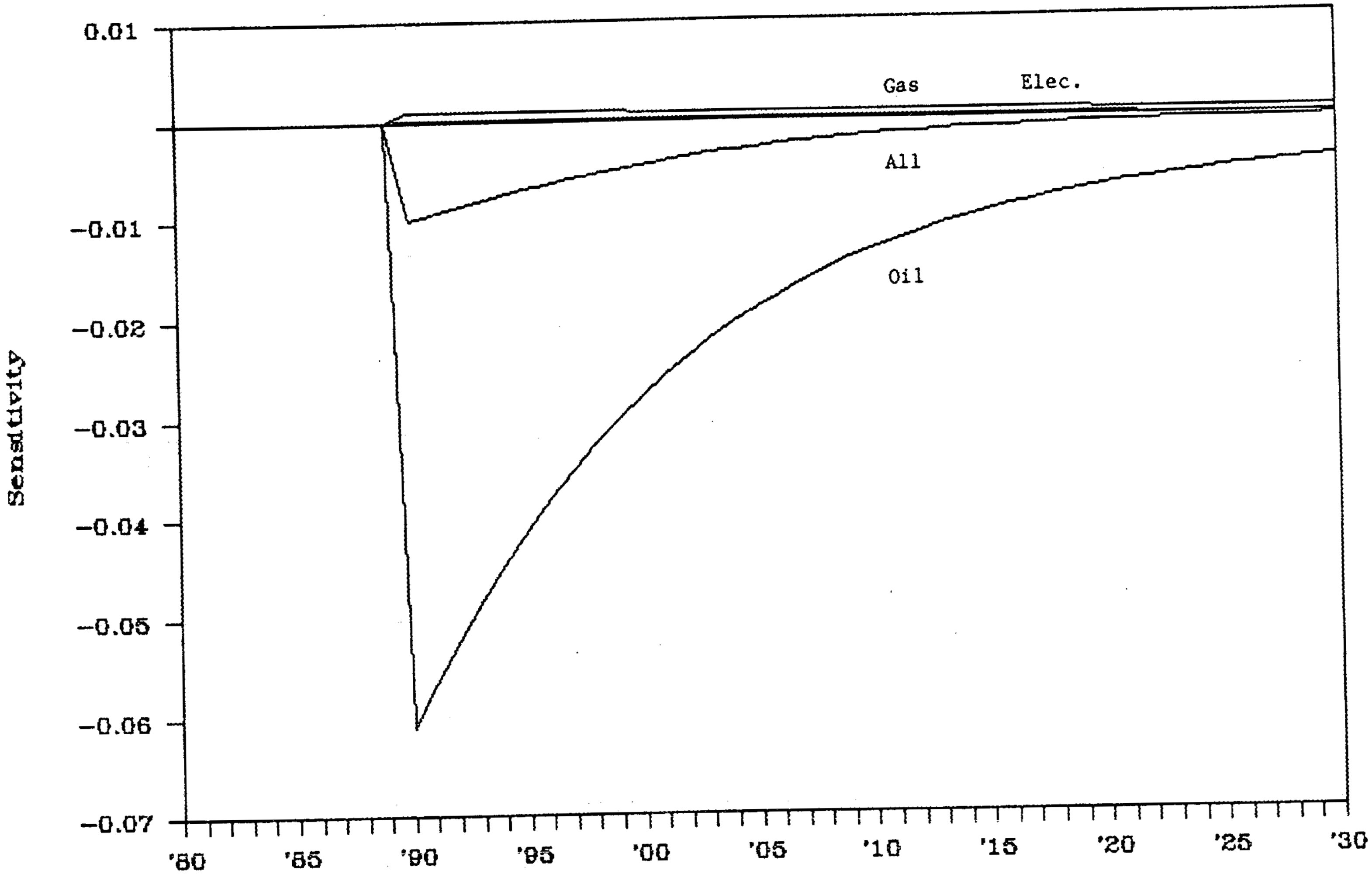

Fig. 1. Sensitivity of fuel use to 1990 price of distillate oil.

ORNL-DWG 87-6016

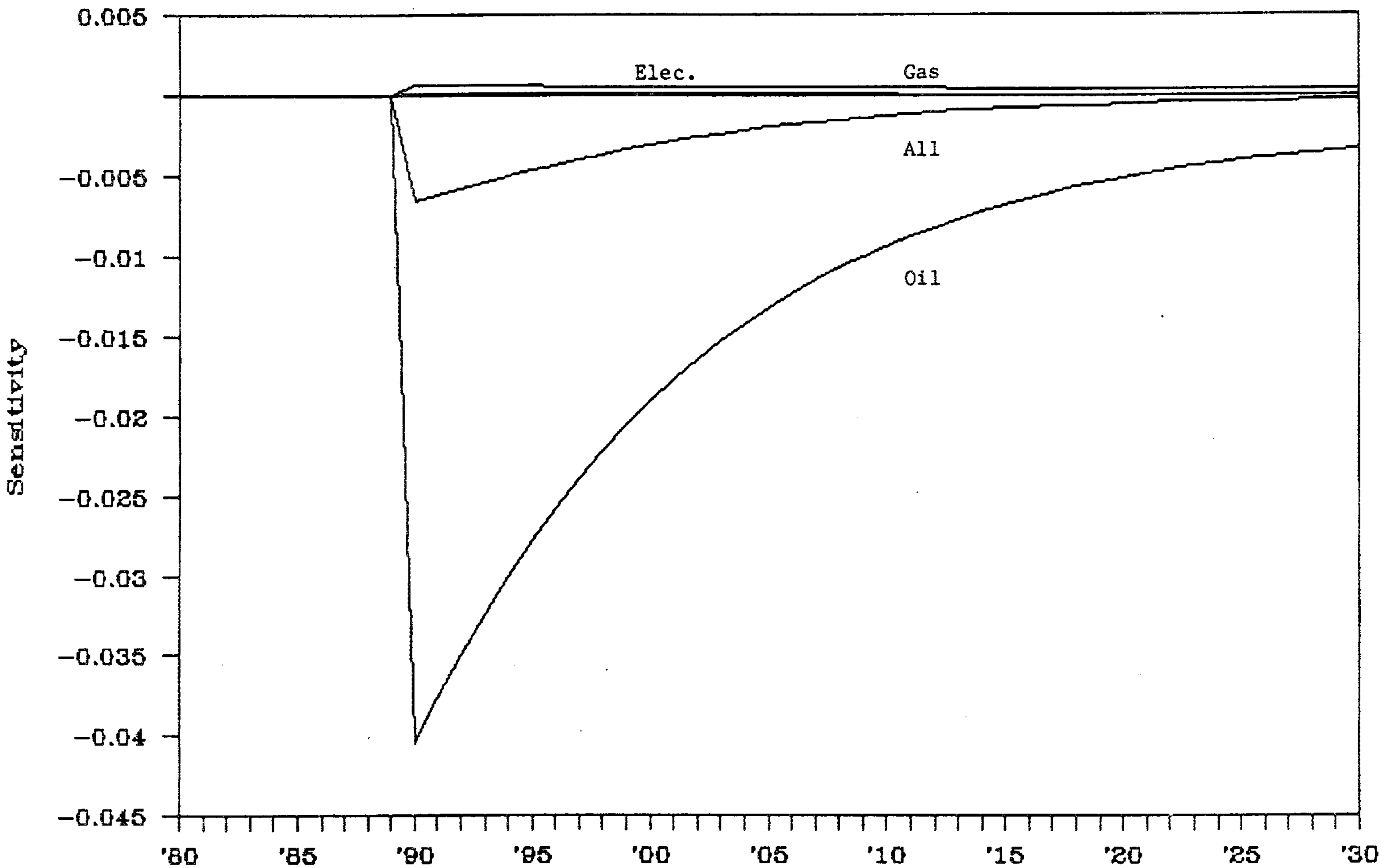

Fig. 2. Sensitivity of fuel use to 1990 price of residual oil.

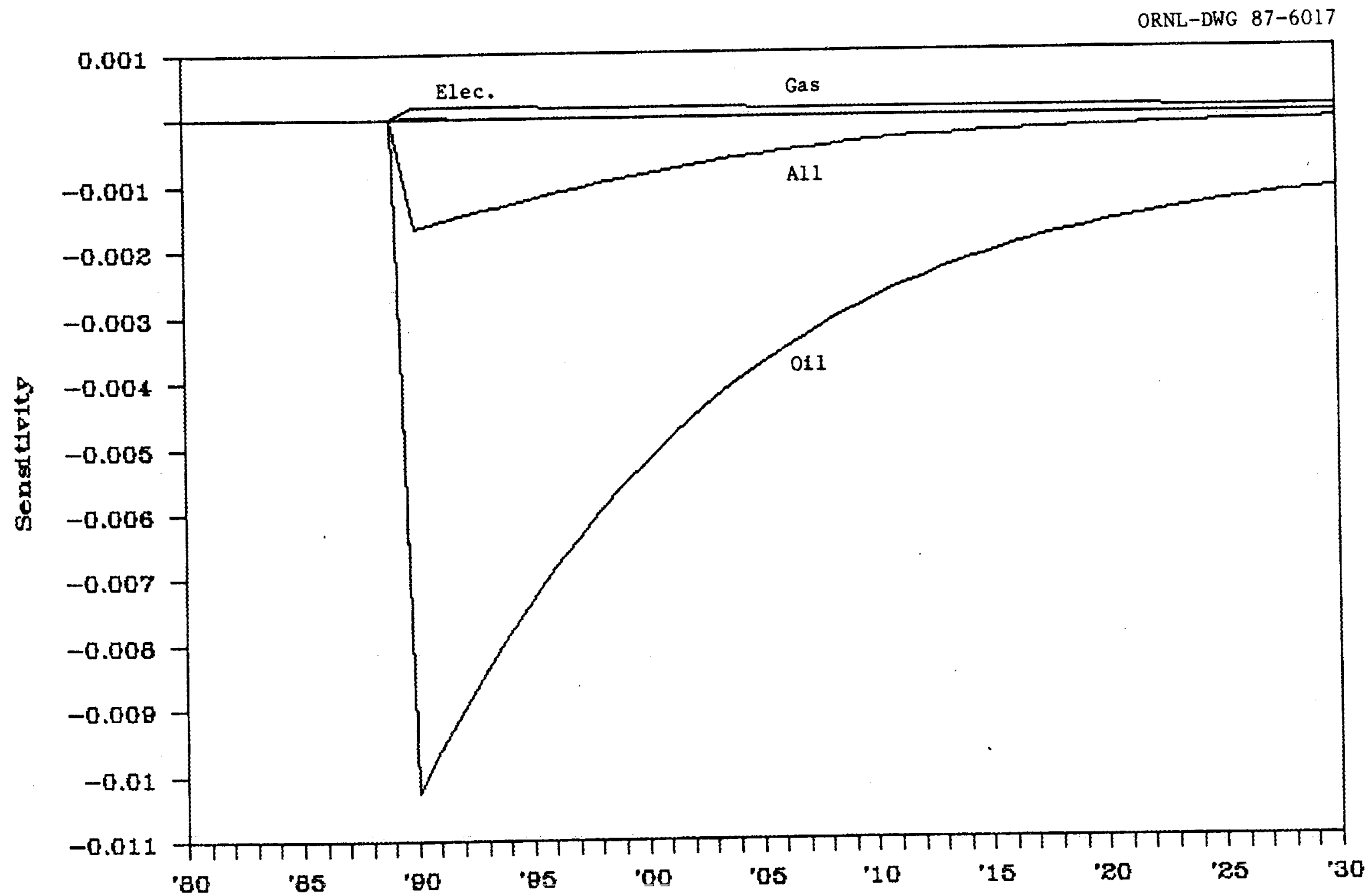

Fig. 3. Sensitivity of fuel use to 1990 price of kerosene.

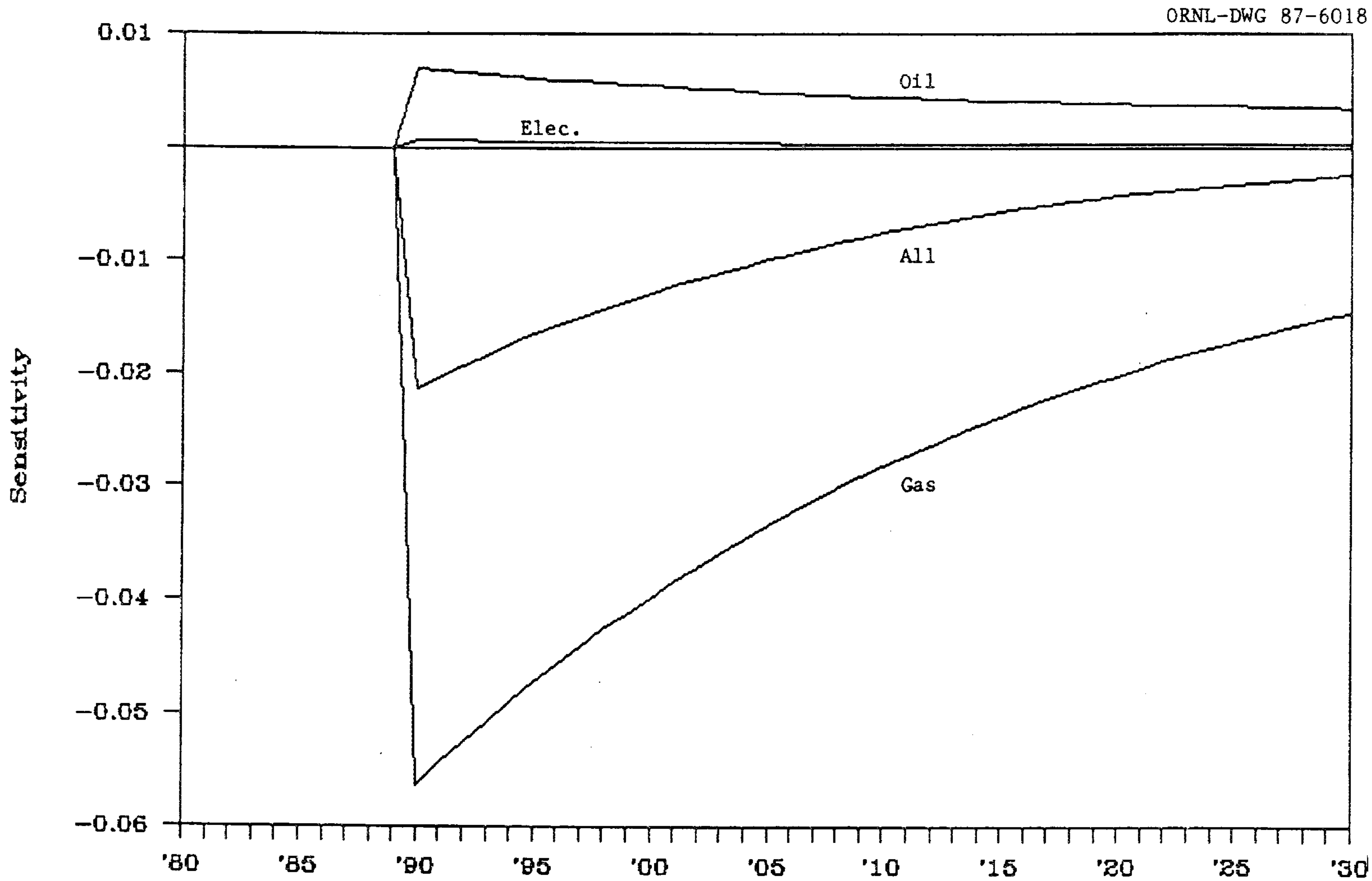

Fig. 4. Sensitivity of fuel use to 1990 price of natural gas.

ORNL-DWG 87-6019

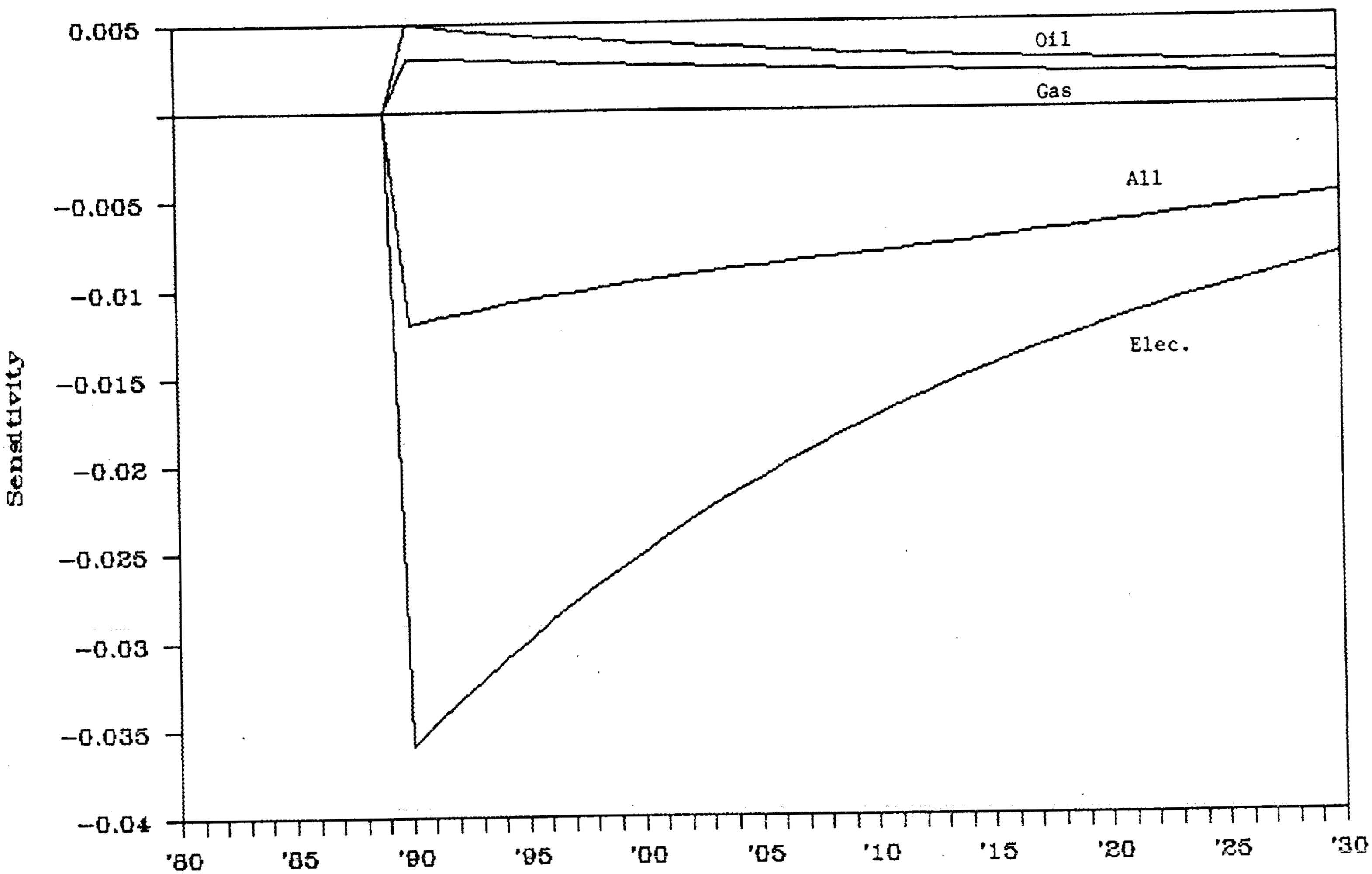

Fig. 5. Sensitivity of fuel use to 1990 price of electricity.

ORNL-DWG 87-6020

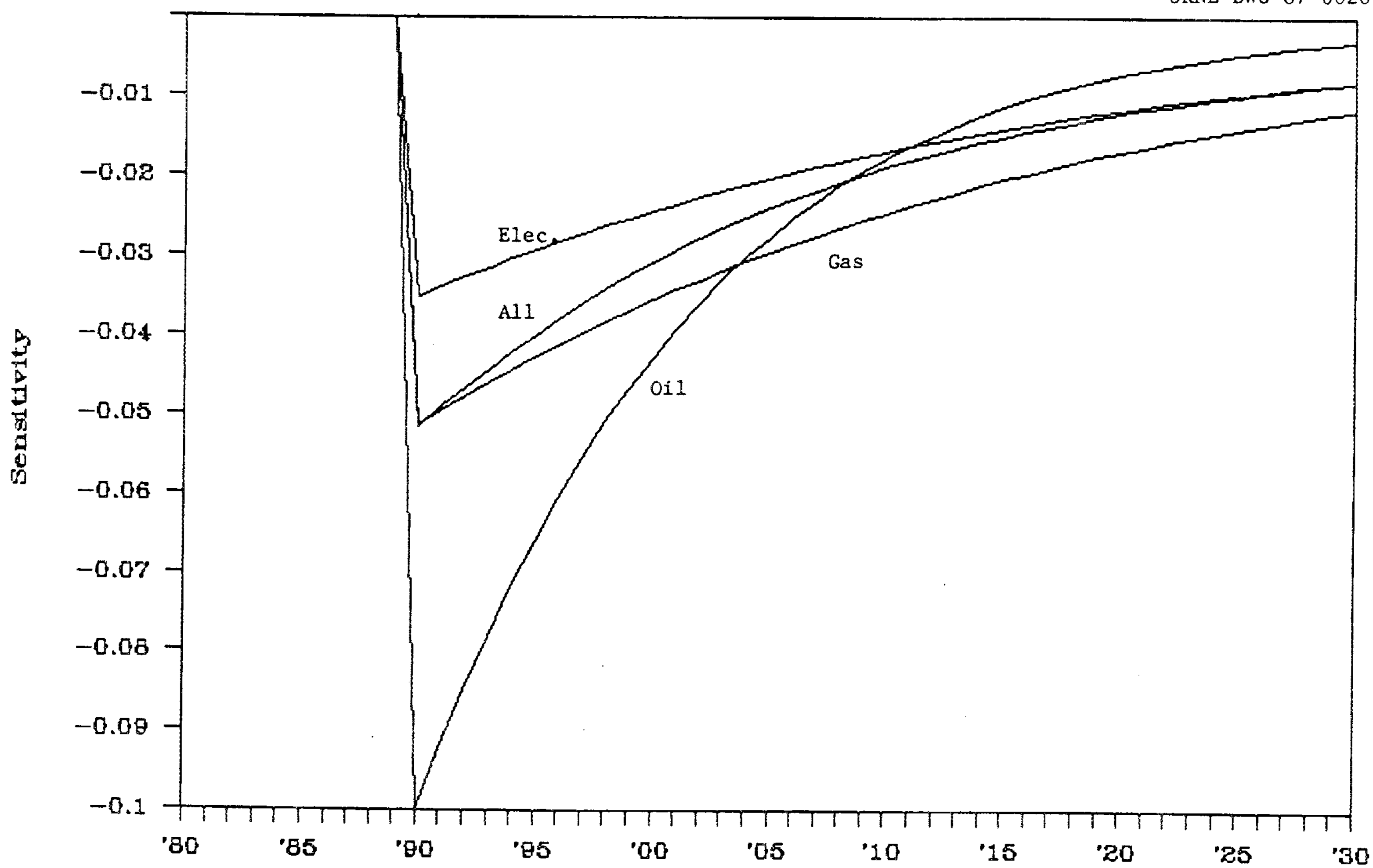

Fig. 6. Sensitivity of fuel use to 1990 price of all fuels, i.e., to a general price change.

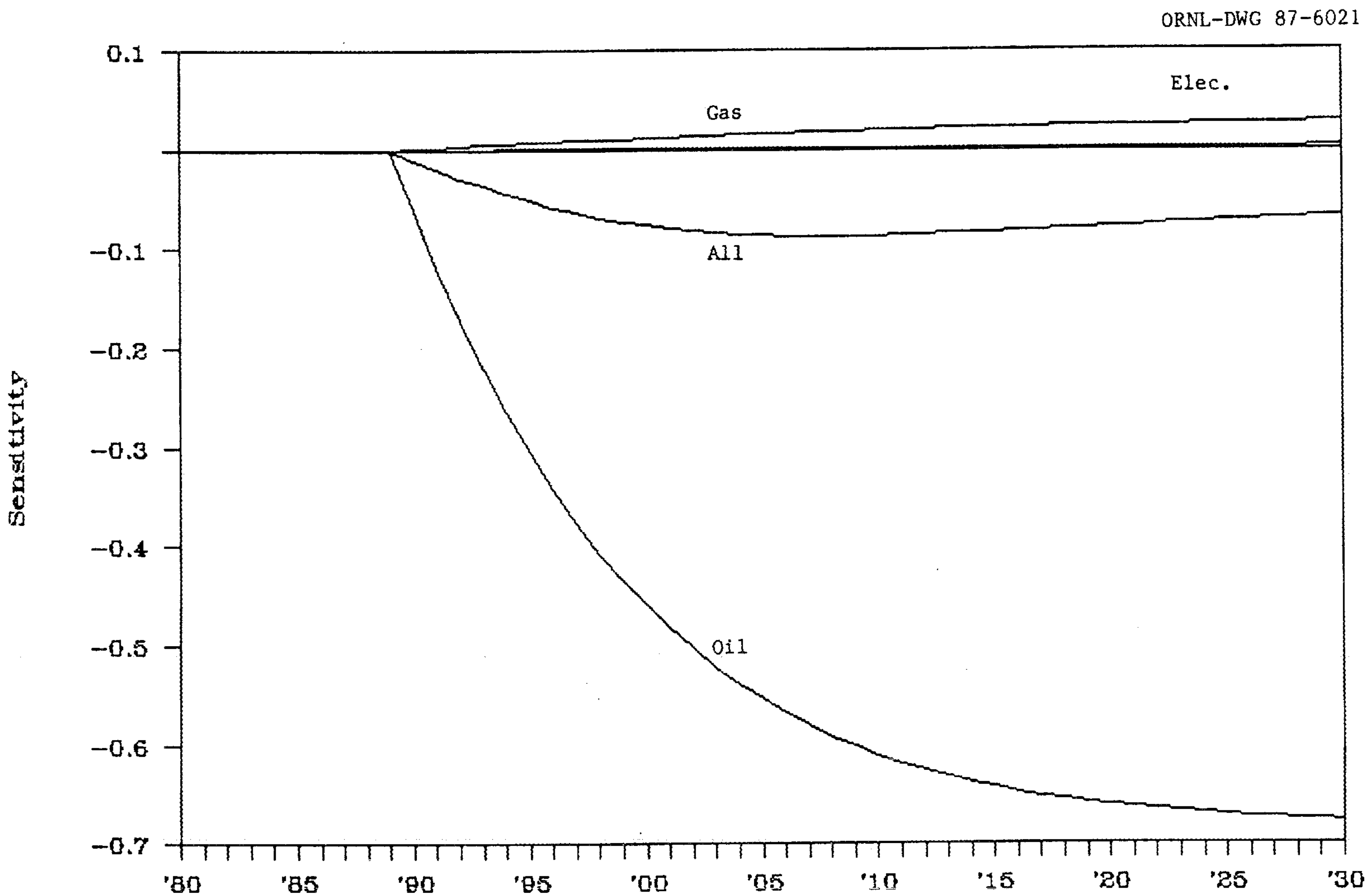

Fig. 7. Sensitivity of fuel use to post-1989 price of distillate oil.

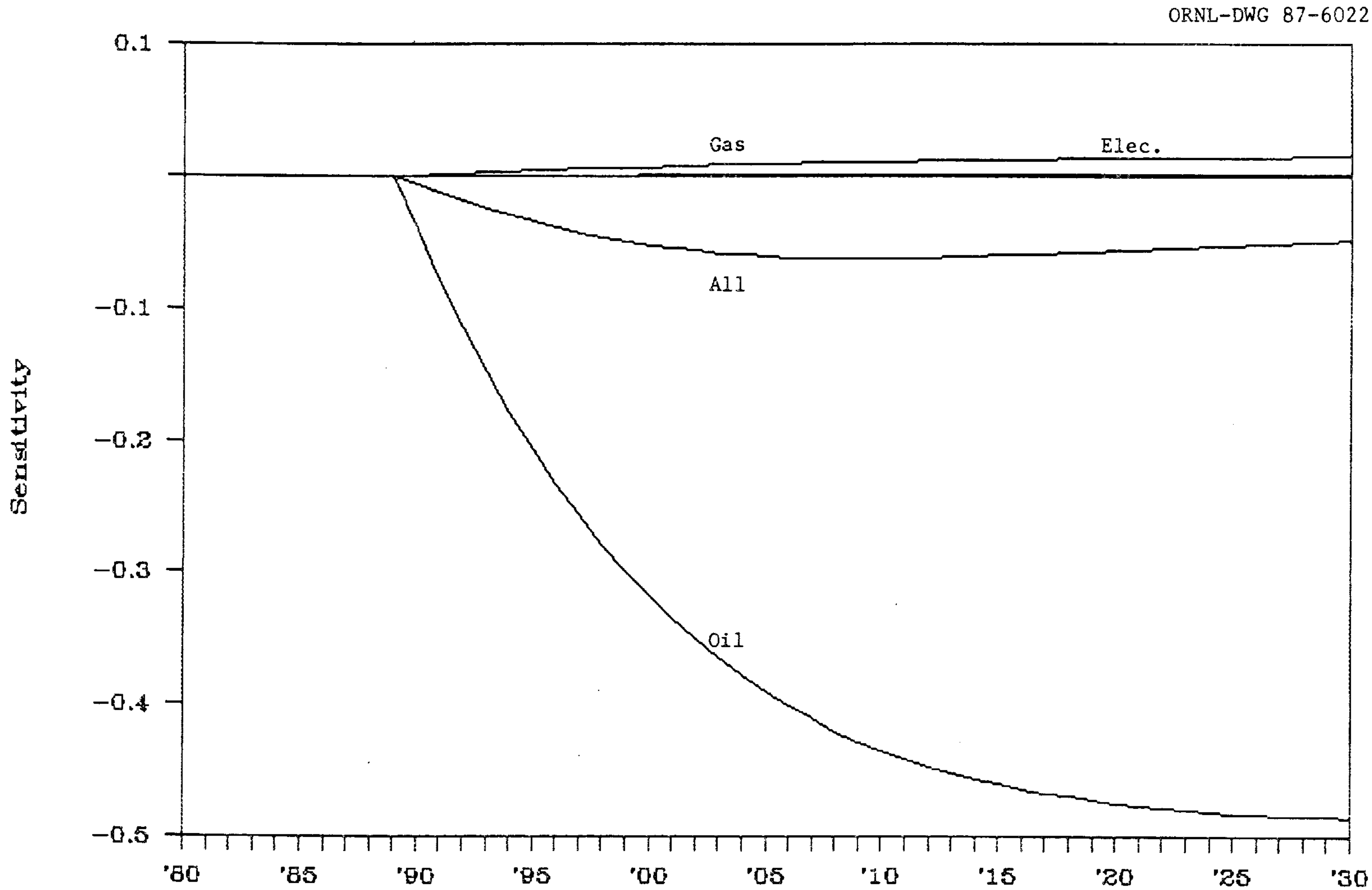

Fig. 8. Sensitivity of fuel use to post-1989 price of residual oil.

ORNL-DWG 87-6023

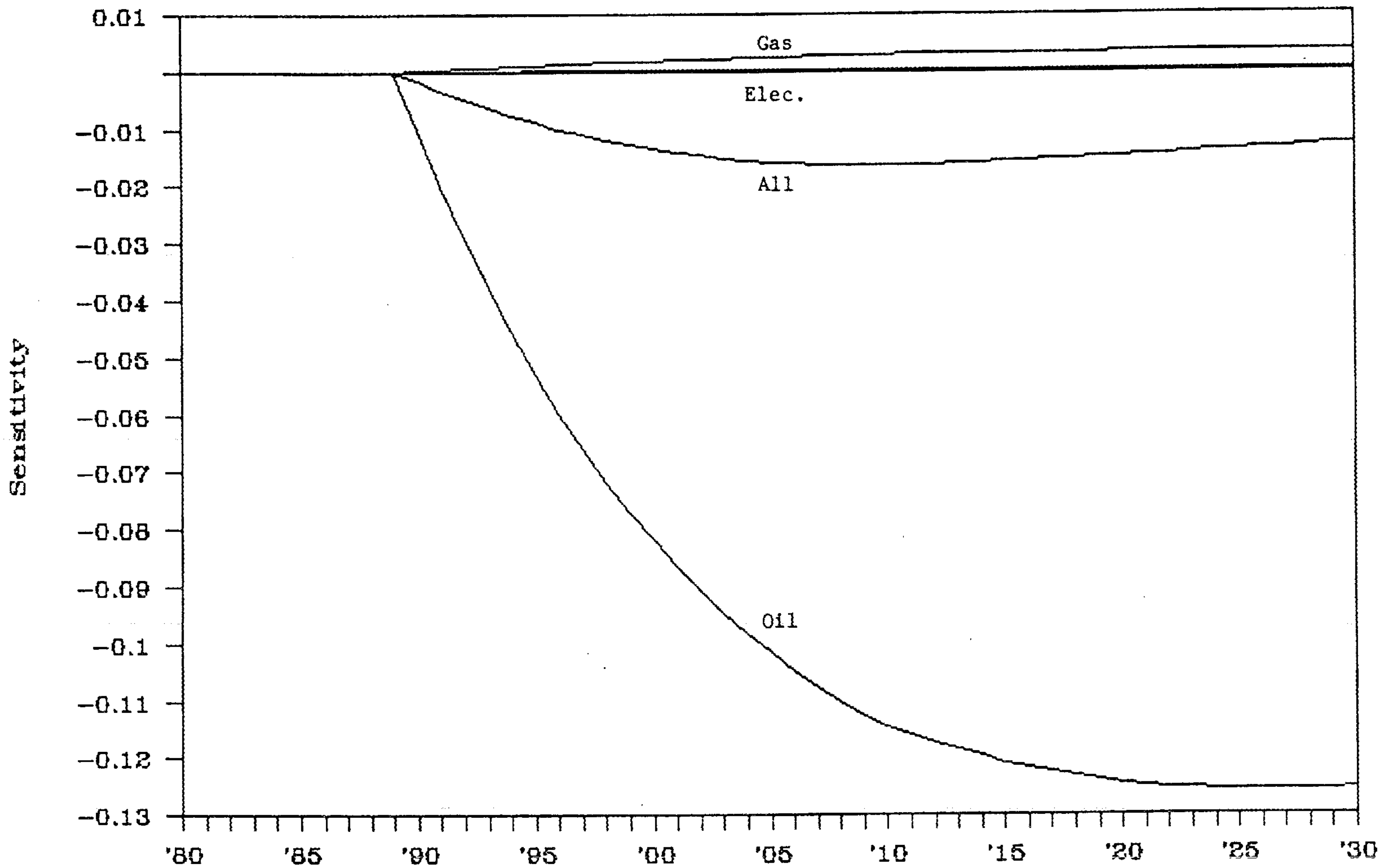

Fig. 9. Sensitivity of fuel use to post-1989 price of kerosene.

ORNL-DWG 87-6024

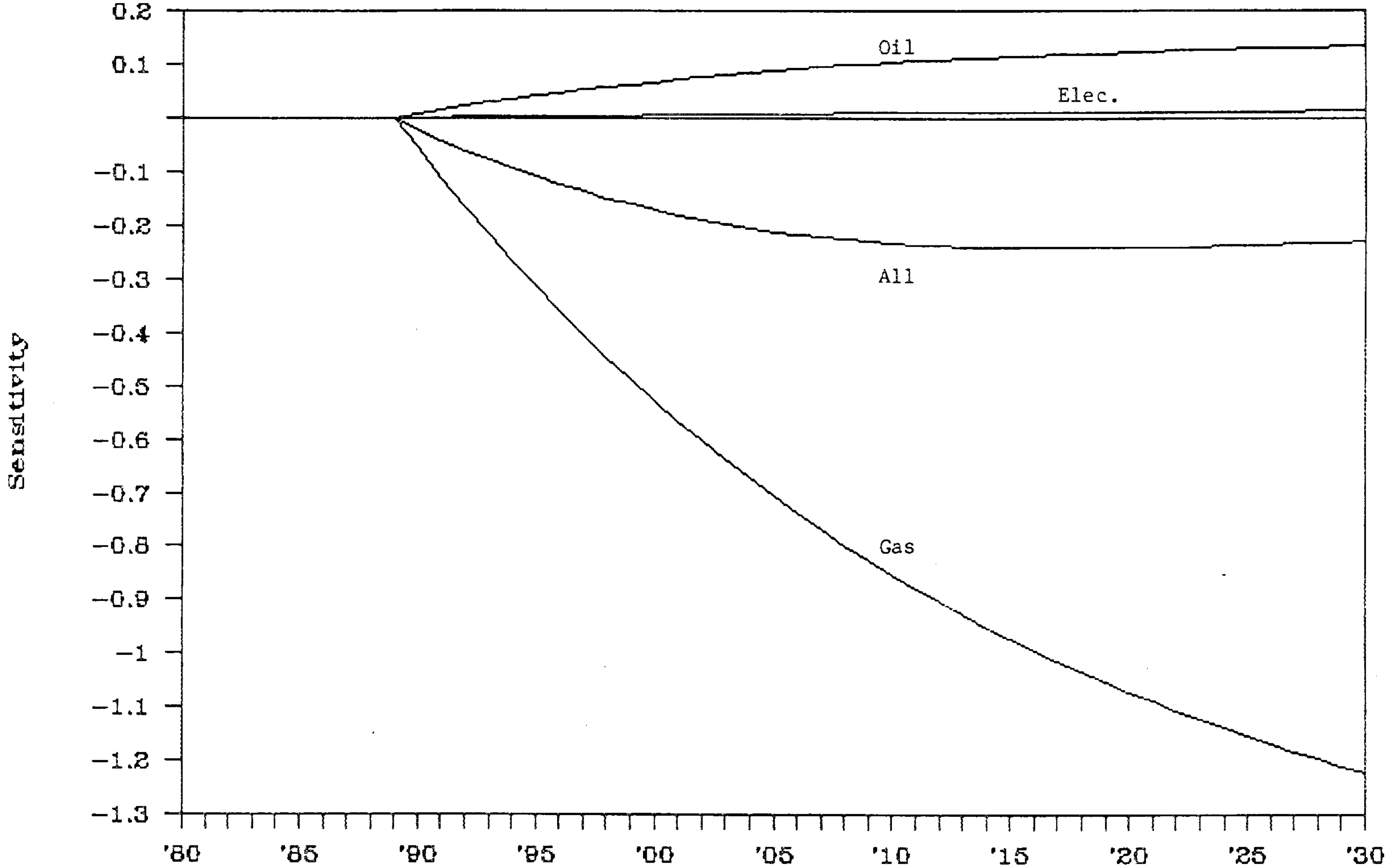

Fig. 10. Sensitivity of fuel use to post-1989 price of natural gas.

ORNL-DWG 87-6025

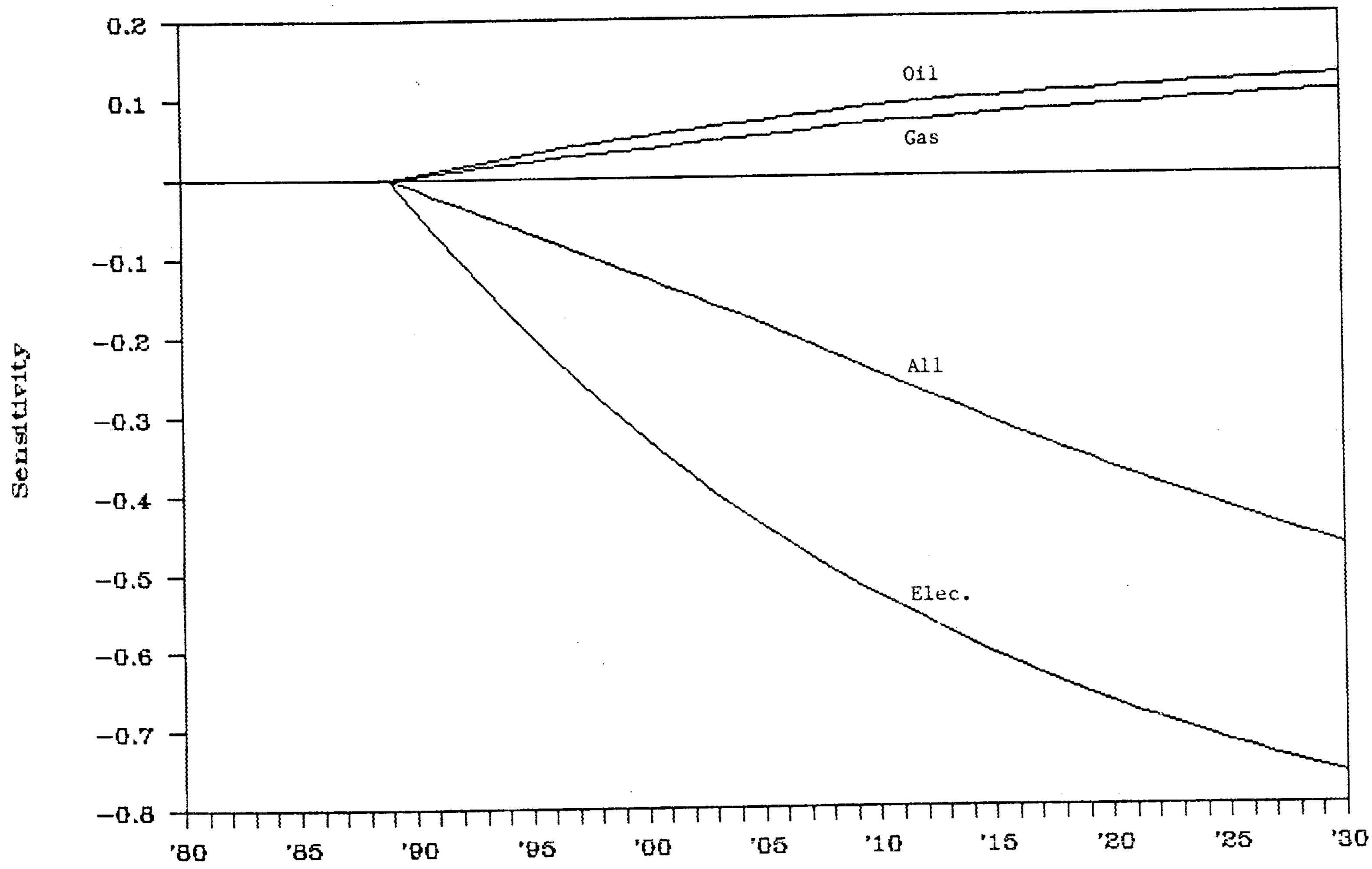

Fig. 11. Sensitivity of fuel use to post-1989 price of electricity.

ORNL-DWG 87-6026

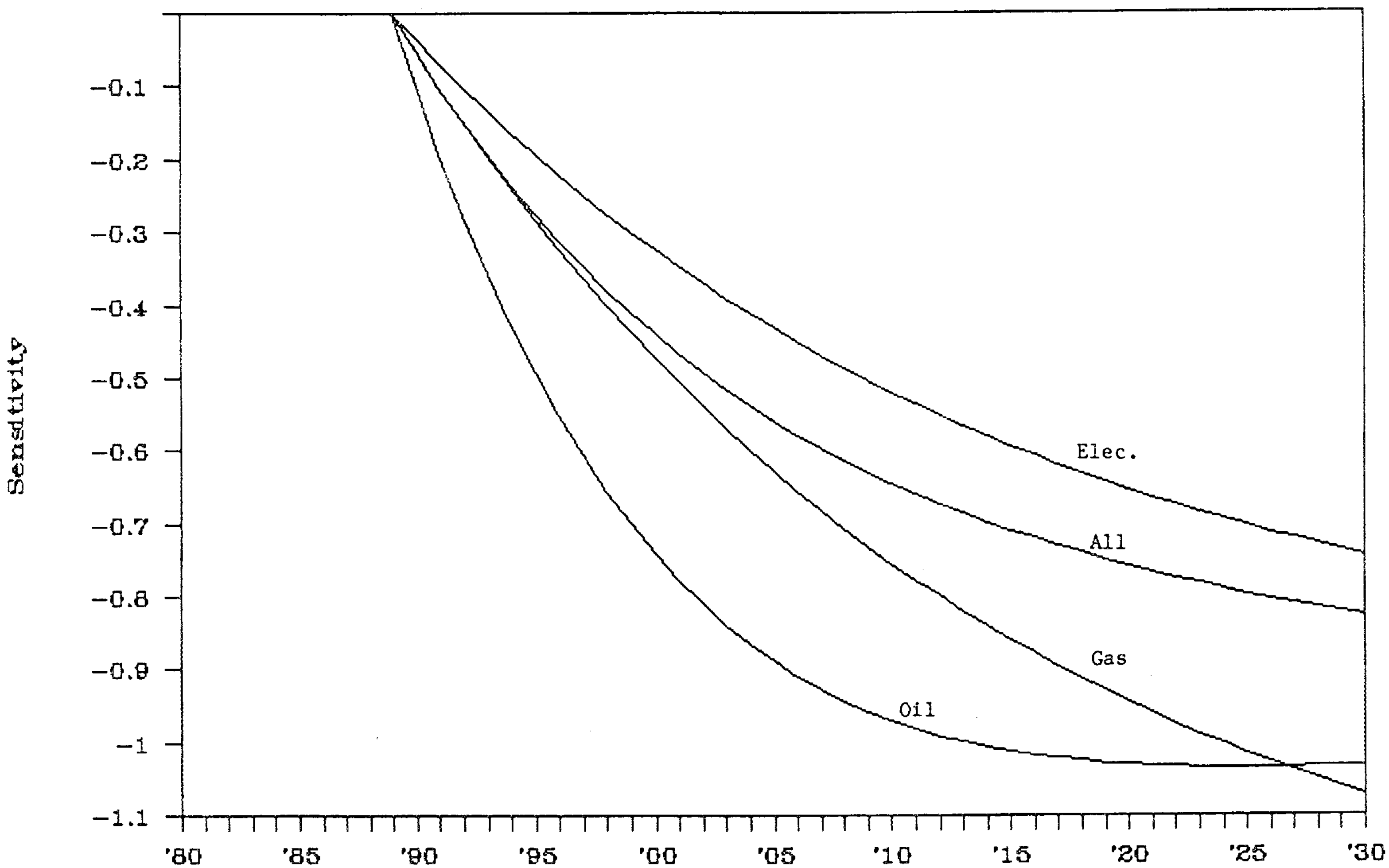

Fig. 12. Sensitivity of fuel use to post-1989 price of all fuels, i.e., to a general, permanent price change.

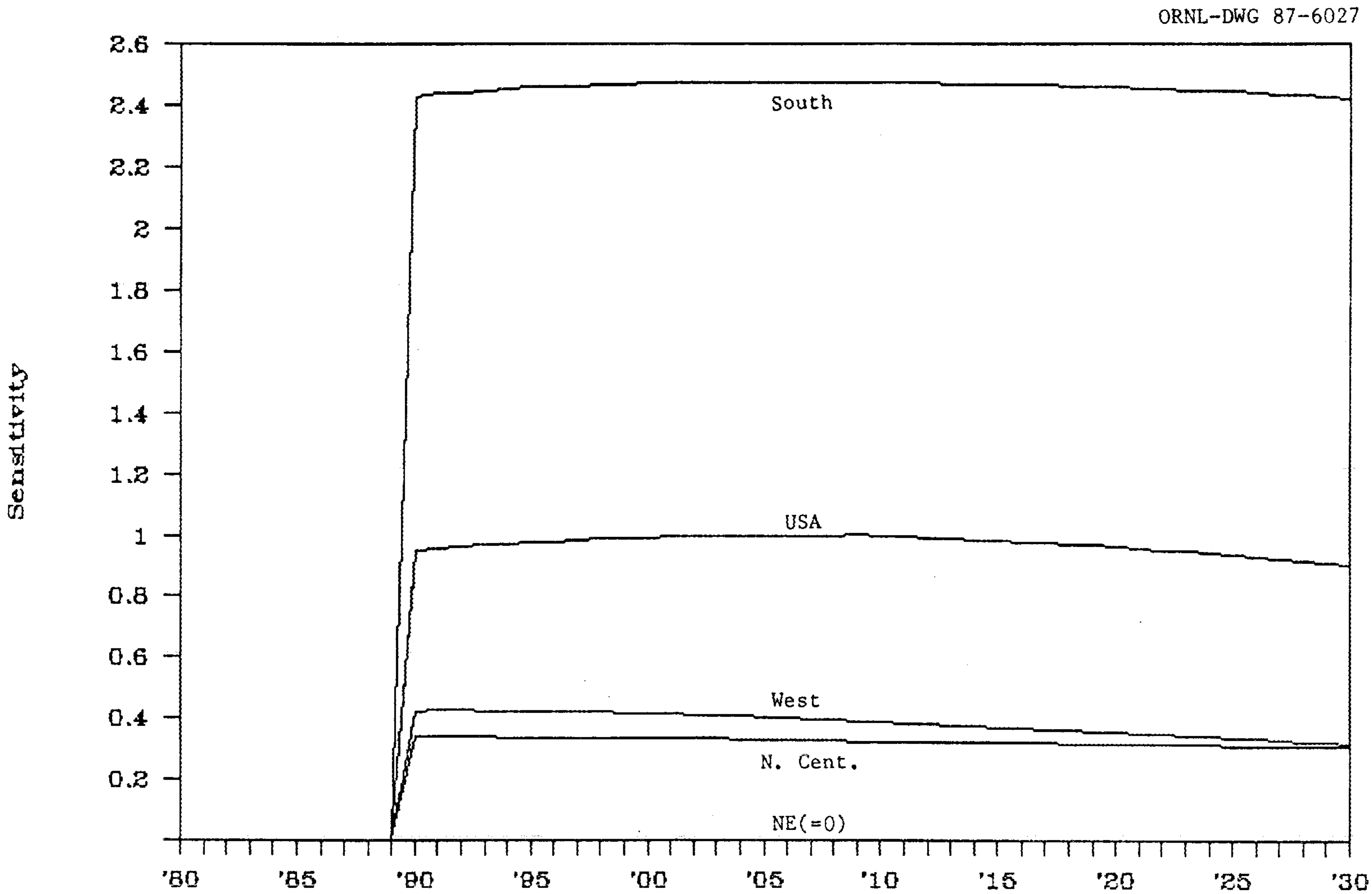

Fig. 13. Sensitivity of regional use of all fuels to post-1989 regional population.

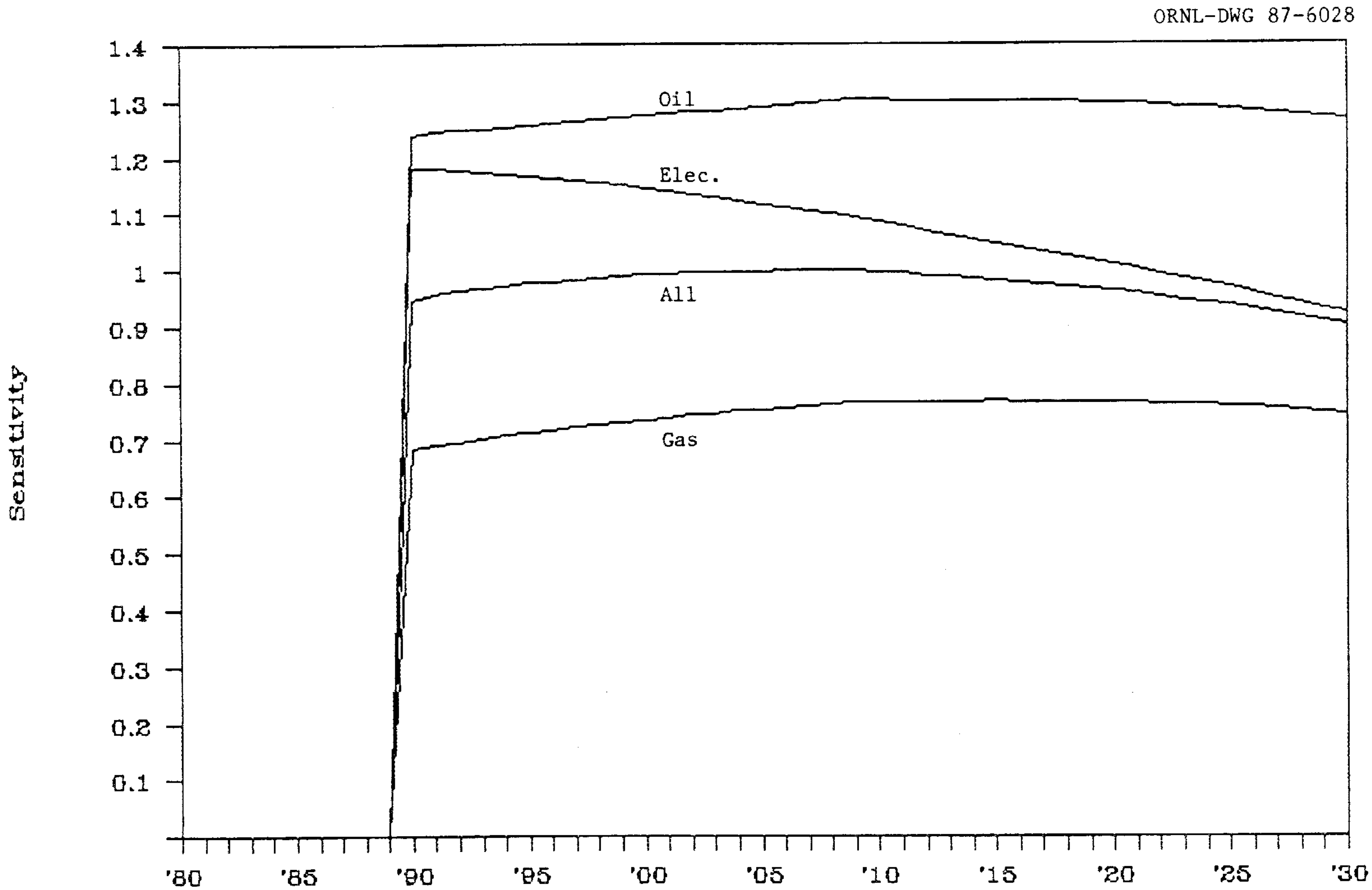

Fig. 14. Sensitivity of national fuel use by fuel to post-1989 national population.

ORNL-DWG 87-6029

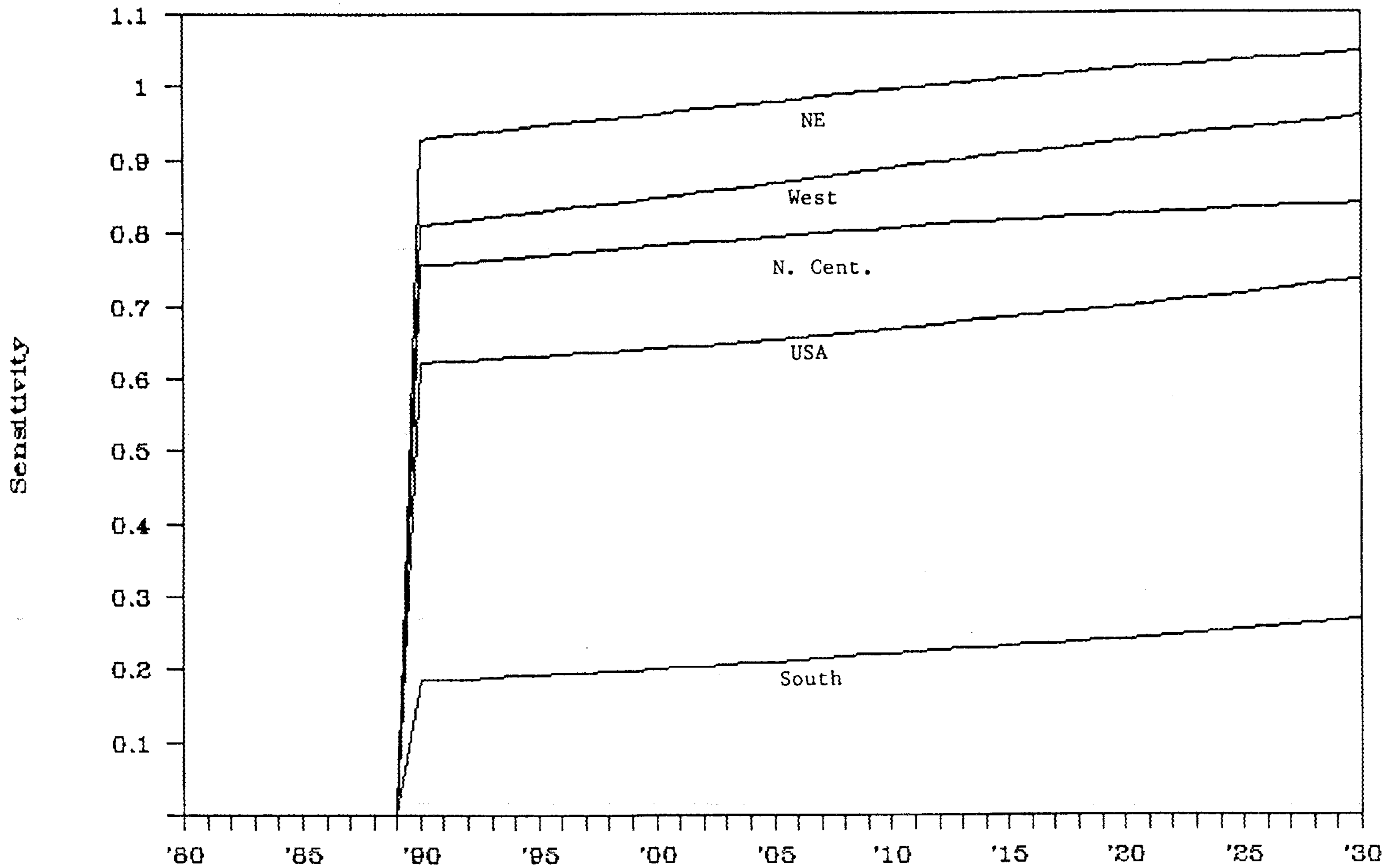

Fig. 15. Sensitivity of regional use of all fuels to post-1989 regional disposable income.

ORNL-DWG 87-6030

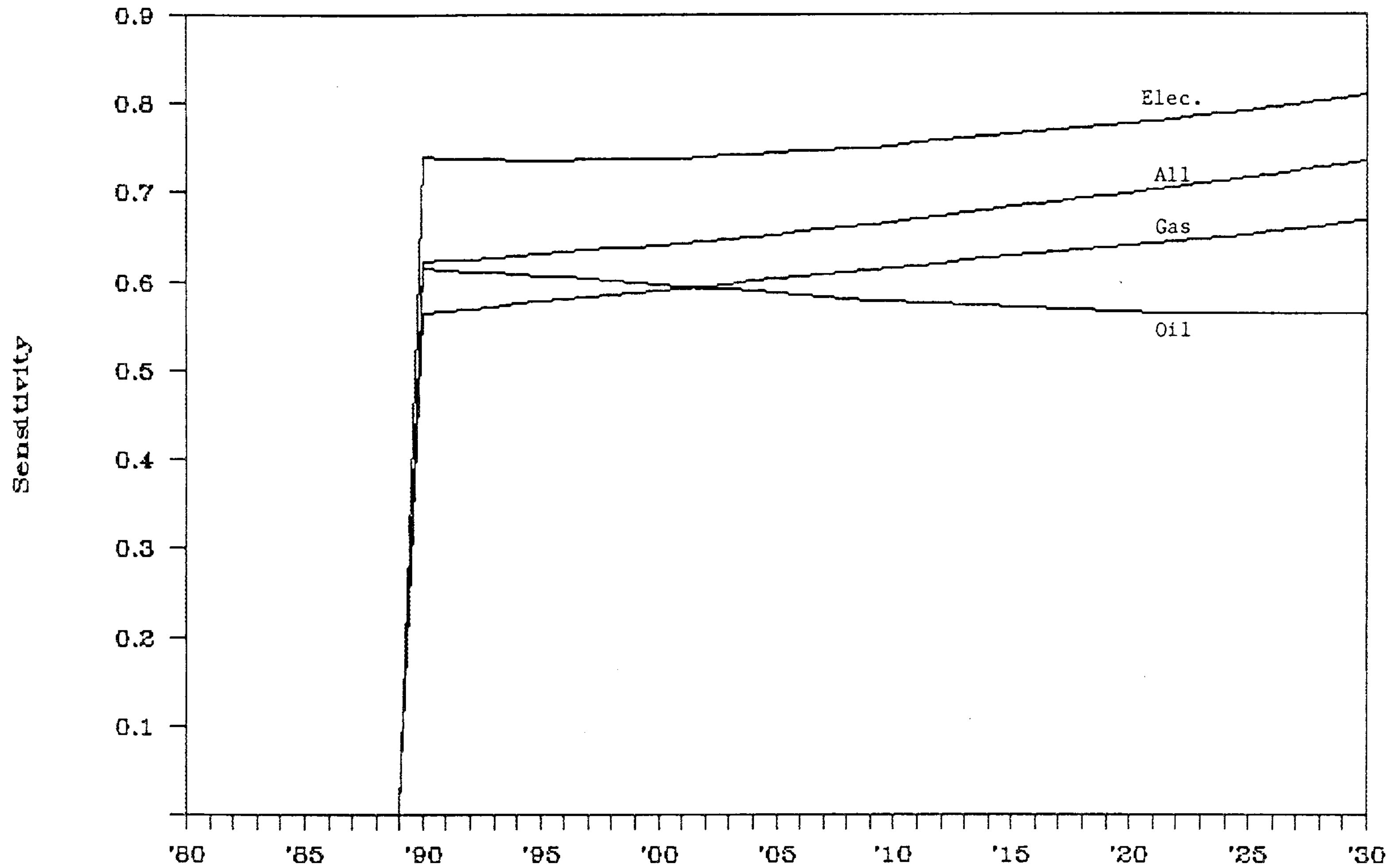

Fig. 16. Sensitivity of national fuel use by fuel to post-1989 national disposable income.

ORNL-DWG 87-6031

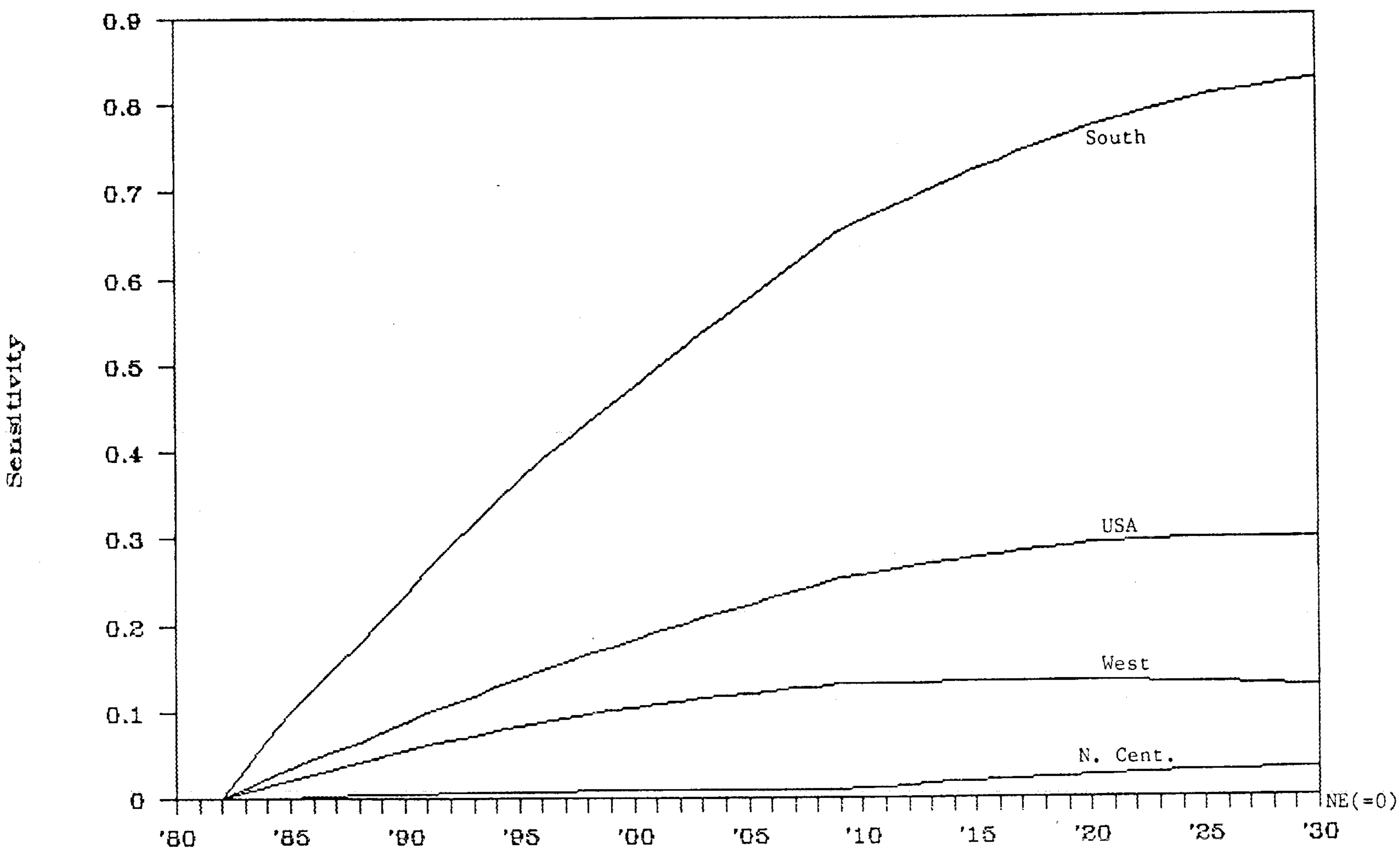

Fig. 17. Sensitivity of regional total fuel use to Floor Stock/population forecast coefficients, aggregated over all building classes.

ORNL-DWG 87 6032

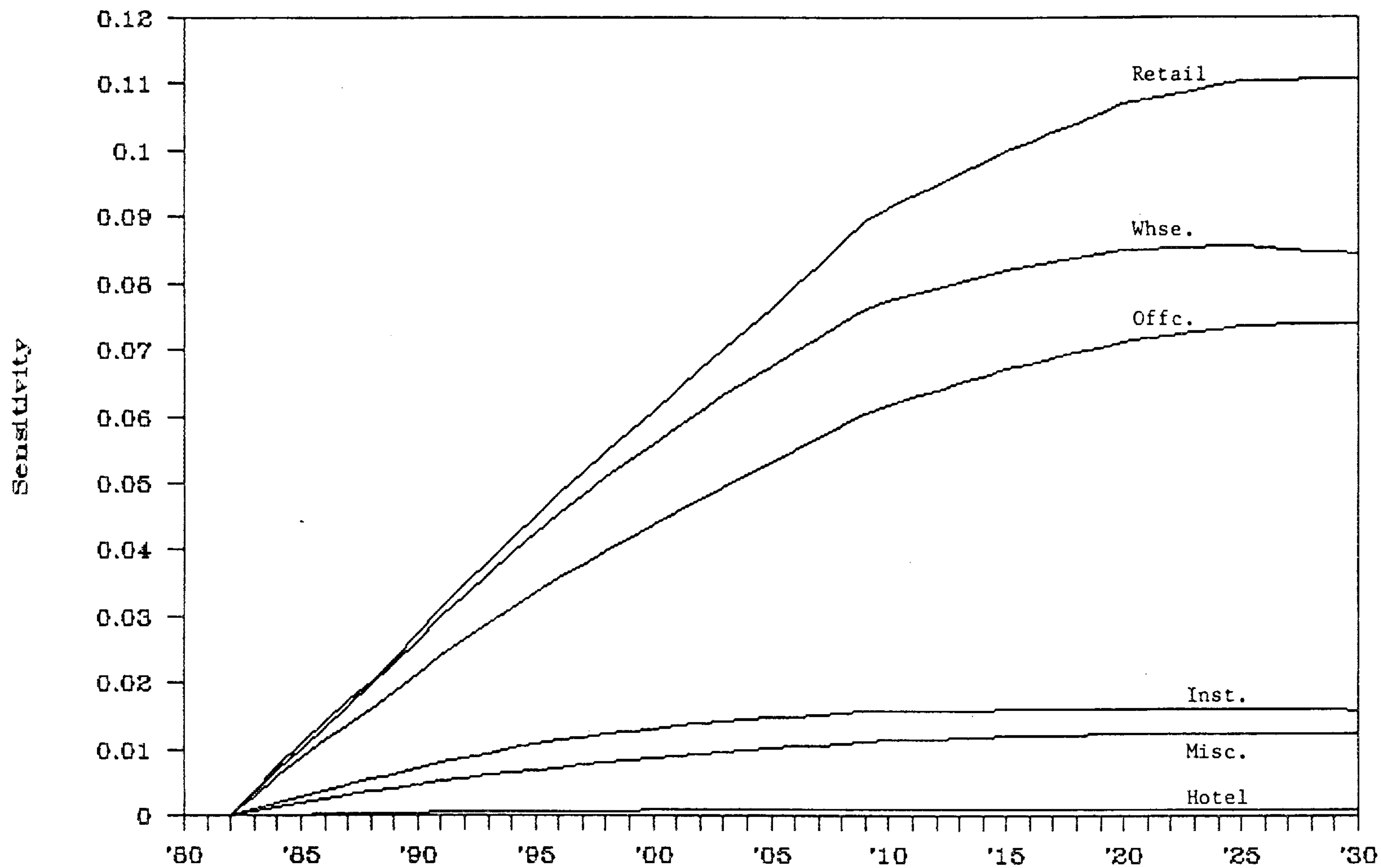

Fig. 18. Sensitivity of total national fuel use to Floor Space/population forecast coefficients for separate building classes. Coefficients for separate building classes are aggregated over all regions.

ORNL-DWG 87-6033

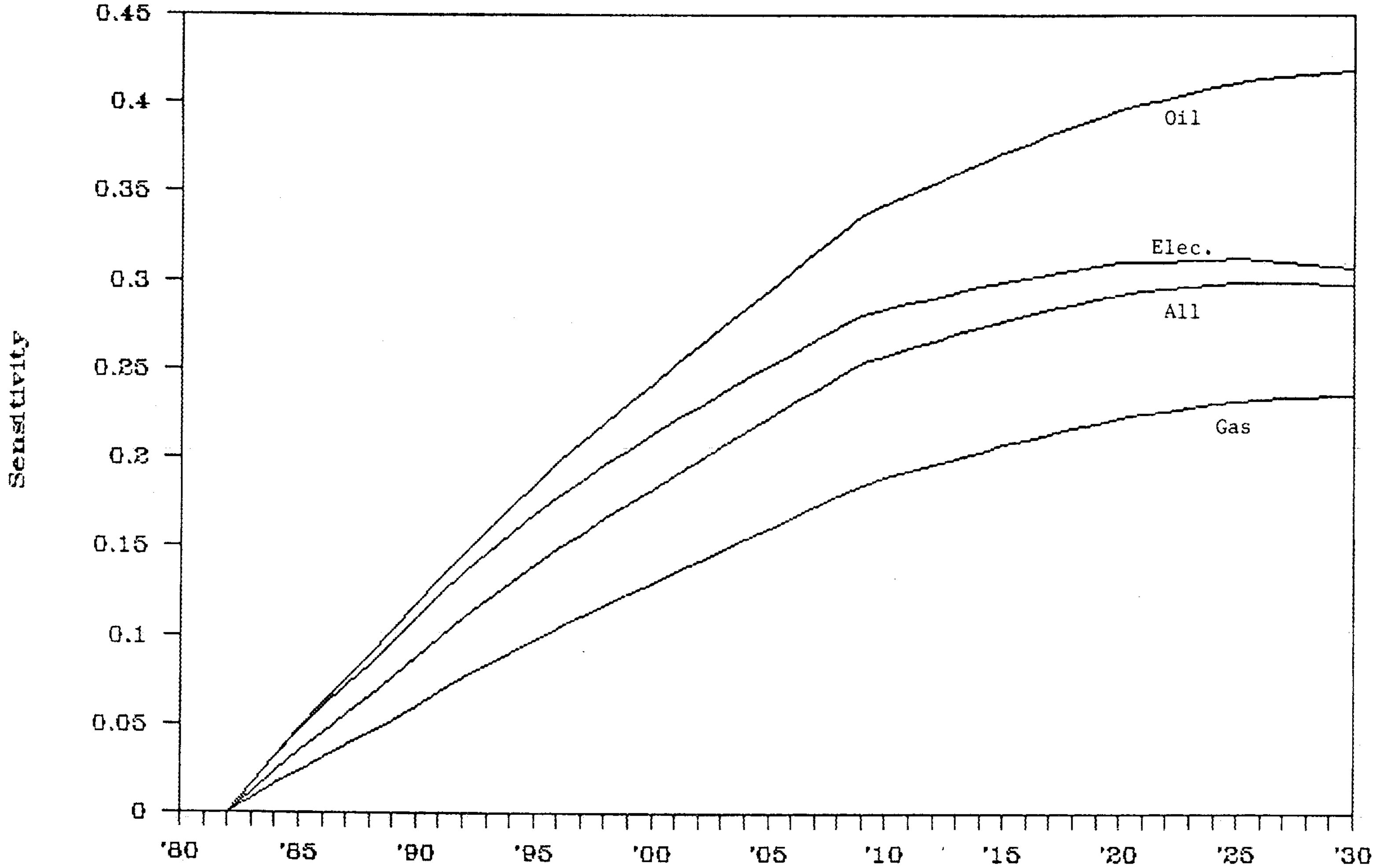

Fig. 19. Sensitivity of national fuel use by fuel to Floor Space/population forecast coefficients, aggregated over all regions and building classes.

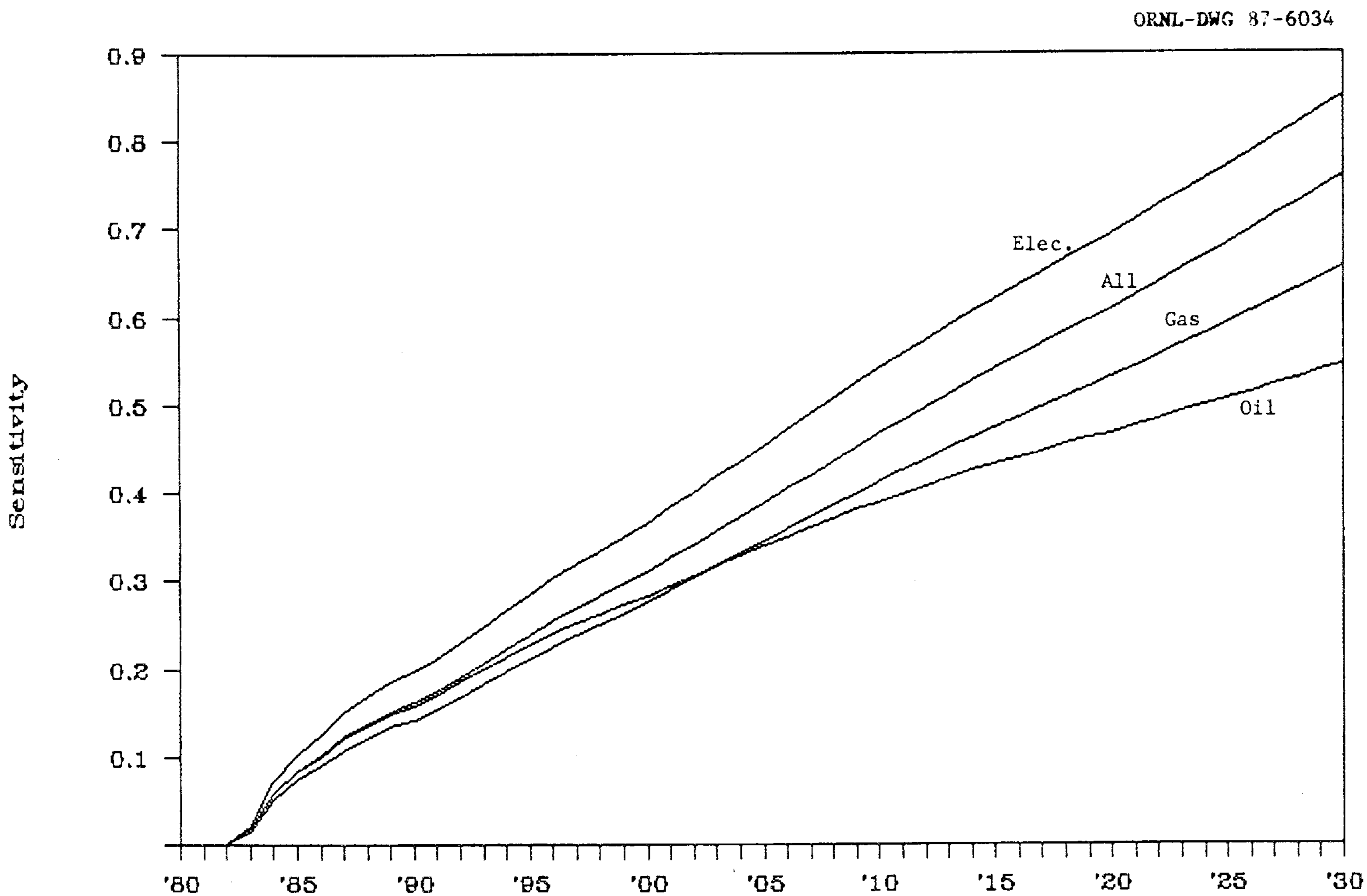

Fig. 20. Sensitivity of national fuel use by fuel to Floor Space/income forecast coefficients, aggregated over all regions and building classes.

ORNL-DWG 87-6035

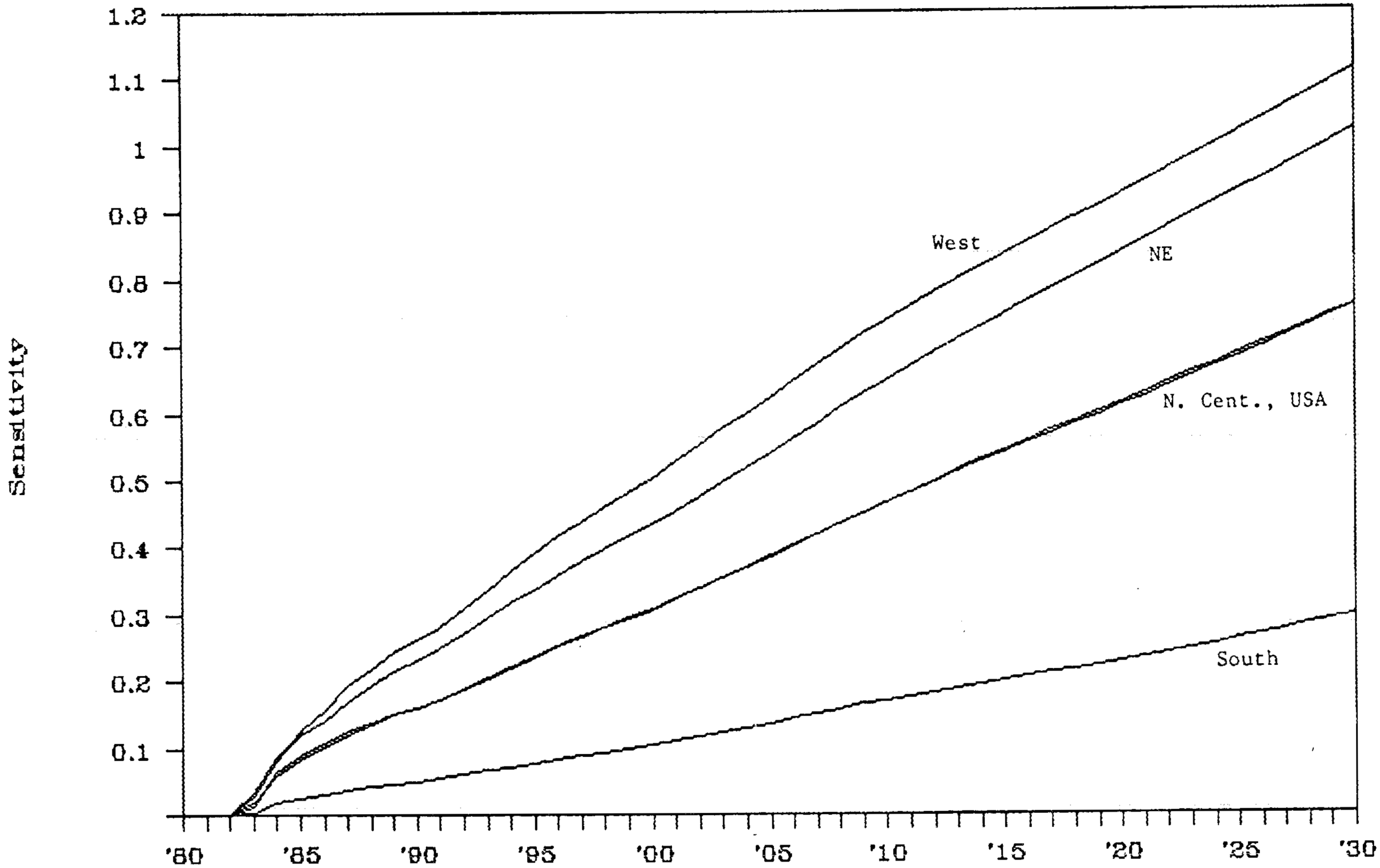

Fig. 21. Sensitivity of total regional fuel use to Floor Space/income forecast coefficients, aggregated over all building classes.

ORNL-dwg 87-6036

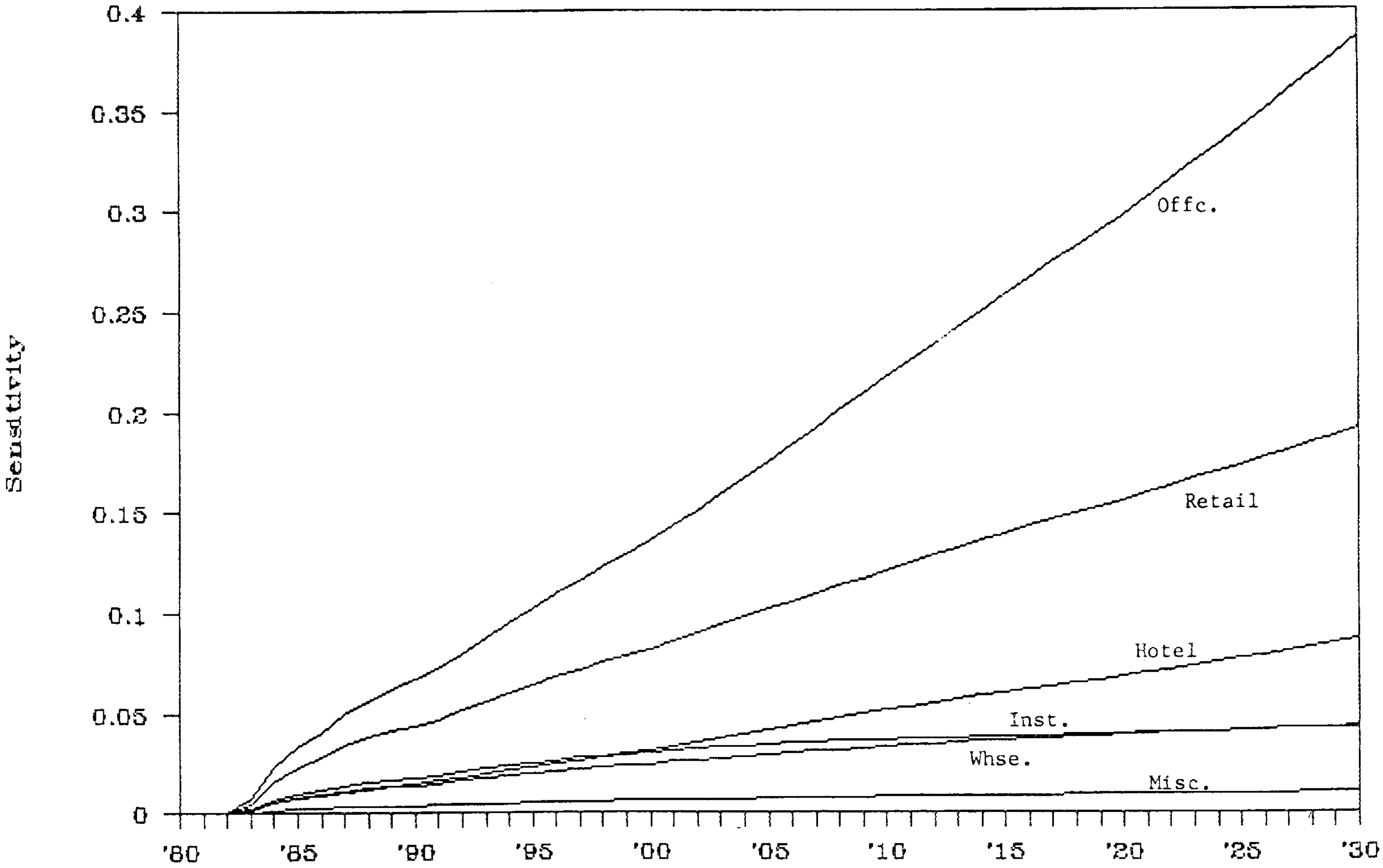

Fig. 22. Sensitivity of total national fuel use to Floor Space/income forecast coefficients for separate building classes. Coefficients for separate building classes are aggregated over all regions.

ORNL-DWG 87-6037

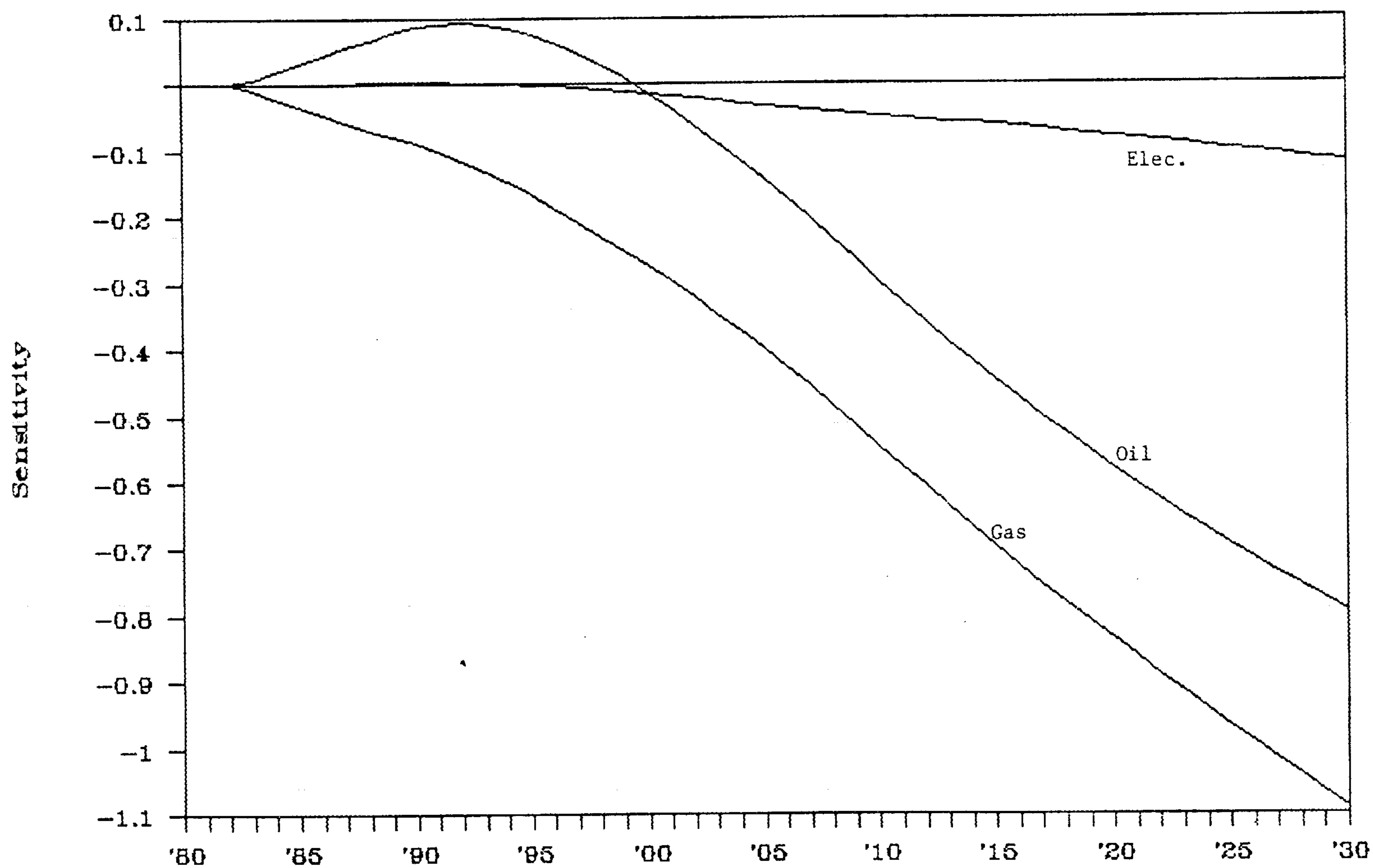

Fig. 23. Sensitivity of fuel use by fuel to individual price elasticities, aggregated over all building classes; e.g., "Oil" curve is sensitivity of oil use to the price elasticity for oil.

ORNL-DWG 87-6038

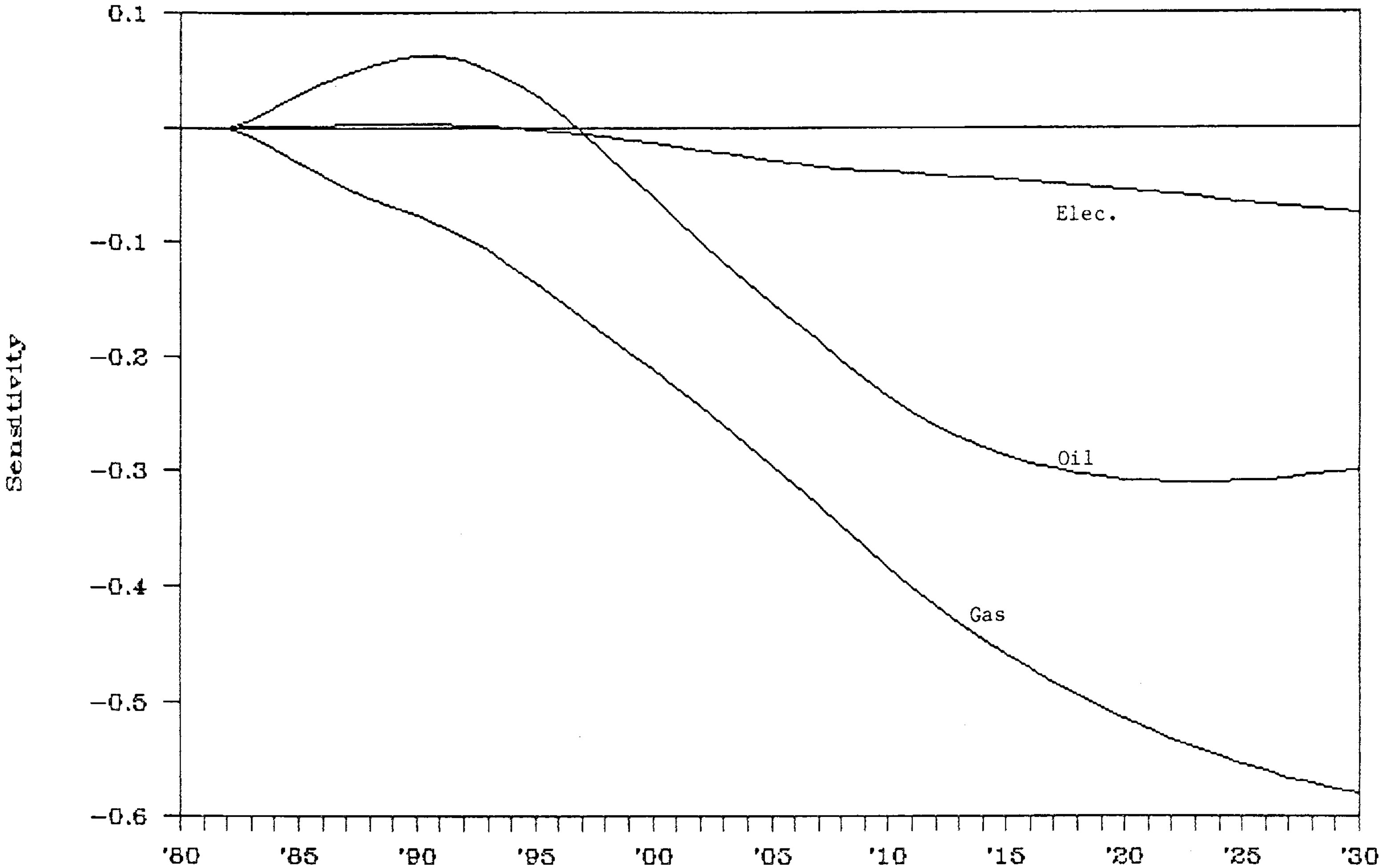

Fig. 24. Sensitivity of fuel use by fuel to individual price response lag parameters; e.g., "Oil" curve is sensitivity of oil use to the lag parameter for oil.

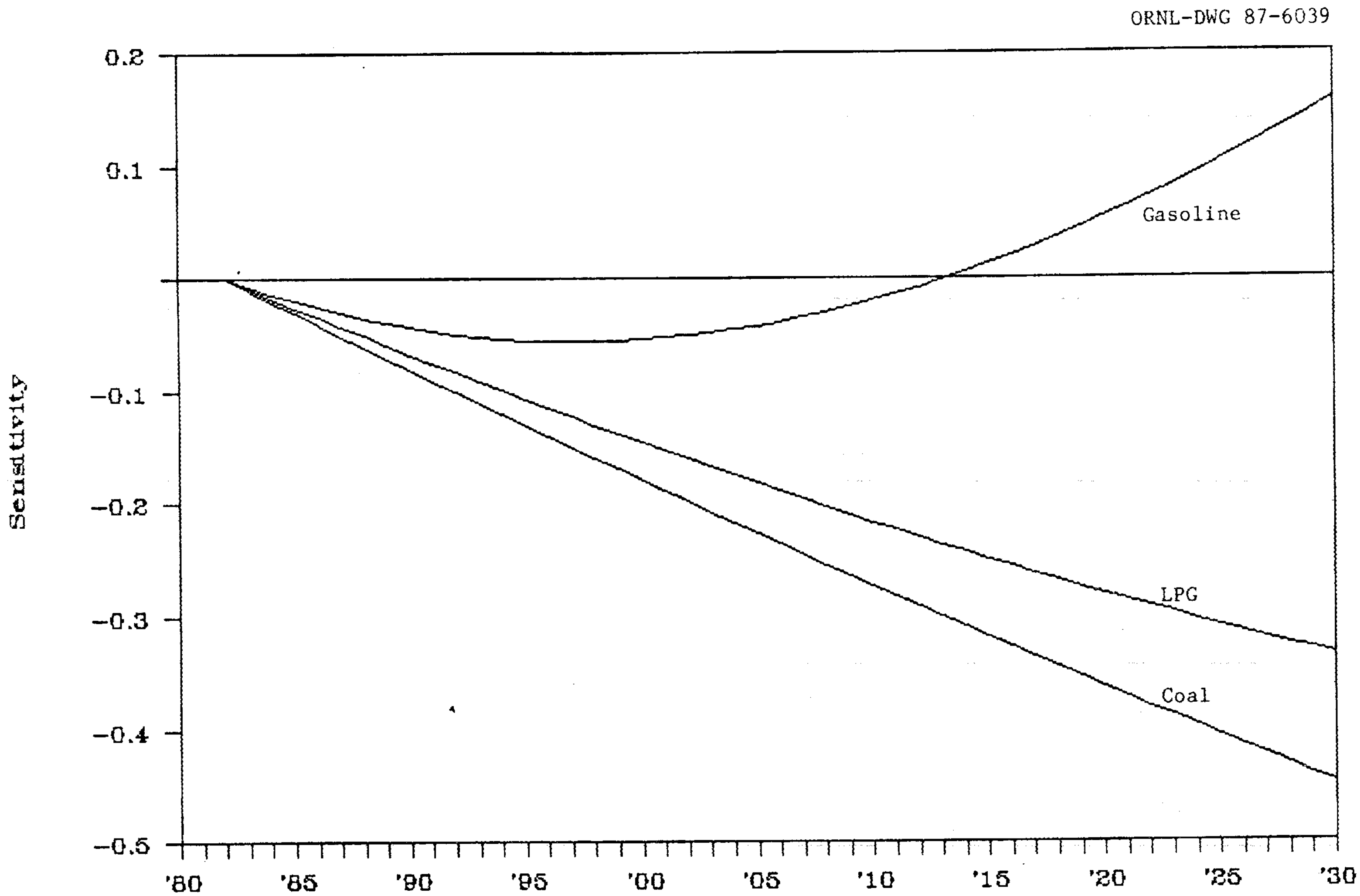

Fig. 25. Sensitivity of minor fuel use to minor fuel growth parameters, aggregated over all regions.

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