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PROJECTING HOUSEHOLD ENERGY CONSUMPTION WITHIN A CONDITIONAL DEMAND FRAMEWORK

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INTRODUCTION

Few models attempt to assess and project household energy consumption and expenditure by taking into account differential household choices correlated with such variables as race, ethnicity, income, and geographic location. The Minority Energy Assessment Model (MEAM), developed by Argonne National Laboratory (ANL) for the U.S. Department of Energy (DOE), provides a framework to forecast the energy consumption and expenditure of majority, black, Hispanic, poor, and nonpoor households. Among other variables, household energy demand for each of these population groups in MEAM is affected by housing factors (such as home age, home ownership, home type, type of heating fuel, and installed central air conditioning unit), demographic factors (such as household members and urban/rural location), and climate factors (such as heating degree days and cooling degree days). The welfare implications of the revealed consumption patterns by households are also forecast. The paper provides an overview of the model methodology and its application in projecting household energy consumption under alternative energy scenarios developed by Data Resources, Inc., (DRI). **DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED**

DISCLAIMER

METHODOLOGY

MEAM is a budgeting model based on a three-stage linear expenditure system (LES). The model is estimated by using the SAS (1984) three-stage nonlinear estimation procedure developed by Amemiya (1985). Structural parameters have been estimated by using a longitudinal sample consisting of approximately 5,000 observations from four Residential Energy Consumption Surveys conducted by DOE (see U.S. Department of Energy, 1982, 1985, 1987, and 1989).

The analysis is done within the context cf a well-structured theoretical framework. Standard neoclassical consumer behavior theory is used along with a complete demand system of equations derived from a constrained utility maximization problem. The utility function is derived from the Stone-Geary utility function.[1] It is also assumed that the demand for energy and non-energy goods is separable. This allows for the construction of a multistage budgeting model; a conceptual presentation is shown in Figure 1.

The explanatory variables in the model include the following:

- Household expenditures
- Electricity price
- Nonelectricity energy price
- Consumer price index, excluding energy

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[1]For a discussion on the general theory underlying the LES model see Geary (1950-51), Klein and Rubin (1947-48), Samuelson (1947-48), and Stone (1954). Muellbauer (1975) and Pollak and Wales (1981) discuss the incorporation of demographic factors into a complete demand system. The development of a dynamic LES model is covered in the work done by Philips (1972 and 1983).

Figure 1 Multistage Budget

The model consists of four equations, which give estimates of total household energy consumption, electricity consumption, energy expenditures, and the weighted household energy price. The equations are:

$$q_{et} = \frac{(1-\beta_e)\ (\Upsilon_e + \alpha\theta S_{t-1})\Psi_{et}}{[1-\Psi_{et}\alpha(1-\theta)]} + \frac{\beta_e}{p_{et}}\ (m_t - p_{ct}\gamma_c) \tag{1}$$

$$q_{elt} = (1-\beta_{el})\psi_{elt}\gamma_{el} +$$

$$\frac{\beta_{el}[1-\alpha(1-\theta)]\{m_{et} - \dfrac{p_{nelt}(\gamma_e + \alpha\theta S_{t-1} - \gamma_{el})}{[1-\alpha(1-\theta)]}\}}{\{[1-\alpha(1-\theta)]p_{elt} + \alpha(1-\theta)p_{nelt}\}} \tag{2}$$

$$p_{et} \equiv \frac{(p_{elt}q_{elt} + p_{nelt}q_{nelt})}{q_{et}} \tag{3}$$

and

$$m_{et} \equiv p_{et}q_{et} \tag{4}$$

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                    ┌─────────────┐
                    │   SAVINGS   │
                    └─────────────┘
                          │
┌──────────┐              │
│  INCOME  │──────────────┤
└──────────┘              │
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                    ┌─────────────┐│ NON-ENERGY  │
                    │ CONSUMPTION │└─────────────┘
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                          │──────────────┤
                          │              │
                          │        ┌──────────┐    ┌───────────────┐
                          │        │  ENERGY  │────│ NON-ELECTRIC  │
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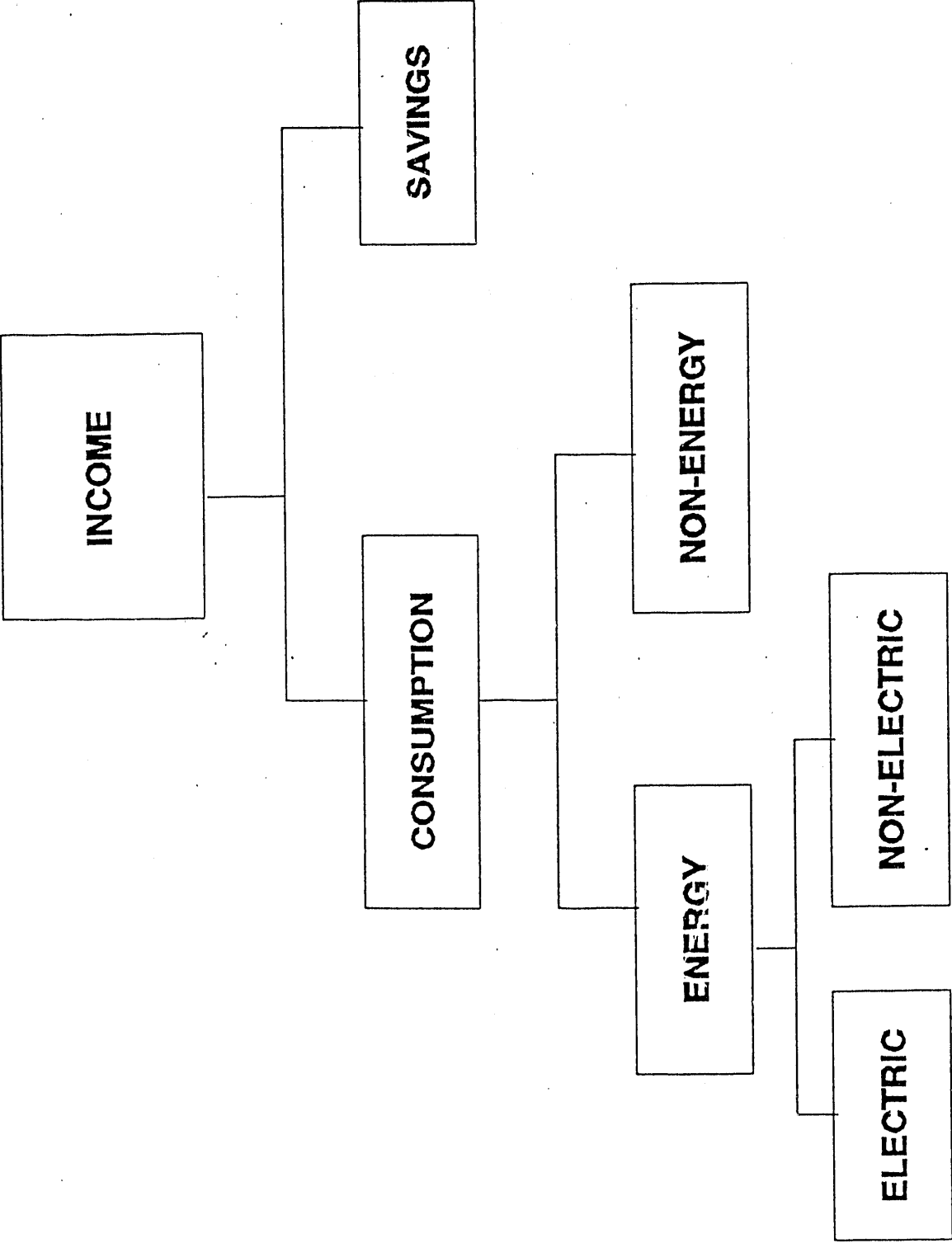
where: q_{et} = energy consumption (10^6 Btu/year)

Ψ_{et} = energy demand scale factor

Υ_e = nondiscretionary energy demand (10^6 Btu/year)

α = dynamic effect parameter

θ = dynamic adjustment parameter

S_{t-1} = state variable in period t-1

β_e = marginal energy expenditure share

Υ_c = nondiscretionary non-energy demand

p_{et} = price of energy ($\$/10^6$ Btu)

p_{ct} = price index of non-energy goods

m_t = household expenditures ($\$$/year)

q_{elt} = electricity consumption (10^6 Btu/year)

Ψ_{elt} = electricity demand scale factor

q_{nelt} = nonelectricity energy consumption (10^6 Btu/year)

γ_{el} = nondiscretionary electricity demand (10^6 Btu/year)

β_{el} = marginal electricity expenditure share

p_{elt} = price of electricity ($\$/10^6$ Btu)

p_{nelt} = price of nonelectricity energy ($\$/10^6$ Btu)

m_{et} = household energy expenditures ($\$$/year)

The energy and electricity demand scale factors play an extremely important role in our analysis; they are used to introduce the potential effect of exogenous factors (such as housing turnover) and interregional population migration on energy demand.

The analysis presented in this paper assumes that through factors affecting the energy and electricity scale factors, the energy demand curve for each of the five population groups shifts

down by 10% while their electricity demand curves shift up by 10%.
In addition to these exogenous shifts in demand, the effects of two
energy price scenarios on energy consumption and expenditures are
analyzed. The two scenarios are a base case (produced by DRI in
Spring 1990) and an Iraq-Kuwait case (produced by DRI in September,
1990, after the Iraqi invasion of Kuwait in August, 1990).

CASE I

The base-case energy forecasts were based on macroeconomic
and energy variable forecasts obtained from Data Resources, Inc.
(DRI, 1990a). Figure 2 shows the nominal cost of imported crude
oil under this scenario (prepared in spring 1990). As the gap
between the world oil demand and supply narrows during the 1990s,
crude oil prices are forecasted to rise moderately in the first-
half of the 1990s and then rise at a double-digit rate in the
second-half of the 1990s. ·This results in crude oil prices of
$18.50/barrel in 1990, $25.40/barrel in 1995, and $41.50/barrel in
2000. Figure 3 shows the average annual rate of increase of
selected key economic variables (used in MEAM) over the last two
years from 1989 to 1999. On the basis of the data shown in the
figure, the nominal household income is forecasted to increase at
a higher rate throughout the 1990s than the rate of inflation (as
measured by the Consumer Price Index [CPI]), which, in turn, will
be higher than the escalation in electricity rates. However, the
escalation in the price of nonelectricity fuels will cross the
escalation in the price of electricity in 1991, the escalation of
the CPI in 1992, and the escalation of income in 1993. Some of the

Case I variable projections are shown in Table 1. The historical values were also obtained from DRI (1989).

The time horizon of the forecast was broken into two periods: 1989-1993 and 1994-1999. Essentially, these periods could be considered intermediate and long-run, respectively. The DRI estimates were used to represent the base case prevailing for the entire period between 1990 and 1999.

CASE II

This special case is based on the Iraq-Kuwait price shock and is referred to as Case II. Case II is based on the DRI macroeconomic scenario "Control 0990" (1990b) released after the Iraqi invasion of Kuwait in August, 1990. This scenario incorporates DRI's expectation of the new crude-oil-price trajectory over the 1990-93 period (Figure 2).

TABLE 1   Case I Annual Rates of Change in Key Macroeconomic and Energy Variables: 1989-1999

	Percent Change	
Variable	1989-93	1993-99
Household Income	5.22	5.81
Consumer Price Index	4.33	5.16
Electricity Price	3.04	4.23
Nonelectricity Energy Price	3.97	8.06

Source: DRI 1989 and 1990a

FIGURE 2 Average Annual Price of Imported Crude Oil, in Nominal
Dollars per Barrel, under Alternative Cases

Imported Crude Oil Prices
under Alternative Cases

Crude Oil Case II

Crude Oil Case I

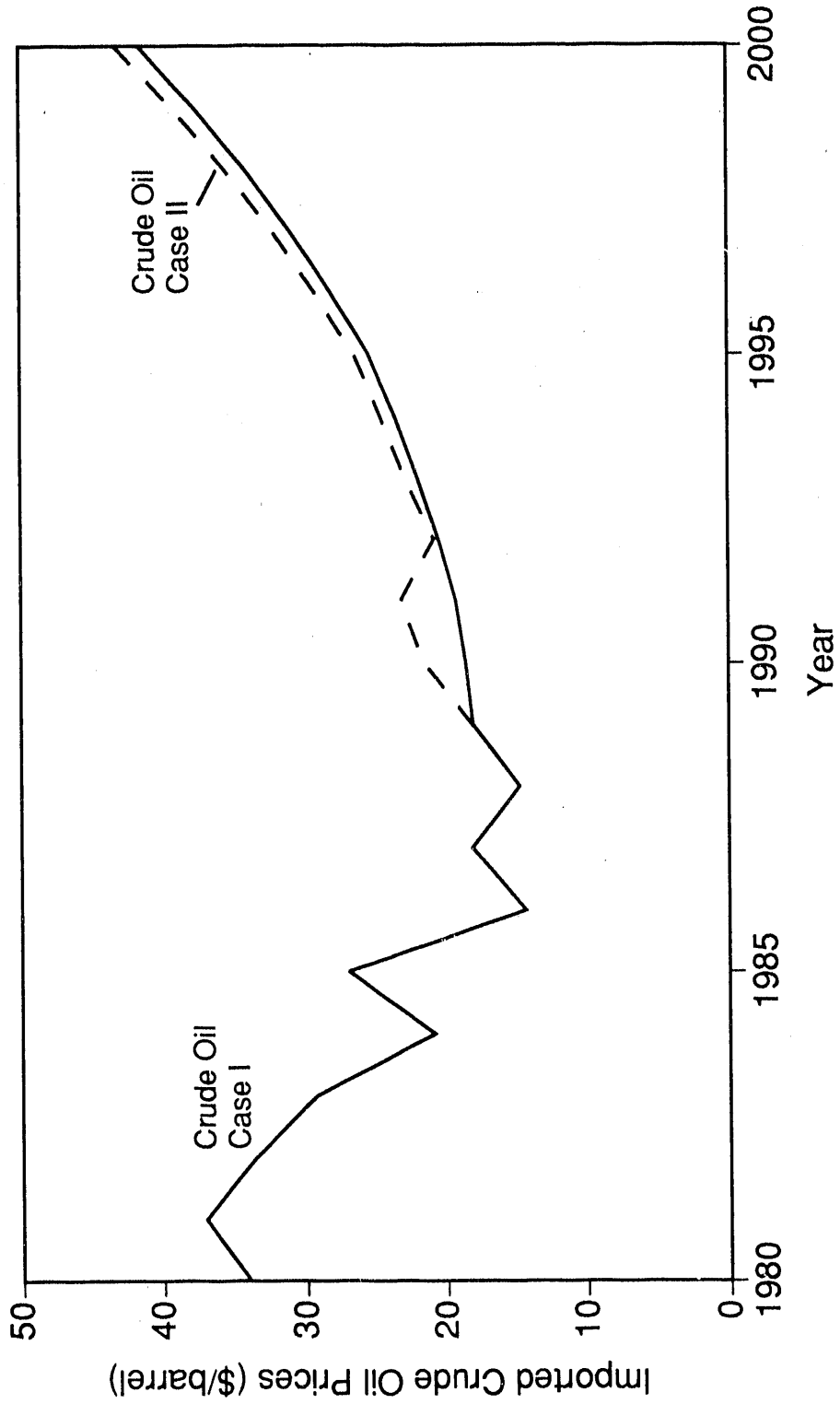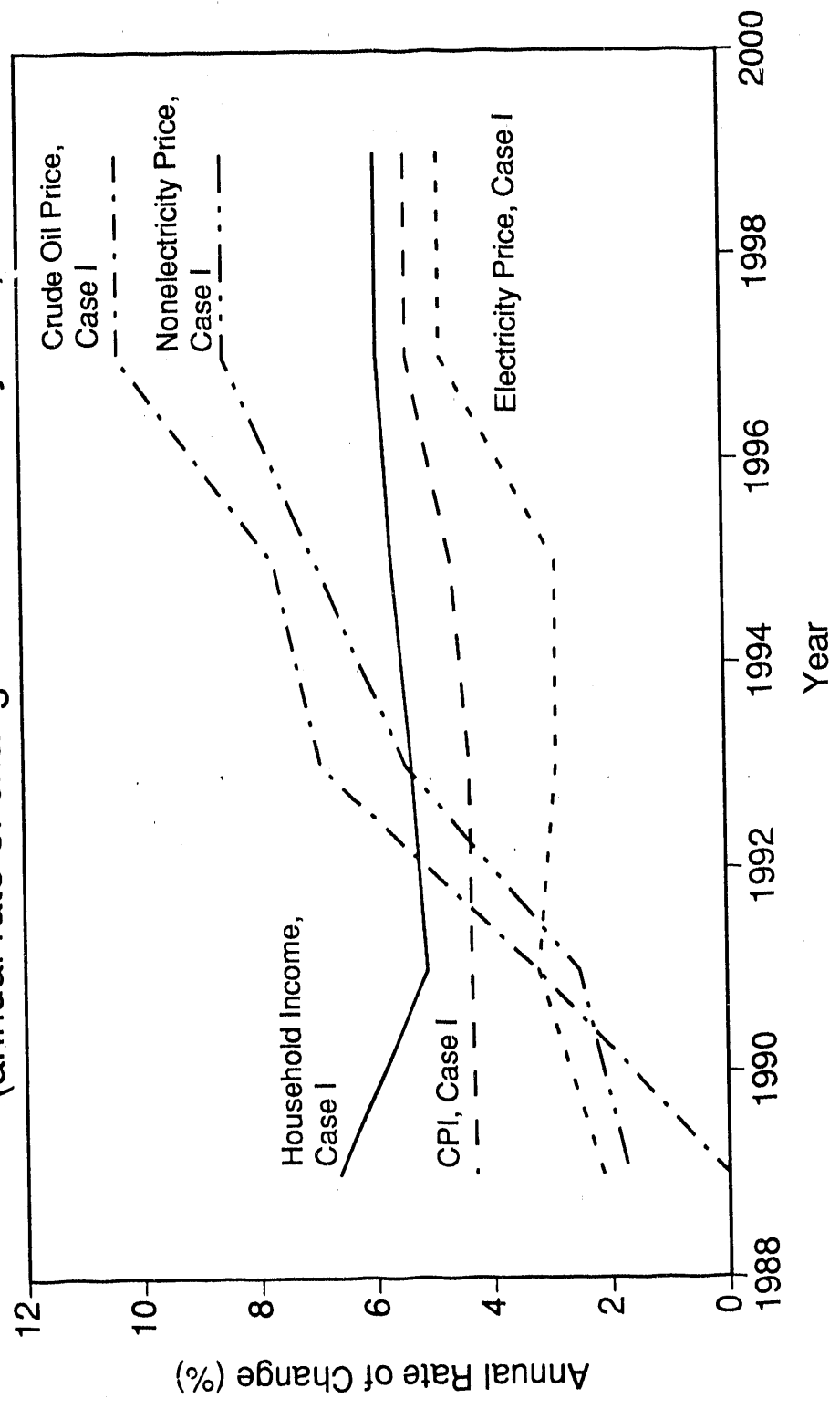Imported Crude Oil Prices ($/barrel)

Year

FIGURE 3   Key Economic Variables under Case I (annual rates of change over the preceding two-year periods)

Key Economic Variables under Case I
(annual rate of change over last two years)

Crude Oil Price, Case I

Nonelectricity Price, Case I

Electricity Price, Case I

Household Income, Case I

CPI, Case I

Annual Rate of Change (%)

Year

The world crude oil market has demonstrated dramatic volatility with respect to oil prices as a result of the events in the Persian Gulf. Crude oil prices in the United States prior to the Iraqi invasion on August 2, 1990, were just over $20/bbl (DRI, 1990b). Because of various developments during the armed conflict in the Persian Gulf, the price of crude oil surged above $30/bbl in August. Prices eased by the end of the month as OPEC temporarily suspended production quotas. West Texas Intermediate and OPEC spot prices retreated to $27/bbl. Against this background, the average price of crude oil is projected to be $27.90/bbl in the fourth quarter of 1990. This corresponds to an average price of $21.50/bbl in the year of 1990 (Figure 2). Even though, as per the scenario assumption, the embargo of Iraqi and Kuwaiti crude oil is likely to extend into mid-1991, the increased production by other OPEC members is expected to leave total world oil production in 1991 just 1.5 million barrels below pre-invasion forecasts. This is expected to lead to an average crude oil price of $23.17/bbl in 1991. With the assumed restoration of Iraqi and Kuwaiti production to the levels of 80% by the end of 1992 and 100% by 1993, the crude oil price will gradually fall to $20.80/bbl in 1992 before slowly firming to the base case projections of $23.50 by late 1993. It is then assumed that the forecast of the four variables given in Table 1 will be the same under both scenarios (Case I and Case II) for the 1994-1999 period. The variable forecasts for the entire period (1989-99) are shown in Table 2. It must be stressed that these values of crude oil prices are subject to large variations that can result from uncertain developments in the Middle East situation.

**TABLE 2   Case II Annual Rates of Change in
Key Macroeconomic and Energy Variables:
1989-1999**

	Percent Change	
Variable	1989-93	1993-99
Household Income	4.73	..81
Consumer Price Index	4.42	5.16
Electricity Price	3.15	4.23
Nonelectricity Energy Price	6.55	8.06

Source: DRI 1990a and 1990b.

HOUSEHOLD ECONOMIC EFFECTS OF ALTERNATIVE CASES

Total Energy Consumption

Table 3 shows 1989 household energy consumption estimates for majority, black, Hispanic, poor, and nonpoor groups. Among these groups, total energy consumption was highest for blacks (112 million Btu/household [mBtu/hh]) and lowest for Hispanics (88 mBtu/hh).

Figures 4 to 8 show forecasts of household electricity and nonelectricity consumption for the above groups under Case I. As shown in Table 1, the prices of nonelectricity fuel (primarily natural gas and fuel oil) escalate faster than the prices of electricity for all households. As a result, the decrease in nonelectricity energy consumption is greater than the increase in electricity consumption, which, therefore, leaves each group's total energy consumption slightly lower (Figures 9 and 10). The conservation in total annual energy consumption from 1989 to 1999 is minimum for poor households (5%) and is maximum for nonpoor households (8%).

TABLE 3   Total Energy Consumption
(10^6 Btu/household)

| | Total Energy Consumption (10^6 Btu/household) by Year | | | | |
| | Case I | | | Case II | |
Group	1989	1993	1999	1993	1999
Majority	101.9	98.7	94.8	98.6	94.6
Black	111.7	107.7	103.8	107.6	103.8
Hispanic	88.4	85.4	82.5	85.2	82.4
Poor	91.2	88.3	86.5	88.3	86.5
Nonpoor	104.9	101.1	96.3	100.9	96.2

Under Case II, the gap between the nonelectricity energy and electricity prices is forecasted to be higher than the gap under Case I (Tables 1 and 2). As such, on a comparative basis for each of the household groups, nonelectricity energy consumption is lower under Case II than under Case I, while electricity use is slightly higher (less than offsetting) under Case II than under Case I (Figures 4 to 8). As such, this leaves each group's total energy consumption slightly lower under Case II than under Case I (Figures 9 and 10). Table 3 provides energy consumption estimates for each of the groups for selected years.

Total Energy Expenditures

Table 4 shows estimated household energy expenditures for majority, black, Hispanic, poor, and nonpoor groups. Among these groups, total energy expenditure was highest for nonpoor ($1188/year) and almost as high for blacks ($1184/year). The expenditures were lowest for poor ($988/year).

FIGURE 4   Majority Household Energy Consumption under Alternative
Cases

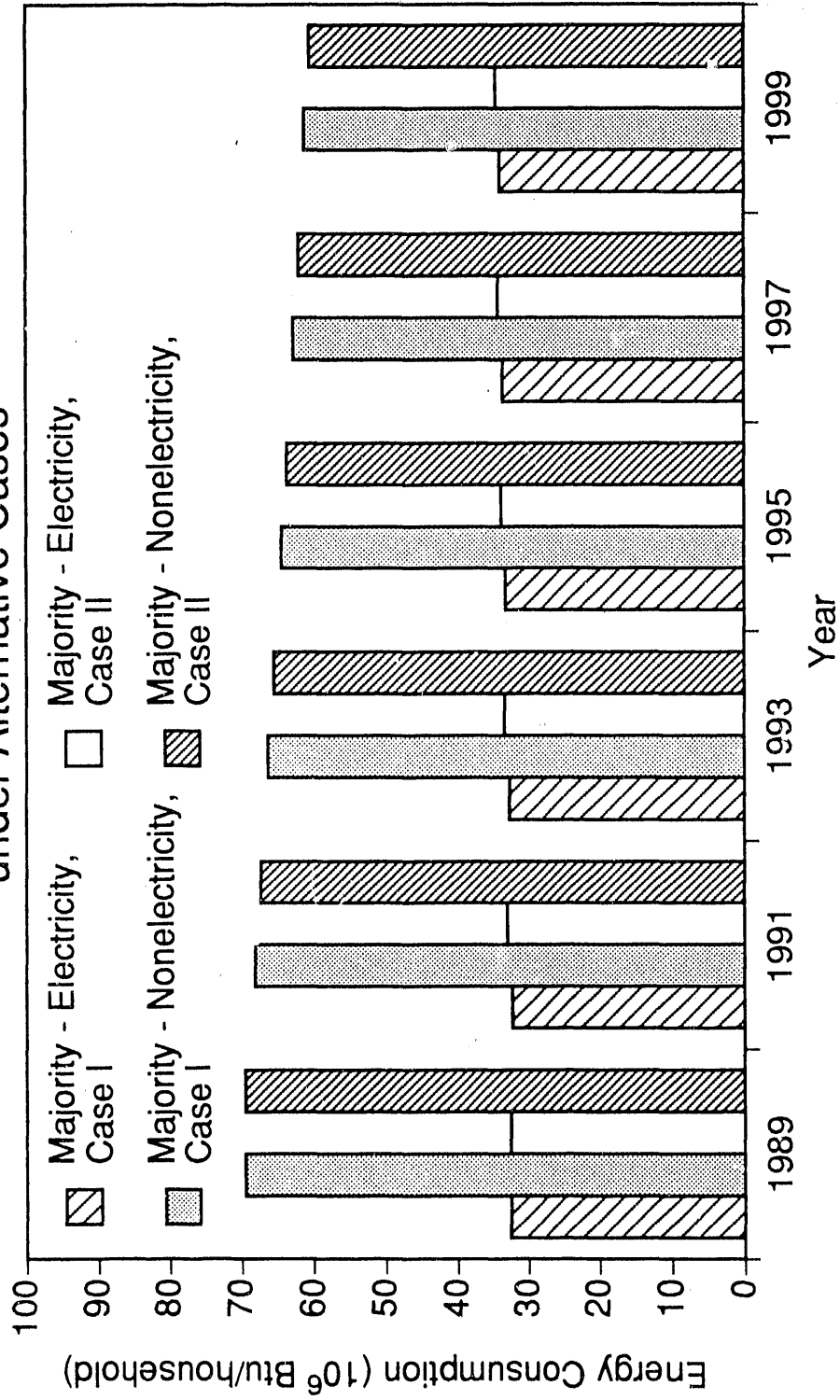Majority Household Energy Consumption under Alternative Cases

Legend:
- Majority - Electricity, Case I
- Majority - Nonelectricity, Case I
- Majority - Electricity, Case II
- Majority - Nonelectricity, Case II

Y-axis: Energy Consumption (10^6 Btu/household)

X-axis: Year (1989, 1991, 1993, 1995, 1997, 1999)

FIGURE 5   Black Household Energy Consumption under Alternative
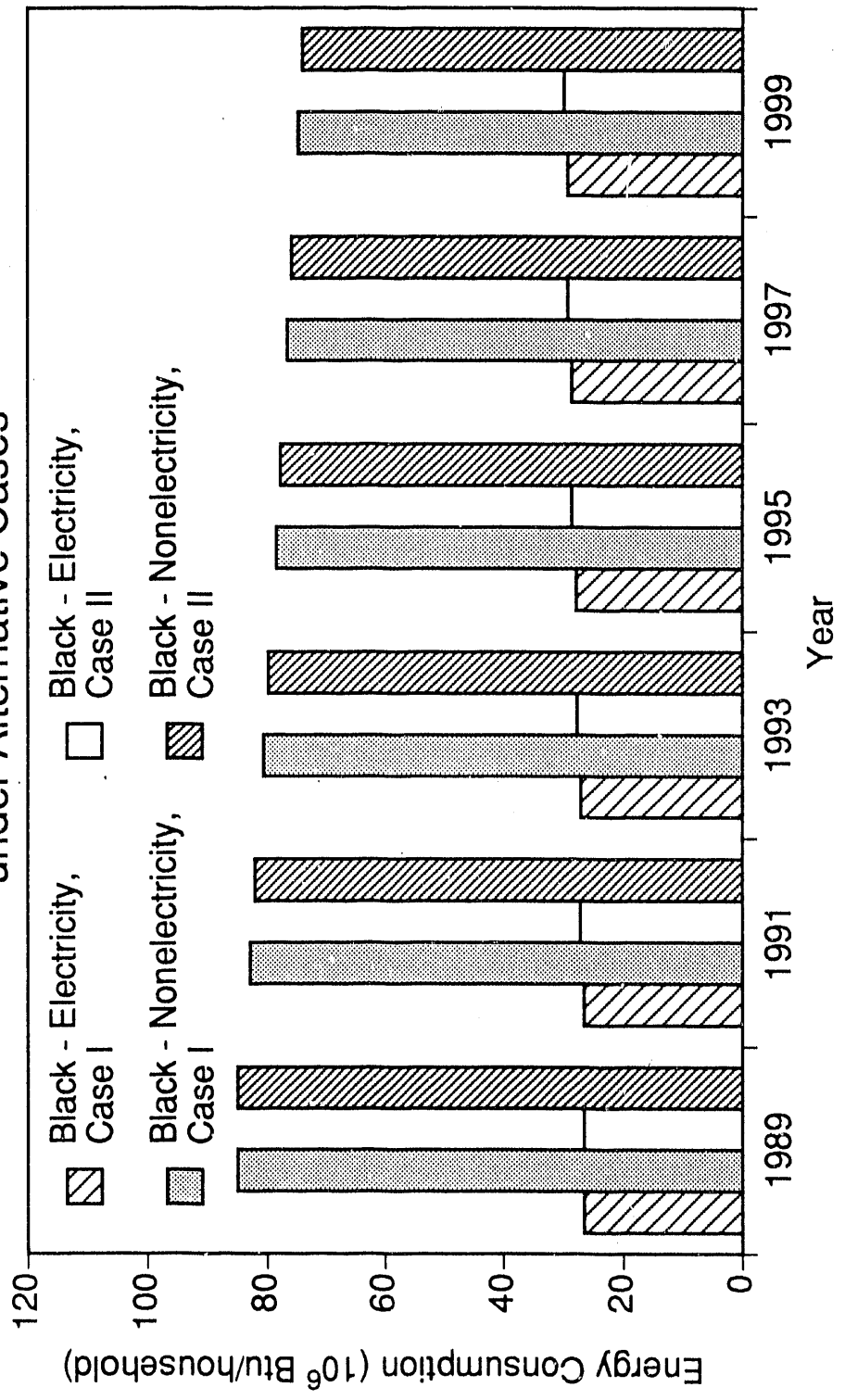Cases

Black Household Energy Consumption
under Alternative Cases

FIGURE 6 Hispanic Household Energy Consumption under Alternative
Cases

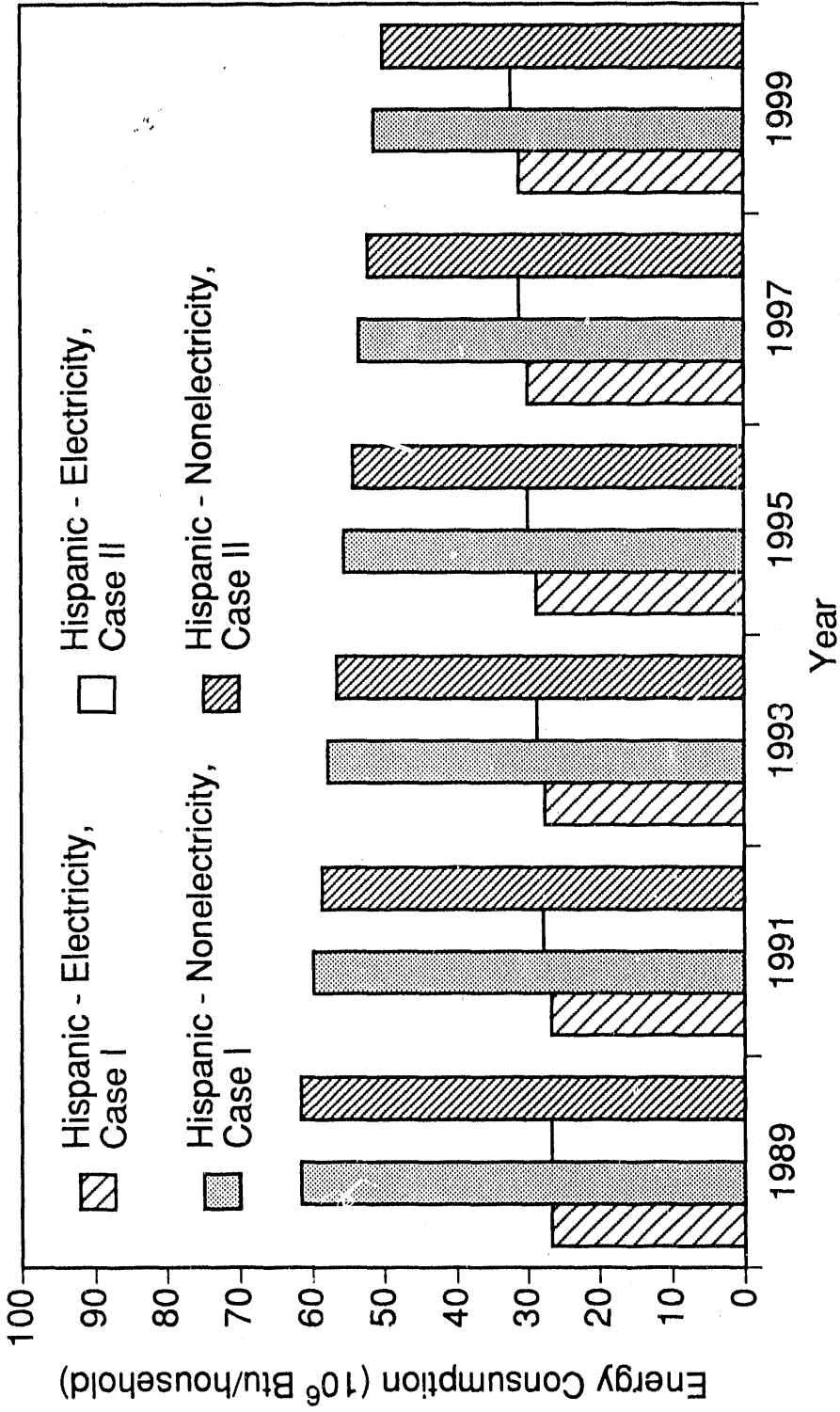Hispanic Household Energy Consumption under Alternative Cases

Legend:
- Hispanic - Electricity, Case I
- Hispanic - Electricity, Case II
- Hispanic - Nonelectricity, Case I
- Hispanic - Nonelectricity, Case II

Energy Consumption (10⁶ Btu/household)

Year

FIGURE 7   Poor Household Energy Consumption under Alternative Cases

Poor Household Energy Consumption under Alternative Cases

FIGURE 8   Nonpoor Household Energy Consumption under Alternative
Cases

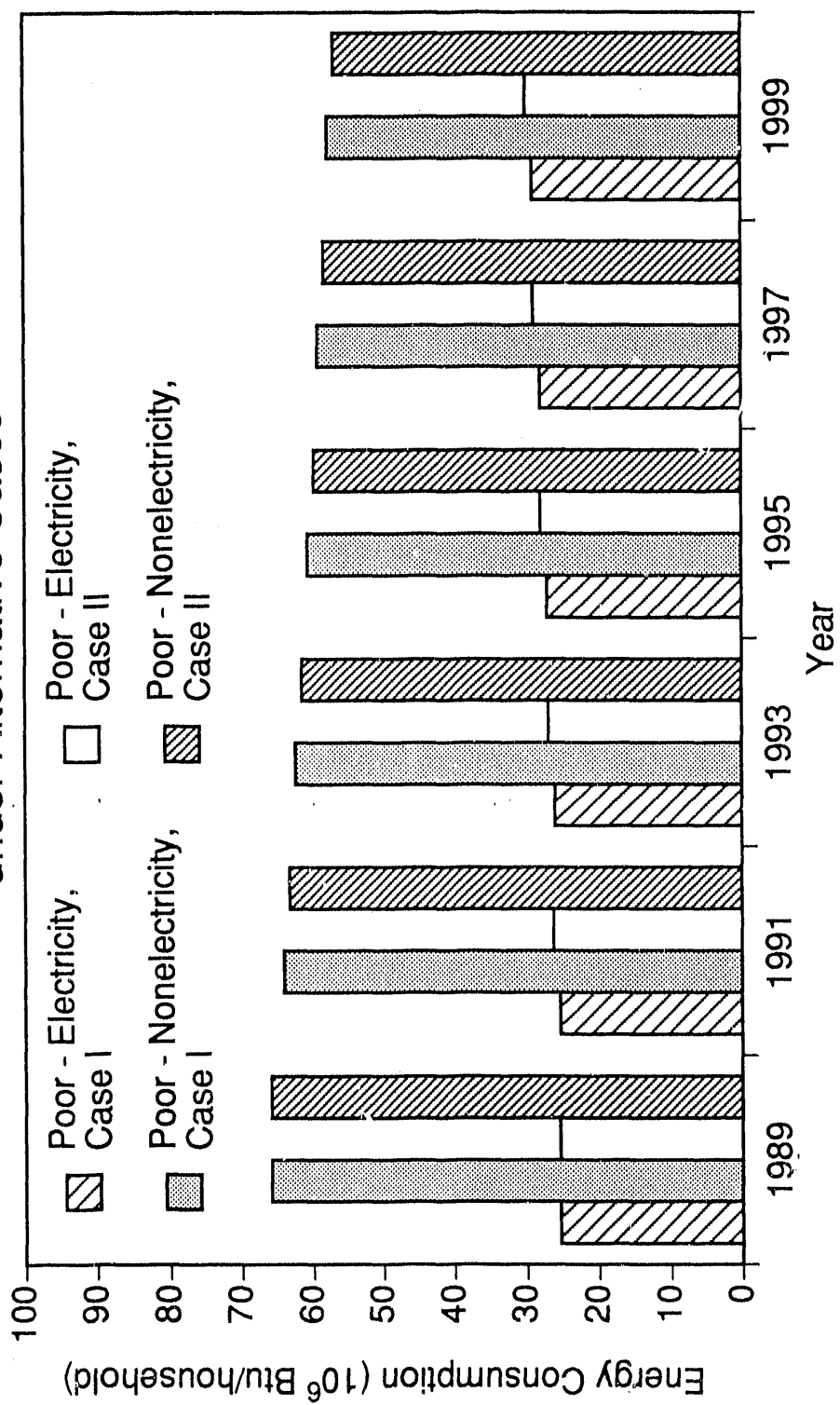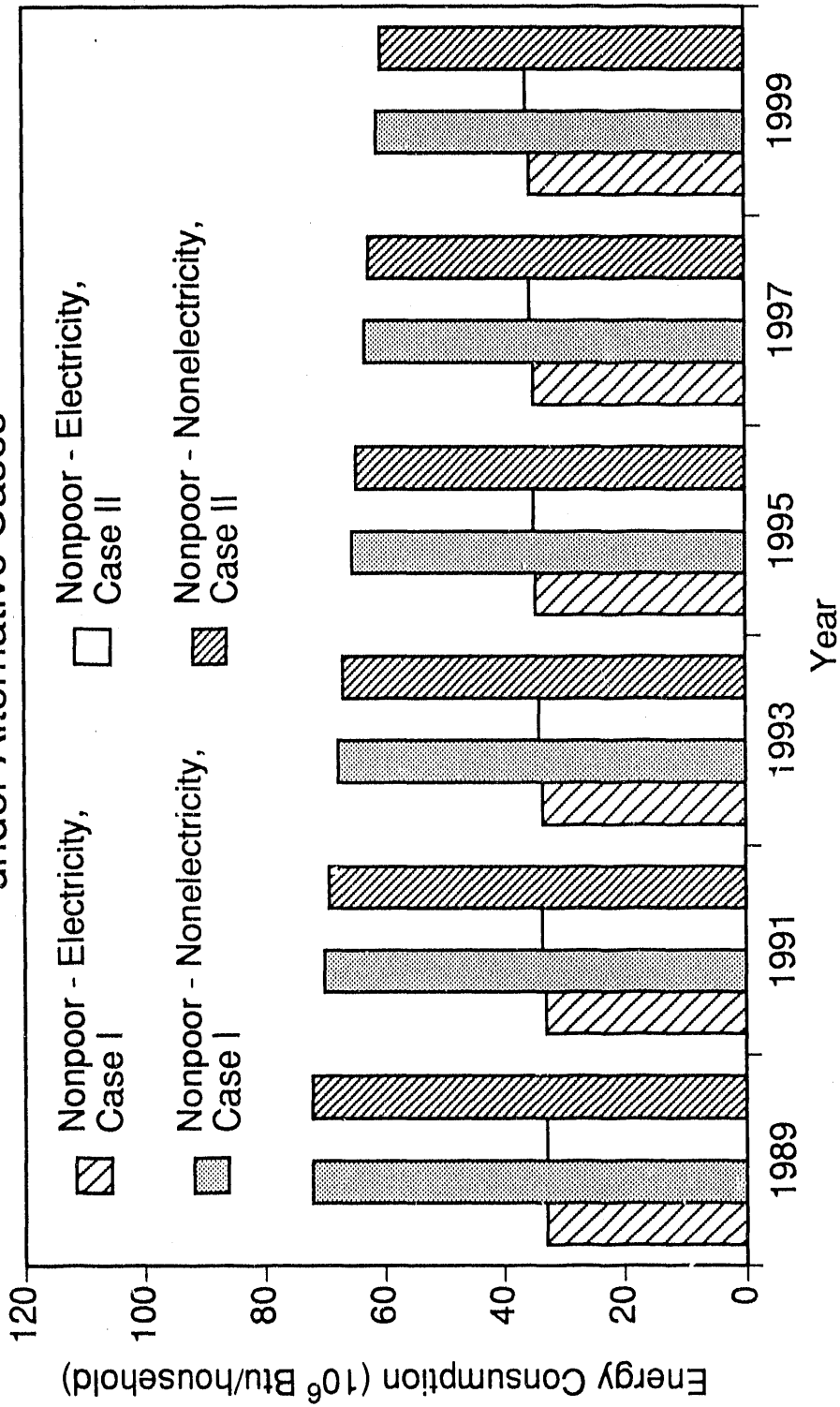Nonpoor Household Energy Consumption under Alternative Cases

Legend:
- Nonpoor - Electricity, Case I
- Nonpoor - Electricity, Case II
- Nonpoor - Nonelectricity, Case I
- Nonpoor - Nonelectricity, Case II

X-axis: Year (1989, 1991, 1993, 1995, 1997, 1999)
Y-axis: Energy Consumption (10^6 Btu/household) (0, 20, 40, 60, 80, 100, 120)

FIGURE 9   Energy Consumption of Majority, Black, and Hispanic
Households under Alternative Cases
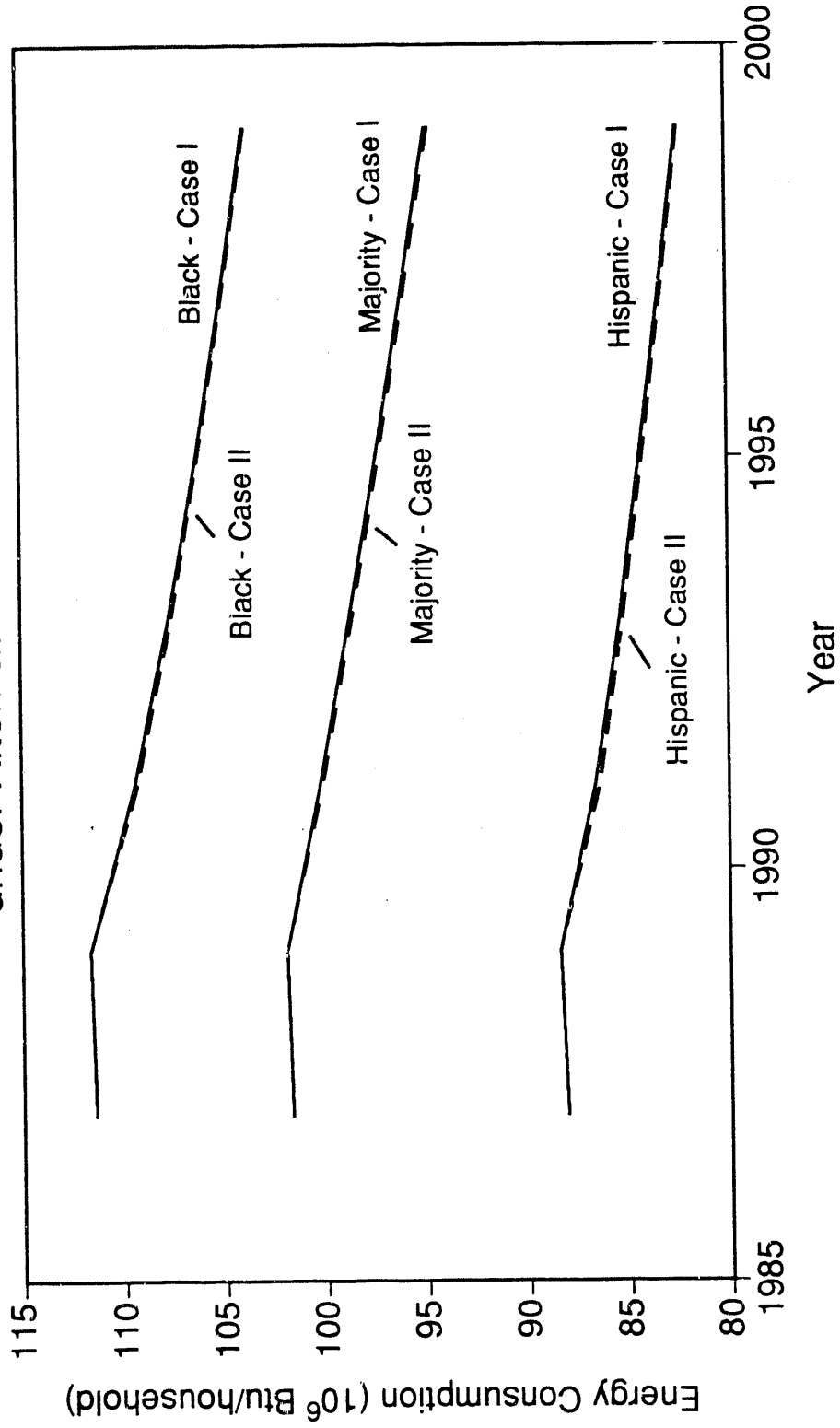
Energy Consumption
under Alternative Cases

Black - Case I

Black - Case II

Majority - Case I

Majority - Case II

Hispanic - Case I

Hispanic - Case II

Year

Energy Consumption (10^6 Btu/household)

115
110
105
100
95
90
85
80

1985
1990
1995
2000

FIGURE 10   Energy Consumption of Poor and Nonpoor Households under
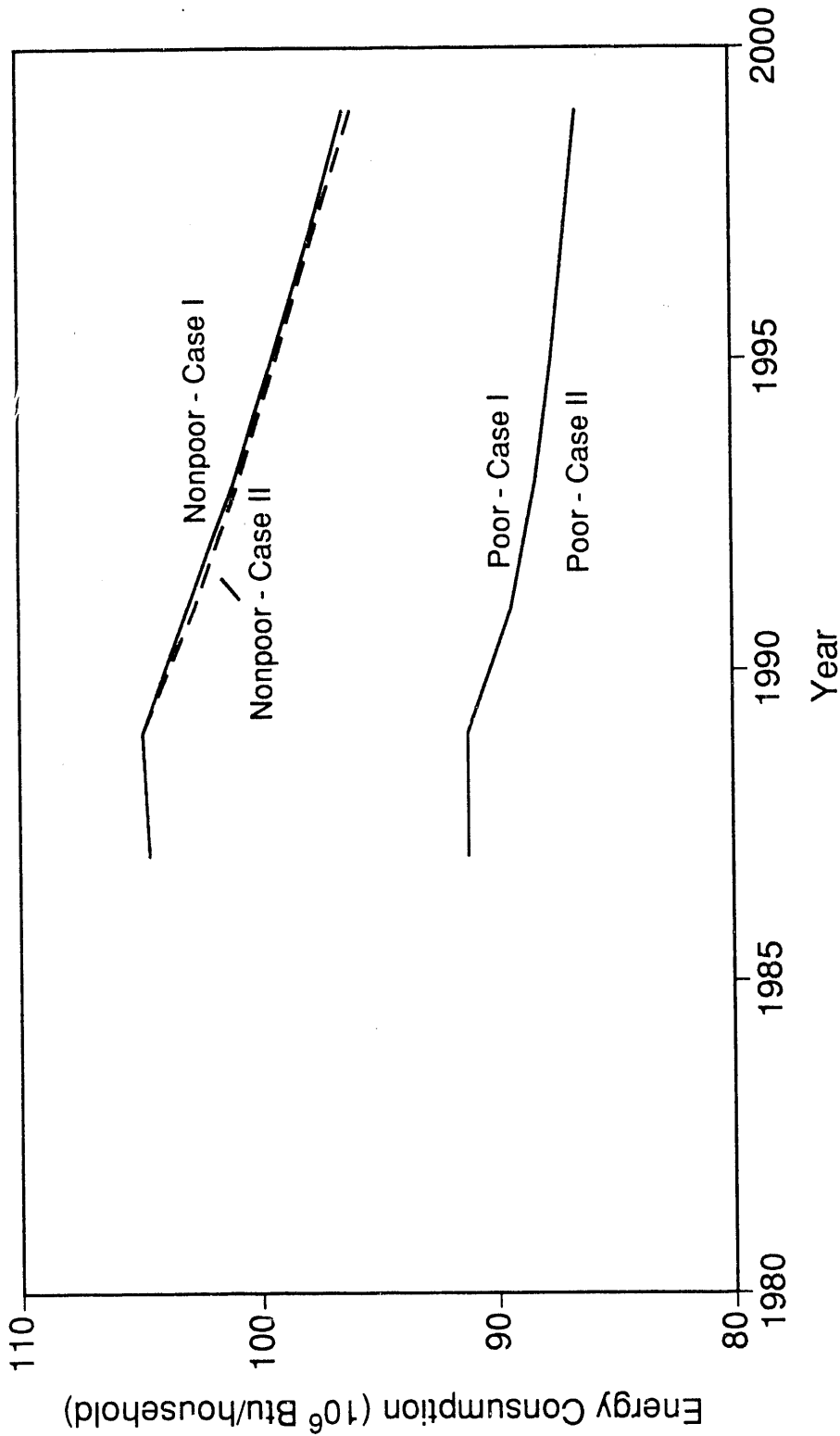Alternative Cases

Energy Consumption
under Alternative Cases

Nonpoor - Case I

Nonpoor - Case II

Poor - Case I

Poor - Case II

Energy Consumption (10⁶ Btu/household)

Year

TABLE 4   Total Energy Expenditures ($/household)

| Group | Total Energy Expenditure ($/household) by Year | | | | |
| | Case I | | | Case II | |
	1989	1993	1999	1993	1999
Majority	1154	1298	1780	1359	1864
Black	1184	1338	1891	1414	1997
Hispanic	1042	1186	1695	1252	1784
Poor	988	1122	1614	1188	1705
Nonpoor	1188	1341	1850	1403	1932

As might be expected, given the relative insensitivity of consumption with respect to rising energy prices, energy expenditures increase rather dramatically for each population group.   Figures 11 to 15 show the projections of household electricity and total energy expenditures for majority, black, Hispanic, poor, and nonpoor groups under the two cases.

The expenditures rise the most for poor households between 1989 and 1999 (64% under Case I and 73% under Case II).   This contrasts with an increase in the consumer price index of 60% under Case I and 61% under Case II.

Table 4 provides energy expenditure estimates for each of the groups for selected years.

Energy Expenditure as Share of Income

As shown in Figure 3 under Case I, household income is forecasted to increase at a higher rate than the rate of escalation

FIGURE 11 Majority Household Energy Expenditures under Alternative
Cases

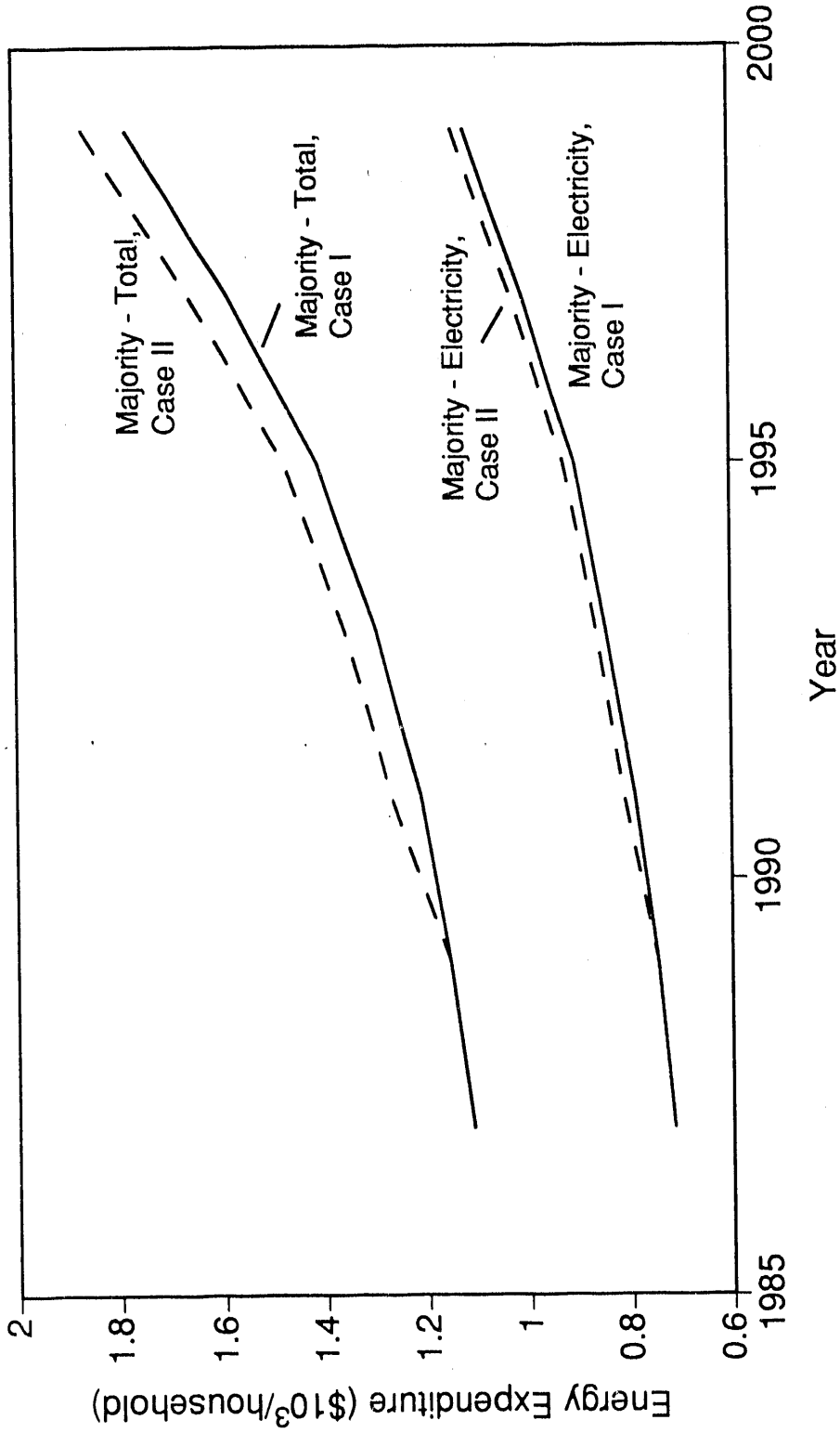Majority Household Energy Expenditures
under Alternative Cases

Energy Expenditure ($10³/household)

Majority - Total,
Case II

Majority - Total,
Case I

Majority - Electricity,
Case II

Majority - Electricity,
Case I

Year

FIGURE 12   Black Household Energy Expenditures under Alternative
Cases

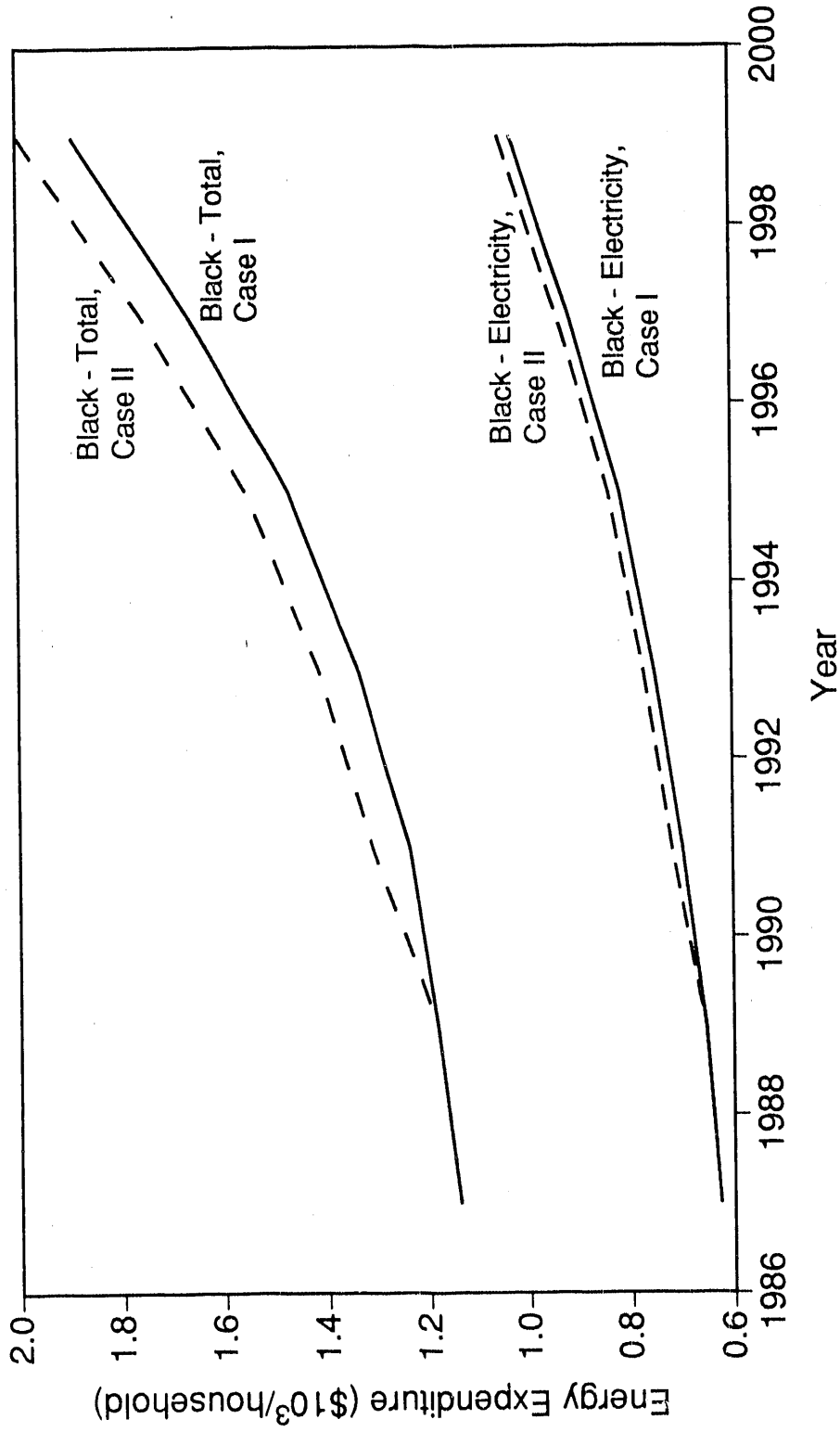# Black Household Energy Expenditures under Alternative Cases

Black - Total,
Case II

Black - Total,
Case I

Black - Electricity,
Case II

Black - Electricity,
Case I

Energy Expenditure ($10³/household)

2.0 1.8 1.6 1.4 1.2 1.0 0.8 0.6

1986   1988   1990   1992   1994   1996   1998   2000

Year

FIGURE 13 Hispanic Household Energy Expenditures under Alternative
Cases

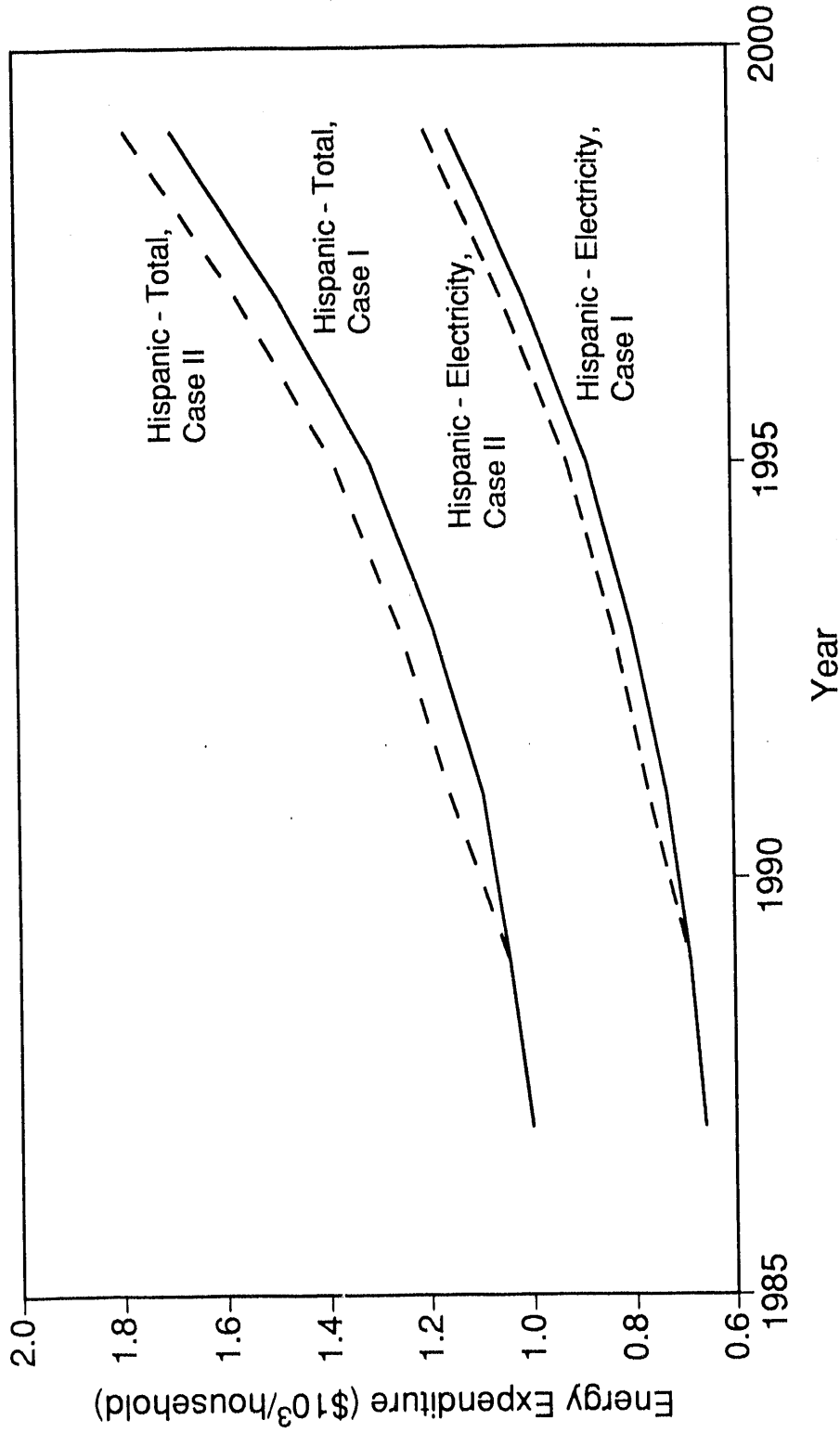# Hispanic Household Energy Expenditures under Alternative Cases

FIGURE 14   Poor Household Energy Expenditures under Alternative
Cases

Poor Household Energy Expenditures
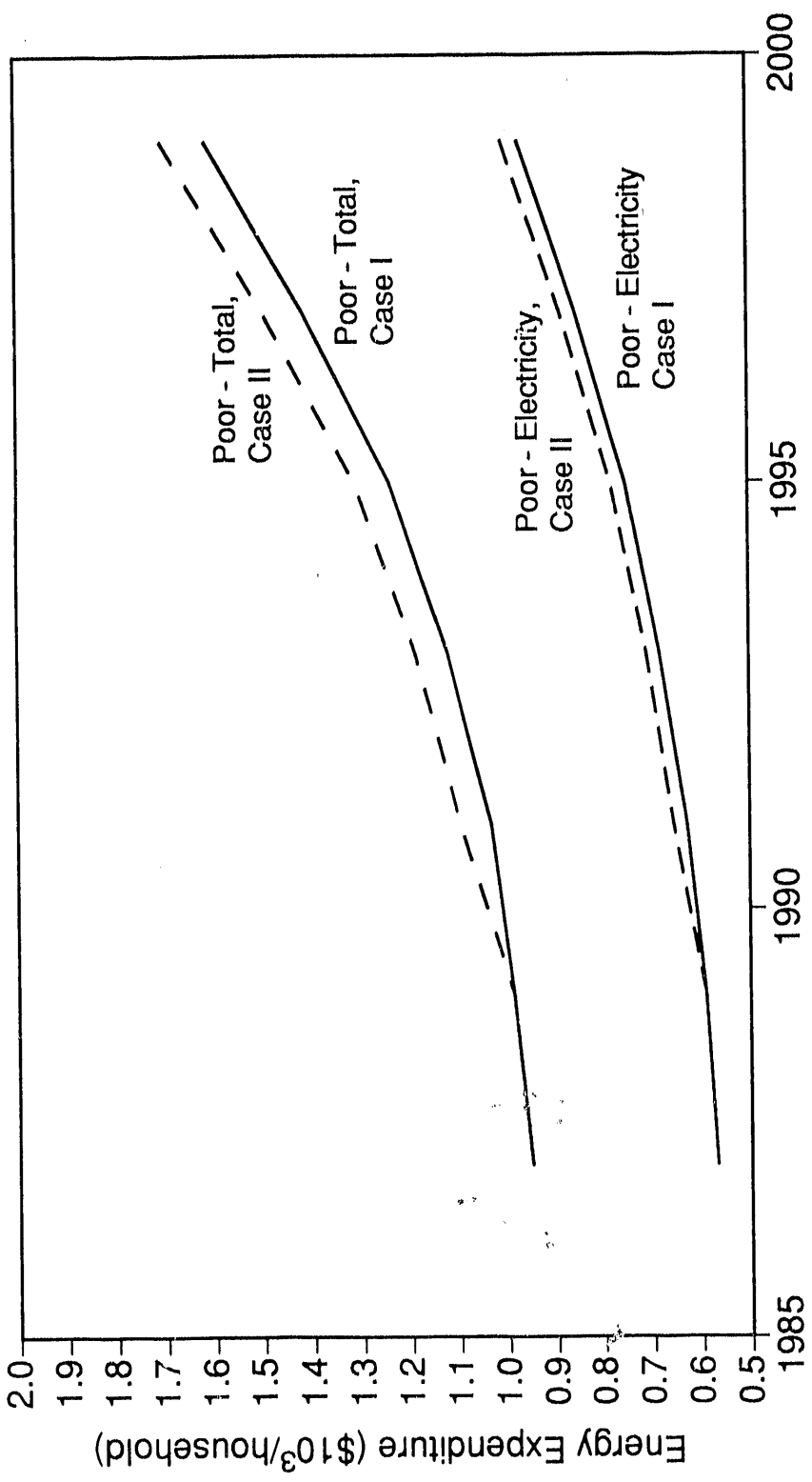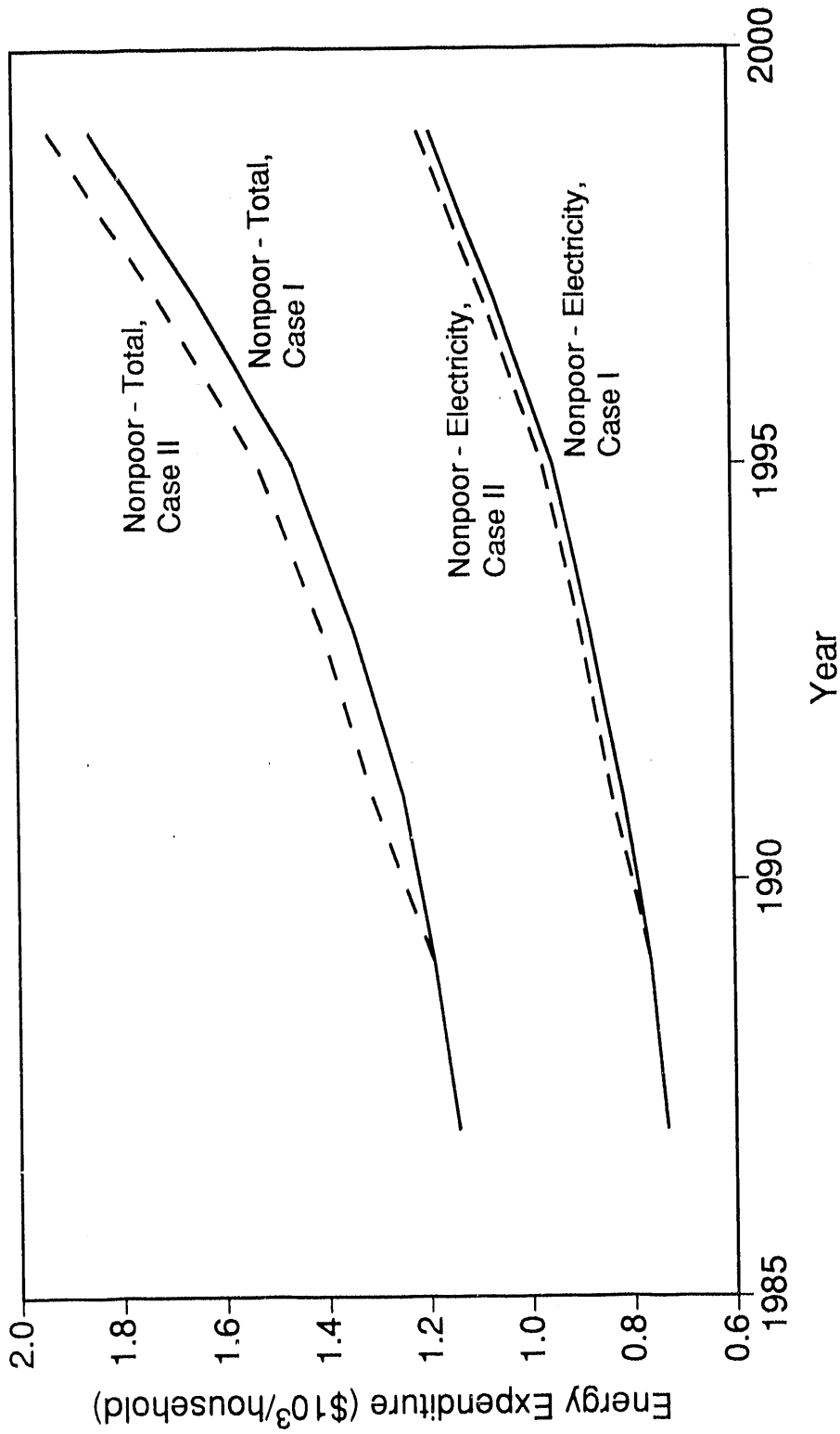under Alternative Cases

Poor - Total,
Case II

Poor - Total,
Case I

Poor - Electricity,
Case II

Poor - Electricity
Case I

Energy Expenditure ($10³/household)

Year

FIGURE 15 Nonpoor Household Energy Expenditures under Alternative Cases

Nonpoor Household Energy Expenditures
under Alternative Cases

Energy Expenditure ($10³/household)

Year

Nonpoor - Total,
Case II

Nonpoor - Total,
Case I

Nonpoor - Electricity,
Case II

Nonpoor - Electricity,
Case I

of (1) electricity prices between 1989 and 1999 and (2) nonelectricity energy prices between 1989 and 1993. As such, the percent of income spent on energy declines continuously from 1989 to 1995 for all groups (Figures 16 and 17). A milder turnaround then begins. By 1999, energy expenditure as share of income for majority households is forecasted to be only 0.33% short of their levels in 1989, 0.38% short for black households, 0.19% short for Hispanic households, 0.61% short for poor households, and 0.28% short for nonpoor households. Under Case II, the above energy expenditure as shares of income for each of the household groups rises in 1991 before it falls in 1993 and 1995 (Figures 16 and 17). It then resumes an upward path for all groups. For the Hispanic and poor groups, the shares cross their 1989 levels in 1997 and continue to rise thereafter. By 1999 the shares are higher than their 1989 levels by 0.05% for Hispanic households and by 0.27% for poor households. For black households, the share in 1999 will reach its 1989 level. However, shares for majority and nonpoor groups will only narrow the difference between their 1989 and 1999 levels. Specifically, the majority households are forecasted to be only 0.14% short of their 1989 levels while nonpoor households are forecasted to be only 0.10% short.

Table 5 provides energy expenditure as share of income for each of the groups for selected years.

FIGURE 16   Energy Expenditure as Share of Income for Majority,
Black, and Hispanic Households under Alternative Cases

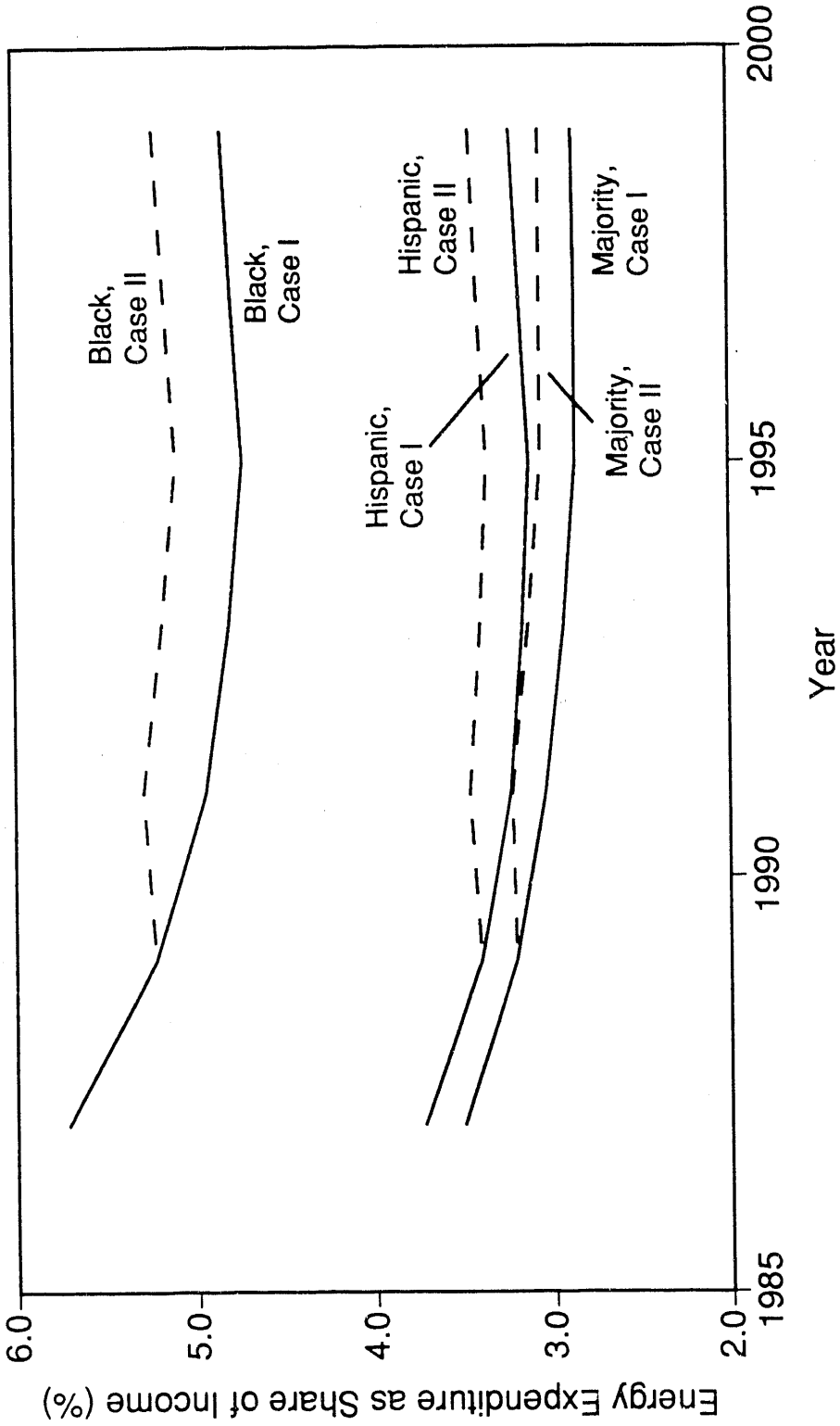Energy Expenditure as Share of Income under Alternative Cases

Black, Case II

Black, Case I

Hispanic, Case II

Hispanic, Case I

Majority, Case I

Majority, Case II

Energy Expenditure as Share of Income (%)

6.0

5.0

4.0

3.0

2.0

1985   1990   1995   2000

Year

FIGURE 17   Energy Expenditure as Share of Income for Poor and
Nonpoor Households under Alternative Cases

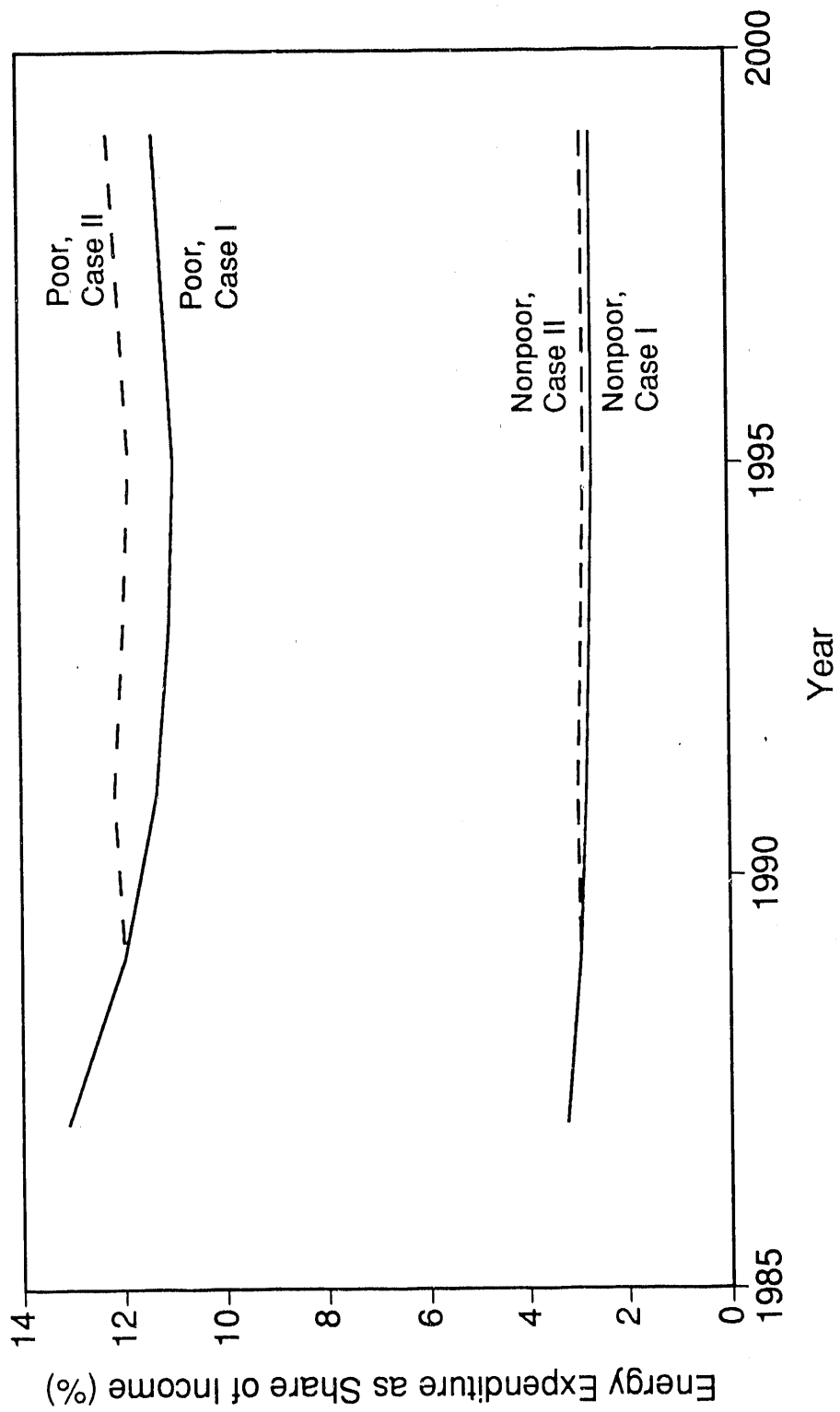Energy Expenditure as Share of Income under Alternative Cases

Poor, Case II

Poor, Case I

Nonpoor, Case II

Nonpoor, Case I

Year

Energy Expenditure as Share of Income (%)

TABLE 5 Energy Expenditure as Share of Income (%)

| | Total Energy Expenditure as Share of Income (%) by Year | | | | |
| | Case I | | | Case II | |
Group	1989	1993	1999	1993	1999
Majority	3.21	2.94	2.88	3.14	3.07
Black	5.23	4.82	4.85	5.19	5.23
Hispanic	3.41	3.17	3.22	3.41	3.46
Poor	11.97	11.08	11.36	11.96	12.24
Nonpoor	2.96	2.73	2.68	2.91	2.86

CONCLUSIONS

With regard to the application of the Minority Energy Assessment Model (MEAM) under two cases, several conclusions may be drawn. Among all household groups in 1989, (1) total energy consumption was highest for black households (112 mBtu/household) and lowest for Hispanic households (88 mBtu/hh); (2) total energy expenditure was highest for nonpoor households ($1188/hh), a close second for black households ($1184/hh), and lowest for poor households ($988/hh); and energy expenditure as share of income was highest for poor households (12.0%) and lowest for nonpoor households (3.0%). Under both cases, the total energy consumption peaks in 1989 for all households. This occurs mostly because the analysis presented in this paper assumes that over the 1989-99 period, the energy demand curve for each of the five population groups falls by 10% while the electricity demand curves rise by 10% to reflect an increase in proportions of households located in the

South and West and a higher incidence of electricity use in new homes. Additionally, because of the resulting higher energy prices, the Persian Gulf Crisis (Case II) slightly reduced household energy consumption for all population groups throughout the period 1989-99. Under both cases, the decline in consumption during the 1989-99 period is lowest for poor households. Under both cases, household energy expenditures over the period 1989-99 increased for all population groups - but disproportionately higher for poor, Hispanics and blacks. This is mostly attributed to the differences in price elasticities with poor and minority energy expenditures more sensitive to the rising nonelectric energy prices. Also, the change in household energy expenditures is a result of the long-term affect of the fuel price shock under Case II. Although crude oil prices declined after the end of the Gulf Crisis, energy prices still remain at slightly higher levels than under the Case I. In addition, many consumer energy conservation measures taken during the crisis are irreversible and remain in effect over the long run. The energy expenditures rise the most for poor households between 1989 and 1999 (64% under Case I and 73% under Case II). This contrasts with a 60% increase in the consumer price index under Case I and a 61% increase under Case II. Under Case I, by 1999 the energy expenditures as shares of income for majority households is forecasted to be only 0.33% short of their levels in 1989, 0.38% short for black households, 0.19% short for Hispanic households, 0.61% short for poor households, and 0.28% short for nonpoor households. Under Case II, the impact on share is more severe than under Case I. Specifically, by 1999, energy

expenditures as shares of income are forecast to be 0.14% short of their 1989 levels for majority households, 0.10% short for nonpoor households, at par for black households, 0.05% higher for Hispanic households, and 0.27% higher for poor households.

Like any model and its application, certain limitations apply. First, the scope of the racial/ethnic minorities in the model is limited to blacks and Hispanics. Because of the limited observations in DOE's Residential Energy Consumption Survey (RECS) data, the model could not be extended to include other minority groups, such as American Indians and Asian-Americans. Second, the parameters of the MEAM equations are estimated from the RECS data base, which is now available only every three years. Because the model captures movements over a two-year period, it is more suitable for medium and long-run analyses than for short-run analyses. Third, the energy demand projections are based on the assumption that household income for each group grows at the same rate -- variations in the actual rates will affect both expenditure share and, to a lesser extent, energy consumption estimates. These analytical limitations indicate areas that warrant further research.

responsibility for the content of this paper remains with the authors; any opinions expressed herein are solely theirs.

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PROJECTING HOUSEHOLD ENERGY CONSUMPTION WITHIN A

CONDITIONAL DEMAND FRAMEWORK

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INTRODUCTION

Few models attempt to assess and project household energy consumption and expenditure by taking into account differential household choices correlated with such variables as race, ethnicity, income, and geographic location. The Minority Energy Assessment Model (MEAM), developed by Argonne National Laboratory (ANL) for the U.S. Department of Energy (DOE), provides a framework to forecast the energy consumption and expenditure of majority, black, Hispanic, poor, and nonpoor households. Among other variables, household energy demand for each of these population groups in MEAM is affected by housing factors (such as home age, home ownership, home type, type of heating fuel, and installed central air conditioning unit), demographic factors (such as household members and urban/rural location), and climate factors (such as heating degree days and cooling degree days). The welfare implications of the revealed consumption patterns by households are also forecast. The paper provides an overview of the model methodology and its application in projecting household energy consumption under alternative energy scenarios developed by Data Resources, Inc., (DRI).

END

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