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We are in 1987.

Free World Total Primary Energy Demand & Oil's Share

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Abstract

We present estimates of future total energy consumption and oil's market share. To make predictions we developed five pairs of regional models that span the Free World. The models' explanatory parameters are income, population, total energy price, crude oil price, and non-oil energy price. The models' coefficients were estimated using the most recently published data. Projections are given of energy demand and oil share through 2000. Sensitivity of future crude-oil demand to changes in income and prices is examined. Estimates made with linear programming were judged better than estimates with least squares, so the former are presented.

Validation used hind casting as well as forecasting. Hind casting revealed that a perfect history match does not always mean that the model will provide reasonable projections. Considerable judgment must be applied to obtain reasonable results.

Introduction

Following two big jumps in the 70s, oil price recently fell precipitously – because the price set by the second jump considerably exceeded that required to equilibrate world oil supply and demand. Shifts in world energy markets triggered by the two price jumps are still in progress. The effect of changes spawned by the recent oil price collapse will not be fully assessable until some time in the future. Since this study's parameters are based upon data for 1970-1985, we can only speculate on how well our projections reflect the impact of this evolving new effect.

We present the principal features of a computer model developed to quantify the effects of changes in energy prices on future total energy consumption and oil's market share. For convenience, we refer to this system by the acronym WEDOS (World Energy Demand and Oil Share). We first sketch the general structure and the demand regions of WEDOS, review our mathematical approach, and list the inputs required. We discuss our coefficient-estimation methods, and give the coefficients selected for making projections. Finally, we present projections of total energy demand and oil's market share through 2000 for plausible future profiles of crude oil price and regional income (GDP), followed by concluding remarks.

Structure Of WEDOS

In WEDOS, the Free World is subdivided into five demand regions. As is shown in Figure 1, each WEDOS region predicts primary energy demand and oil demand vs time. Each prediction involves four stages.

1. Organize and manipulate historical data (1970-1985). Activities include
    - Estimate parameters (price, income and share elasticities and response-lag fractions)
    - Generate smoothed historical time series of annual rates of charge (growth rates) of population, per capita energy consumption and oil's share of total energy demand.

2. Calibrate (history match) dynamic growth models for population, per capita consumption and oil share using parameters estimated.
3. Define assumptions (scenarios) and input to WEDOS.
4. Calculate predicted demand for total energy and oil vs time.

Figure 2 displays the calculation steps for a year in each region's total energy demand and oil share models. Growth rates of population and per capita consumption are used to predict values of these variables in the next year which, when multiplied together, give total energy demand in a region. Similarly, the predicted growth rate in oil share is transformed into next year's share. Multiplication of share times total demand gives next year's oil demand. Finally, summing the regional values gives Free World total energy and oil demand.

The demand regions considered in WEDOS are:

US	United States of America
WEUR	Austria, Belgium, , Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxemburg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom
JAPA	Japan
CAAN	Canada, Australia, New Zealand
FOFW	Rest of the Free World

This regional structure was selected after careful consideration of energy market share, economic output, and population growth rate for various regional combinations. Table 1 displays the 1985 data for these items in each of the regions selected.

Table 1 1985 Values of Regional Factors

Region	Population Million	Pop Growth Rate, % / YR	Real GDP Growth Rate, % / YR	% of Total Energy Used	% of Oil Used
US	238.89	0.968	2.2	37.9	35.2
WEUR	405.29	0.596	2.5	25.4	25.7
JAPA	120.83	0.675	5.0	7.5	9.2
CAAN	44.37	1.070	4.5	6.5	4.5
ROFW	2446.27	2.599	3.2	22.7	25.4

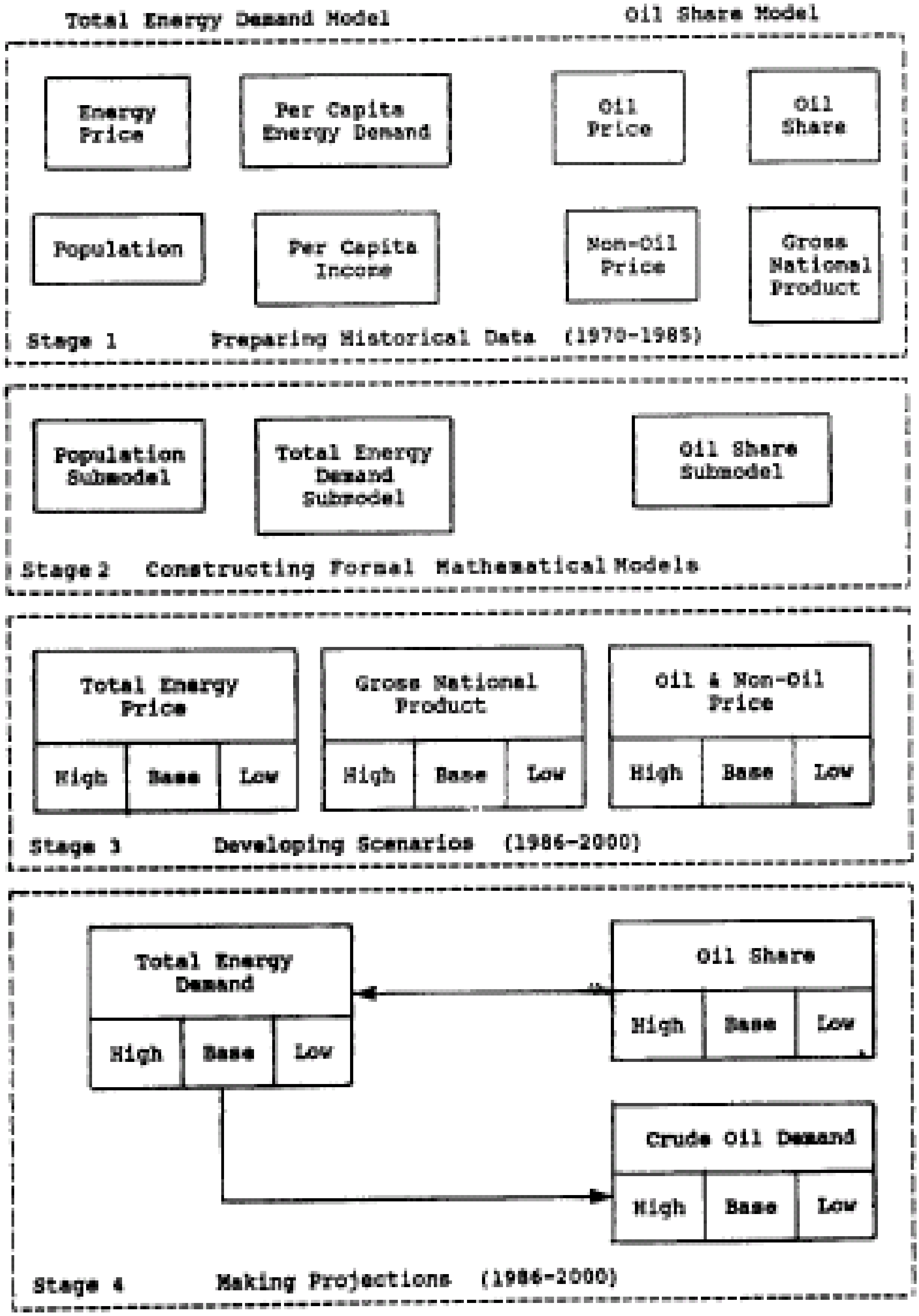

Fig. 1—General structure and methodology of WEDOS.

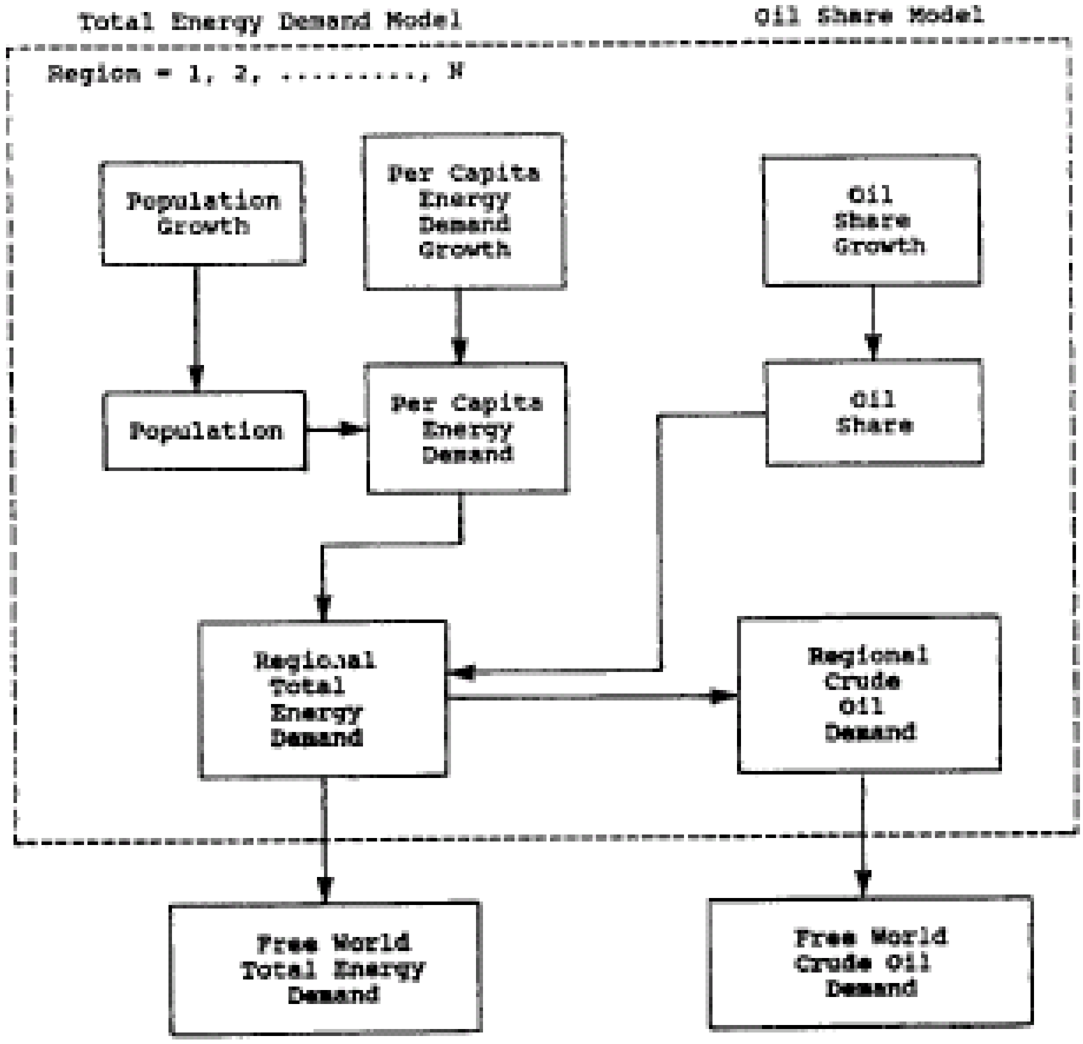

Fig. 2—Regional calculation steps in WEDOS.

Mathematical Approach In WEDOS

WEDOS's energy demand and oil share equations differ from those normally used. The quantity determined by each of these two equations is the annual rate of change rather than demand and oil share for the year. A parallel calculation starting from a base year level gives actual demand or oil share. The derivation of this form of the demand functions is given in SPE16290 [(1)]. More details may be found in AL-Blehed [(2)].

Using annual rate of change as the dependent variable is advantageous for two reasons.

1. Rate of change directly conveys an intuitively useful measure of the significance and sensibility of a projection. If, instead, level of demand or oil share is presented, the rate of change must be calculated to get a feel for the forecast's plausibility.
2. Oil price is denominated in (current) US dollars. However, real price in local currency determines consumer demand. Given a nominal dollar price in some future year, to compute

real price in local currency one must know exchange rate and cumulative inflation in the region. Fixing growth rate in real terms in each region for a scenario avoids this onerously difficult conversion.

3. The demand equation (Eq(8),SPE16290) expresses regional per capita energy demand growth as a linear function of the growth rates of energy price and regional income and of the previous year's per capita energy demand growth.
4. The share equation (Eq(19),SPE16290) linearly relates the rate change in oil share to growth rates of regional income, oil price and non-oil price and to the previous year's rate of change in oil share.
5. To factor out the effect of inflation, growth rates in income and all prices are expressed in real terms.

Inflation and Exchange Rates

Presently, oil price is the primary determinant of all energy prices. With oil price denominated in $US, behavior of a regional energy market is affected by local rate of inflation and the exchange rate of local currency to the US dollar. Although future values of these quantities are highly unpredictable, they must be taken into account in interpreting past energy market trends. Therefore, in estimating the parameters in WEDOS's demand functions, the 1970-85 income and price data were adjusted for regional inflation and exchange rate before being entered into the calculations. To allow these adjustments, average values of inflation and exchange rate vs time were determined for each region. Details of this conversion process are given in Al-Blehed [(2)]. It is not necessary to specify future values of exchange rates and regional inflation rates if growth rates in the demand equations are stated in real terms in each region. However, to check if these stated growth rates were reasonable, the implied inflation rate for a constant exchange rate was determined in each region. The average inflation rate for the US used in our projections was 4%/yr. The implied values for the other industrialized regions varied from this average by at most 2.5%/yr. The implied value for ROFW was approximately 15%/yr. The sensitivity of demand projections to possible variations in these rates could be tested with WEDOS, but results of such tests are not included.

Estimation Procedures

Although coefficients in demand functions are commonly estimated using least squares – which prints out statistical measures of reliability of coefficients – we did not use that procedure. We believed that if we could place judgmental restrictions on the values determined by the estimation procedure, the demand and share equations used in WDEOS would be more robust & reliable. This we could do minimizing sum of absolute deviations with linear programming (LP). With this premise, we proceeded as follows:

1. Compiled elasticities and lag parameters from all available energy demand studies. After scrutiny, a representative value range was selected for each coefficient in each region.
2. Using the LP iteratively derived from each region's historical time series values that for the demand and share equations
   - fell within the assigned value range,
   - yielded a reasonable profile of errors (actual minus predicted value vs time),
   - resulted in sensible projections, and
   - minimized errors during the historical period.
   - On the first iteration impose no constraints on the values that the LP could select.

- On the second iteration, add constraints to the LP that force coefficient values to fall within the range set.
- On subsequent iterations, modify and/or add constraints until all parameters were consistent and satisfactory.

3. Fine-tune the projection equations with a hind cast using the parameter values. A hind cast is the inverse of a forecast.
   - Starting from the most recent observation, calculate demand and share backward in time through the historical period.
   - Inspect graphs comparing the hind cast and observed energy demand and oil share.
   - If differences not acceptable, modify constraints in the LP and recalculate parameter values.
   - Repeat this fine tuning cycle until historical error profiles are acceptable.
4. Forecast demand and share through 2000.
   - Inspect graphs of results.
   - If predicted trends not acceptable, fine-tune some more.

Table 2 lists the estimated values of the parameters. Projections given below were made with these. Mathematical details of using LP estimate parameters are given in Al-Blehed [(2)].

Table 2 Demand & Share Parameters

	Total Energy Demand			**Oil Share**			
Region	**Income Elast.**	**Energy Price Elast.**	**Lag**	**Income Elast.**	**Oil Price Elast.**	**NOPrice Elast.**	**Lag**
US	**.66**	**-.21**	**.84**	**.63**	**-.41**	**.17**	**.97**
WEUR	**.74**	**-,25**	**.84**	**.71**	**-.45**	**.24**	**.91**
JAPA	**.64**	**-22**	**.71**	**.61**	**-.43**	**.23**	**.92**
CAAN	**.74**	**-.19**	**.93**	**.74**	**-.49**	**.19**	**.89**
ROFW	**1.05**	**-.075**	**.88**	**.98**	**-.29**	**-.18**	**.93**

Future Scenarios

Energy demand and oil share projections require future values of oil, non-oil and average energy price and of regional income. To portray the uncertainty of these latter assumptions, projections for three scenarios are presented. The three crude oil price profiles (in current $US/bbl) are shown in Fig 3 along with the historical (1970-85) values used in this study. Fig 4 gives these oil price profiles in real 1980 $US/bbl.

1. The high trend assumes $14/bbl in ’86, $21/bbl ‘87 and to 1985's prevailing price in ‘92. After ‘92 price rise steadily to $45/bbl in 2000.
2. The base case scenario assumes oil price, increases gradually from 1986 to 2000, returning to $20/bbl in ‘90 and $34/bbl in 2000.
3. The low price trend assumes price recovers in ’89 increasing to $18/bbl in ’95 and $30/bbl in 2000. This trend could only occur if OPEC’s production is loosely uncontrolled.

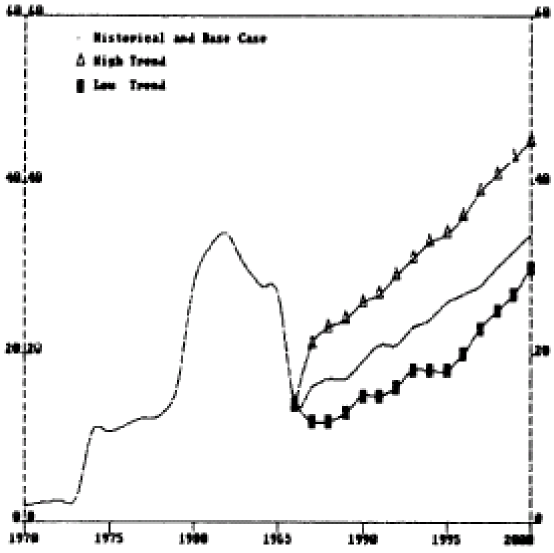

Fig. 3—Crude oil prices, current $U.S./barrel.

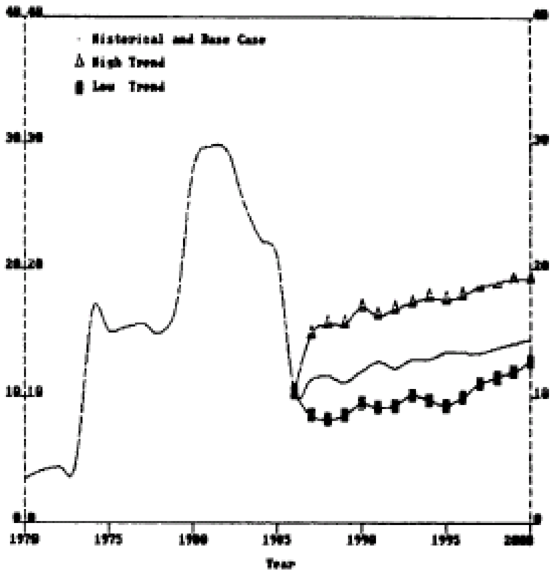

Fig. 4—Crude oil prices, real 1980 $U.S./barrel.

Natural gas price is assumed to be 75% of BTU parity with oil through the projection period. With no supply shortage in the foreseeable future, coal price is assumed to increase gradually in step with inflation. As a result, coal price is only about 40% of oil on a Btu basis, thus maintaining its clear-cut economic attractiveness.

Table 3 lists the growth rates of real regional GDP used in the three scenarios. The effect of oil price on economic growth rate is assumed to be the same in the US, WEUR and CAAN -- moving from the low to the high oil price trend decreases GDP growth rate by 1 %yr. The other two regions, JAPA and ROFW, are also assumed to experience a 1 %/yr reduction in economic growth rate, but from higher levels (3.5►4.5 in JAPA and 3.0►4.0 in ROFW).

Table 3 Real GDP Growth Rate, % / YR

Region	GDP Scenarios (1986 – 2000)		
	High Oil Price	Base Rate	Low Oil Price
US	2.0	2.5	3.0
WEUR	2.0	2.5	3.0
JAPA	3.5	4.0	4.5
CAAN	2.0	2.5	3.0
ROFW	3.0	3.5	4.0

Results And Discussion

This section presents highlights of projections made with WEDOS using the coefficients given in Table 2 for the three scenarios presented above. Tables 4-12 in SPE16290 (1) list results for all regions and Free World totals. Figures 6-11 show time profiles of results for the US and Total Free World. More detailed results for these three scenarios and additional sensitivity analyses are given in Al-Blehed [2]. The unit of energy demand used is million barrels of oil equivalent per day (MMBOE/D).

To provide a checkpoint on the validity of the LP method of estimating parameters, coefficients in the US total energy demand function were also determined using statistical regression techniques. Projections made for the same assumed future conditions (not one of the three scenarios) with these models are compared in Figure 5 - SPE16290 [1]. The difference is well within a realistic error tolerance for such projections. This and similar comparisons convinced us that a demand function estimated using the LP method is as valid as one estimated with regression.

TOTAL ENERGY DEMAND PROJECTIONS

Figures 6 & 7 show projected total energy demand for the US and the Free World, respectively, for the three scenarios. Average annual growth rate in total energy demand from 1985 – 2000 varies from

1. 1.5 – 2.4 %/yr for the Free world. A large portion of Free World growth occurs in ROFW – 42% for the base case (mid-range price). This concentrated growth occurs because per capita energy demand in ROFW is only 10% of the average in the four industrialized regions, whereas ROFW's population is thrice that of the other regions combined. Growth would be larger if it were not constrained by a shortage of funds.
2. 0.7 – 1.6 %/yr for the US. US growth rate is only about 60 percent of WEUR's, one-half of JAPA'S and CAAN'S and one-third of ROFW'S. Finding the US growth rate to be lowest is presumably an indication that, given its higher per capita energy consumption rate, the US can more readily improve energy efficiency -- US energy/GDP ratio should continue to decrease.

As Figures 6 & 7 illustrate, increasing oil price from mid to high price trend results in comparable growth rate reduction in all (0.3-0.4%/yr) in all regions. Lowering oil price increases demand growth by about 0.3-0.7%/yr in all regions. Figures 6 shows the impact of differing growth rates – in 2000, US demand with low price exceeds that with high price by nearly 15 percent of energy demand in 1985.

OIL SHARE PROJECTIONS

Figures 8 and 9 display the projected change with price in oil's share of energy demand. For the Free World as a whole, the two price jumps in the 70s triggered a decline in oil share that is projected to continue through the end of this century. In all regions but the US, oil share falls continuously through 2000. The higher the price, the lower the share – in 2000 share with high price is 3 - 5% less than with low price in US and Free World.

In no case does oil share rise back to the peak level of the '70s. As Fig 8 shows, the recent drop in oil price acts to stabilize US share, but even with the low price scenario, the US share does not rise to the level existing prior to 1979's price jump. The most dramatic drop in share occurs in WEUR – 1.3%/yr vs less than 1%/yr elsewhere. WEUR's share is above that of the US in 1985, but falls to 7% below the US's share in 2000.

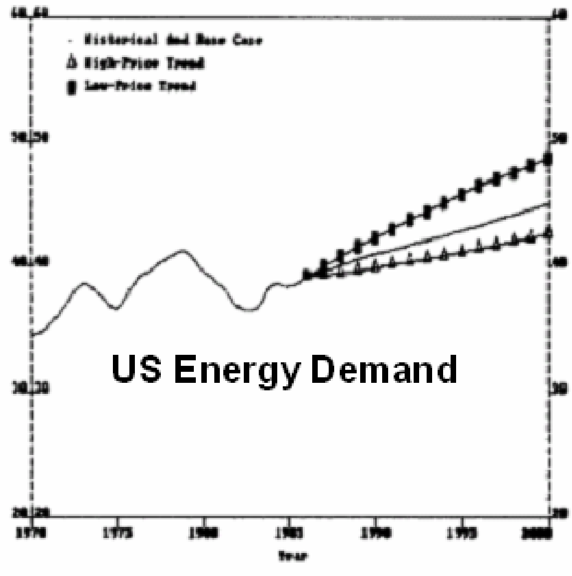

Fig. 6—U.S. total energy demand (MMBOE/D).

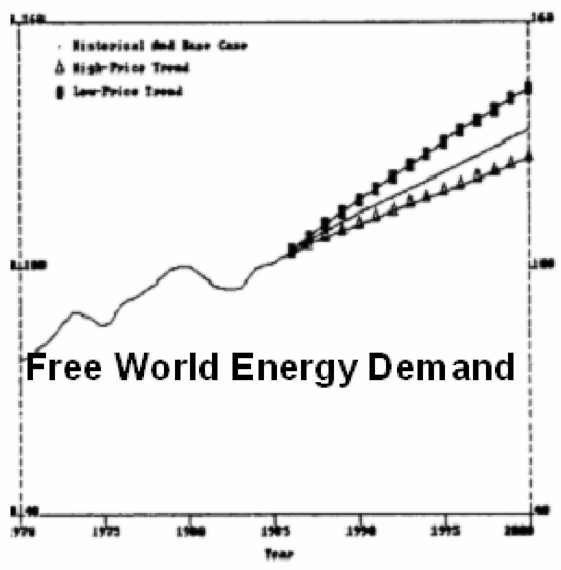

Fig. 7—Free World total energy demand (MMBOE/D).

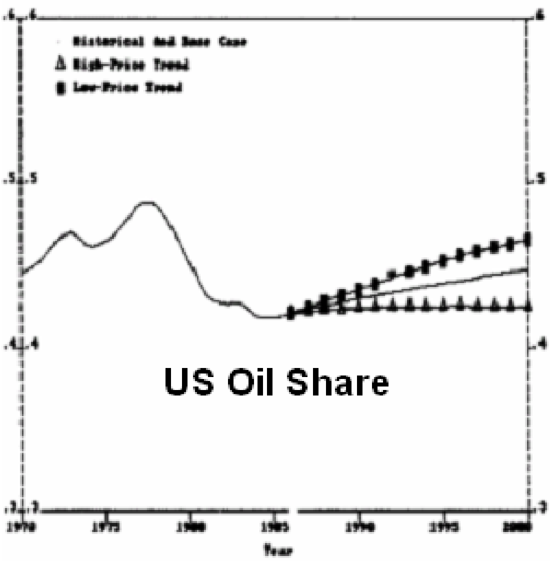

Fig. 8—U.S. oil share (fraction).

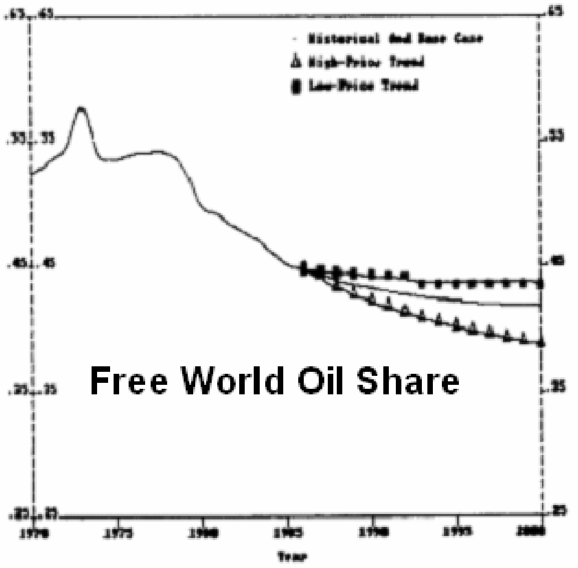

Fig. 9—Free World oil share (fraction).

CRUDE OIL DEMAND PROJECTIONS

The projected rate of oil consumption increases for all price scenarios -- except WEUR and JAPA in the high oil price scenario. Between 1985 and 2000 US demand increases

1. for the low price scenario by over 6 MMB/D,
2. for the medium price scenario by 4 MMB/D, and
3. for with the high price scenario by 2 MMB/D.

Taking into account the impact of price on the rate of development of domestic oil producing capacity, the US energy supply situation for these three scenarios might be termed:

- low price -- calamitous,

- medium price -- critical,
- high price -- serious.

With the medium price scenario Free World demand increases over 10 MMB/D by 2000. Taking into account declining production capacity, with this price profile the current capacity excess of about 10 MMB/D will have disappeared in the early 1990s. On the other hand, with the high price scenario projected Free World demand in 2000 is less than 50 MMB/D. This figure suggests that if the higher price scenario comes to pass, daily newspapers will still be reporting on OPEC's haggling over who sells how much a decade from now. Note, however, that the stringency of the higher price profile as presented in Figure 3 is strongly affected by inflation rate. Between 1985 and 2000, the nominal rate of price increase for this profile is 8.7%/year, which, given our assumed 4%/year inflation rate implies 4.7%/year real price increase. This steep real growth rate causes the suppression in oil demand growth.

Figures 10 and 11 compare projected and historical oil demand profiles for the US and the Free World, respectively. For the US, the medium price trend results in oil demand in 2000 slightly above the peak rates in the 70s. For the Free World the projected and historical demand patterns are similar to those for the US -- a consequence of the similarity of price sensitivities in all regions.

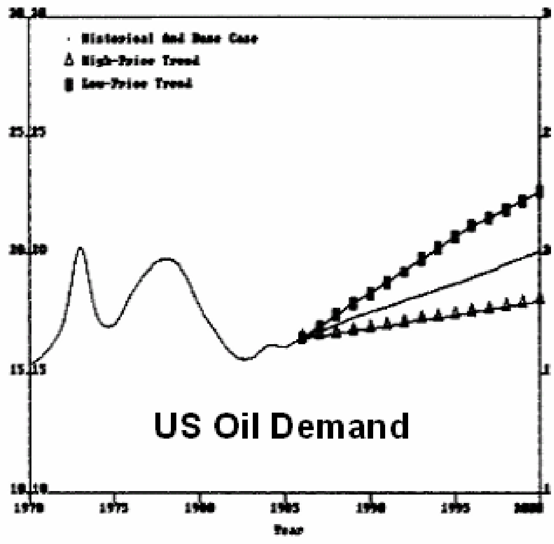

Fig. 10—U.S. crude oil demand (MMB/D).

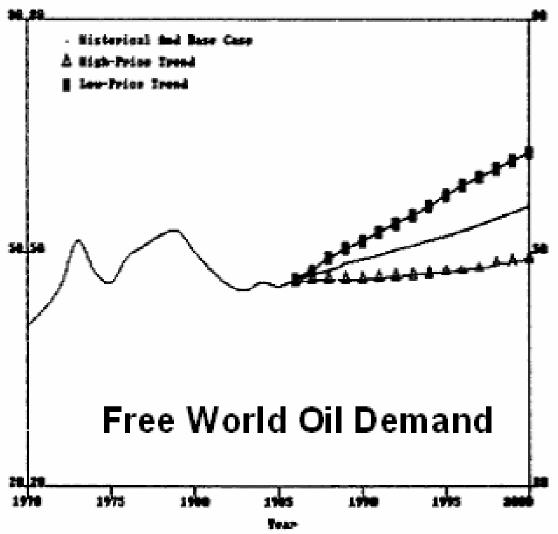

Fig. 11—Free World crude oil demand (MMB/D).

How About Now – 2009?

Quite naturally, looking back after 20 years, you ask, “How good was my prediction?” Extrapolating the curves in Figure 10 to 2010, we see that the high-price (lower) curve follows actual crude oil consumption in the US fairly closely. The BP Statistical Review of World Energy_2009 gives US consumption nearly constant at 20 MMB/D from 2000 -09. The BP total includes around 1MMB/D of NGL liquids. The high-price curve of Figure 3 projects to close to today’s $70/bbl. Not too bad!!

In contrast, the low-price (upper) curve of Figure 11 extrapolates to around 70 MMB/D. By comparison BP’s Total World – Former Soviet Union = 80.4 MMB/D. Subtracting 10 MMB/D of NGLs, we arrive at the extrapolated value. How to explain this anomaly – demand growth corresponding to low-price curve? Inspect Table 3 and the reason jumps out. Growth rate of

GDP in ROFW – China, India & Rest of Asia in particular – was about double the value assumed for the high-price scenario.

Comments And Conclusions

We believe the results of this study confirm the soundness of the approach used to determine energy demand functions.

1. Review all demand studies that bear on the energy sector and/or type under consideration and compile a table of the reported elasticities and lag fractions.
2. Assign a feasible range for each parameter in each region. A parameter's value is allowed to fall outside the assigned range only if thorough "history matching" tests strongly support such an allowance.
3. Perform a constrained error minimization. LP was used to minimize the sum of the absolute values of the deviations because with LP one can conveniently place bounds on the parameter values. This allows the demand function to be "molded" into a best fit. Comparison with least squares indicated there is likely little difference in the quality of the demand functions obtained.
4. Test the performance of the demand equations – here using a hind cast as well as an examination of the optimal error profile.
5. Make forecasts and intuitively assess results. If predictions do not make sense, fine-tune parameters.

Projections made with our models provide a frame of reference within which to view the future. The primary benefit obtained from consideration of such projections is a foundation for asking questions. Such questions fall into two general classes, "How does the energy system behave?", and "What actions or policies are in order if the projections are correct?"

The recent sharp drop in oil price reverses the downward trend of oil share in the US but not in the other regions. During most of the historical period, US consumers felt only about two-thirds of the increases in world oil price, this "protection" obtained at the expense of the domestic petroleum industry by price controls on US oil and gas production. Perhaps because of this Federal cosseting the conservation ethic is less firmly implanted in the US as elsewhere. The upturn in CAAN's oil share for the low price trend supports this hypothesis, since Canada maintained price controls on domestic production even after decontrol in the US.

A key question relative to future oil share is the reversibility of reductions brought on by conservation and fuel switches. Much of the past decade's reduction was made possible by capital investments in more efficient equipment, or in means to produce and consume other fuels. Since much of this equipment continues to operate, it exerts a ratchet-like hold on reduced oil share, preventing oil demand of yesteryear from rematerializing. Others accounted for the ratchet effect by breaking losses in oil share into reversible and irreversible categories. Such detailed consideration, even if it could improve forecasting accuracy (which is not yet demonstrated), is outside the scope, or the means, of our effort.

Motor gasoline and residential fuel present different views of change. Fuel efficiency of new automobiles in the US has increased substantially in the last 15 years -- this increase has been accelerated by Federally mandated minimum fleet-average miles per gallon. Ford and General Motors have obtained short-term reductions in these minimums, but this relief may be transient. In spite of this increase in efficiency, with lower pump prices consumption of motor gasoline jumped 5% in the past year. More cars are being driven more miles, as any distraught commuter in any US metropolitan area will tell. A portion of gasoline consumption has been irreversibly cut, but the demand response of this fuel to changes in income and price does not seem to have been affected.

Because of the recent drop in oil price, residual fuel burned in the US jumped by 12% in the past year. This increase, equal to a little over 1% of total US crude oil consumption, has come about almost entirely from fuel switching from natural gas. Thus, for residual fuel the change is almost entirely reversible in nature. However, there is no evidence to support the belief that the demand response to price change is significantly different from that of motor gasoline. As a result of our qualitative observations of these and other categories, we conclude that a properly calibrated demand model will, with annual or biannual updates, satisfactorily account for the so-called "ratchet effect" without intuitive considerations of reversibility of change.

Perhaps the most sobering question raised by the projected levels of US oil consumption is "Can the US afford it?" US output of crude oil and total hydrocarbon liquids (crude oil plus NGL) both dropped about 5% in 1986. During the same period, consumption of hydrocarbon liquids increased 3.5%. A vitally important policy question is "When will Imports equal one-half of domestic consumption?" Given average consumption of 16.8 million barrels per day, the answer to this question is obtained by solving the equation

$$1.035 * (16.8/2)^t = 10.05 * (0.95)^t$$

The result is 2.09 years, at which time this simple equation projects US consumption to be slightly over 18 million barrels per day. Imports of 9 million B/D of crude oil and products at the start of 1989 along with the prospect of steadily declining US production is worrisome. Even grimmer is the prospect of US consumption of 20 million B/D in 2000. It seems that now is the time to devise and initiate a policy that will limit US imports to one-half of consumption.

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