DOCUMENTATION OF THE

PETROLEUM MARKET MODEL (PMM)

APPENDIX: MODEL DEVELOPER'S REPORT

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1. Introduction.

The Office of Integrated Analysis and Forecasting (OIAF) is required to provide complete model documentation to meet the EIA Model Acceptance Standards. The *EIA Model Documentation: Petroleum Market Model of the National Energy Modeling System* provides a complete description of the Petroleum Market Model's (PMM) methodology, and relation to other modules in the National Energy Modeling System (NEMS). This *Model Developer's Report* (MDR) serves as an appendix to the methodology documentation and provides an assessment of the sensitivity of PMM results to changes in input data.

The MDR analysis for PMM is performed by varying several sets of input variables one-at-a-time and examining the effect on a set of selected output variables. The analysis is based on stand-alone, rather than integrated, National Energy Modeling System (NEMS) runs. This means that other NEMS modules are not responding to PMM outputs.

The PMM models petroleum refining and marketing. The purpose of the PMM is to project petroleum product prices, refining activities, and movements of petroleum into the United States and among domestic regions. In addition, the PMM estimates capacity expansion and fuel consumption in the refining industry. The PMM is also used to analyze a wide variety of petroleum-related issues and policies, in order to foster better understanding of the petroleum refining and marketing industry and the effects of certain policies and regulations.

The PMM simulates the operation of petroleum refineries in the United States, including the supply and transportation of crude oil to refineries, the regional processing of these raw materials into petroleum products, and the distribution of petroleum products to meet regional demands. The essential outputs of this model are product prices, a petroleum supply/demand balance, demands for refinery fuel use, and capacity expansion.

The refinery sector of PMM is modeled by a linear programming representation. A linear programming model is developed for each of the five Petroleum Administration for Defense (PAD) Districts and represents an aggregation of the individual refineries in the PAD District. The PMM linear programming model also contains a transportation structure to move products from the refining regions to the Census Division demand regions. Because a single demand region can be supplied by more than one refining region (if the transportation connections exist), changes in one refining region can affect operations in other refining regions. An optimal

solution for the five-PAD District representation as a whole is found by minimizing the costs of meeting the demands. Revenues are derived from product sales, and costs are incurred from the purchase and processing of raw materials and the transportation of finished products to the market. The model chooses a set of petroleum industry activities (e.g. crude oils, processing units, etc.) to produce a product mix that maximizes the refinery's economic benefits. The activities are constrained by material balance requirements on the crude oil and intermediate streams, product specifications, processing and transportation capacities, and demand. Economic forces also govern the decision to import crude oil or refined products into the regions.

2. Theoretical Considerations

For any LP, one and only one of the following statements is true:

(a) The LP is infeasible,

(b) The LP has an optimal solution (unique or alternative),

(c) The LP has no optimal solution, because the problem is unbounded.

The PMM incorporates "distress" imports and exports to minimize the possibility of system failure as a result of an infeasible linear program. Distress imports and exports are, respectively, supplementary supplies of products available at very high prices and auxiliary outlets for products at very low prices. They will only be part of the solution when no other options exist. Nonzero quantities of distress imports or exports indicate a problem with the solution and can distort the results.

The PMM always produces a solution when reasonable and consistent inputs are provided into the model because all of the functions in the PMM are linear, continuous, and differentiable in the domains of applicability of the model. Uniqueness, however, cannot be assured. Non-uniqueness is not usually problematic for this model. However, non-uniqueness or near non-uniqueness of any model can slow convergence of the entire NEMS. Convergence of an individual LP is not an issue (see Solution Methodology section).

The PMM may produce nonsensical results, however, if inconsistent sets of inputs are chosen, or if distress imports or exports are brought into the solution. Furthermore, the crude and product import supply functions that the PMM inputs from the International Energy Module have upper limits on quantities for each year. Thus, in scenarios with increased demands or lower product import prices, the imports may reach their limit and any additional demand must be met from domestic sources. The user-analyst needs to be aware of scenarios that may provide nonsensical, unintended, or uninterpretable results. The following examples illustrate some of these areas.

- Inputs to the capacity expansion iteration need to be kept in line with the scenario inputs, depending upon foresight assumptions. If the capacity expansion inputs are not updated, the scenario changes will serve as unanticipated shocks to the industry.

- Import prices for crude oil types need to be varied uniformly. Crude oil types are valued based on qualities and the relationships among them should be maintained. That is, light, low sulfur crudes should command a higher price than heavy, high sulfur crudes.

- Proportions of petroleum product demands should be kept within reasonable limits. Increasing LPG demand to 50 percent of petroleum product demand, for example, may lead to distortions in the results.

- Import prices for products should be kept within reasonable ranges. Raising prices on some imports, for example, and not others will provide incentives to import the relatively cheaper products, which may be an unintended result.

- Product specifications should be kept within reasonable ranges. Severe specification requirements may cause price spikes, especially if unanticipated.

LP's can exhibit "knife-edge" solution tendencies; that is, small changes in an input can change the mix and levels of the decision variables (primal variables) as well as the dual variables. The changes in the mix and levels of these variables can result in discontinuities. Such discontinuities are far more likely when the LP formulation is simplistic and does not capture the complexities of the market being modeled. Recognizing that potential pitfall, we have attempted to represent sufficient complexity of the petroleum refining and marketing industry in the PMM to avoid most occurrences of discontinuities. For example, early in the PMM formulation, low sulfur residual fuel oil was not allowed to satisfy the demand for high sulfur residual fuel oil. Consequently, the price of high sulfur exceeded by a wide margin the low sulfur residual fuel price. To capture the reality of the market dynamics, low sulfur residual fuel was allowed to satisfy the high sulfur demand whenever the prices allowed. The somewhat simple and intuitive reformulation corrected the non-intuitive result of the early version of the PMM.

3. Solution Methodology

The solution procedure for the PMM model uses a variant of the simplex algorithm which is a very efficient algorithm for solving LP models. Given that the number of variables and constraints is finite in PMM, the algorithm will converge to a solution of the model, if one exists, in a finite number of iterations. Convergence is therefore not an issue since the algorithm will terminate after examining a certain number of the finite number of vertices defined by the constraints and bounds.

The PMM requires no estimate of the current-year solution to compute the solution. The current year solution depends on only the values of inputs from PMM input files or other NEMS modules. However, estimates of future-year product demands, import prices, and other inputs do influence the PMM's capacity expansion decisions.

The sensitivity runs discussed in later sections of this report illustrate how the model behaves with respect to the adjustment of eight selected inputs to the model. Rigorous tests have not been performed to determine the maximal ranges and input interdependencies over which the model remains valid. Nonetheless, sensitivity analysis, based on shifts in the selected input variables, provides an indication of ranges for which the model has proven to be valid. It must be stressed that care must be exercised in selecting the proper range, especially with inputs which are correlated, so that the model produces feasible outputs.

4. Analysis Approach

The analysis performed assessed the sensitivity of selected output variables to perturbations in selected variables. The sets of input variables were changed either one-at-a-time or as a set and the results were analyzed. Table I lists the selected output variables and Table II the selected sets of input variables.

Because the analysis proceeds on the basis of "one-at-a-time" perturbations to a single input or a set of input variables, one must be very careful in the interpretation of the results presented in this study. For example, the results section will show that changing product import prices while keeping crude import prices constant had a greater impact on end-use prices than the opposite test where product import prices were held constant and crude import prices changed. However, it is difficult to conceive of a situation where product import prices could be changed without some residual effect on crude prices.

Table I: Output Variables. (National average by year)

Transportation gasoline price.	1992 cents/gal.
Transportation distillate (diesel) price.	1992 cents/gal.
Residential distillate price.	1992 cents/gal.
Crude oil net imports.	MMbbl/cd
Petroleum products net imports.	MMbbl/cd
Domestic refining capacity (atmospheric distillation).	MMbbl/cd
Utilization rate of domestic refining capacity (atmospheric distillation).	Percentage

Table II: Set of Input Variables.

Set number	Set name	Elements of set
1	Motor gasoline demands.	RFG = Reformulated (2% oxygen) TRG = Traditional RFH = Reformulated High Oxygen (2.7%) TRH = Traditional High Oxygen (2.7%).
2	Distillate transportation demands.	DSL = Low Sulfur Diesel Fuel
3	Residual fuel demands.	N6I and N67 = residual oil ≤ 1% sulfur N6B and N68 = residual oil ≥ 1% sulfur
4	Imported reformulated gasoline prices.	RFG = reformulated gasoline
5	Imported distillate prices.	N2H = No. 2 Heating Oil
6	Imported low-sulfur distillate prices.	DSL = Low Sulfur Diesel
7	Prices of all crude oil imports.	Five aggregate groups: FLL, FMH, FHL, FHH, FHV
8	Prices of all imported petroleum products.	LPG = Liquified Petroleum Gas RFG = Reformulated Gasoline TRG = Traditional Gasoline JTA = Jet Fuel N2H = No. 2 Heating Oil DSL = Low Sulfur Diesel N6I, N6B = residual oil OTH = Other PCF = Petrochemical Feed Stock

The PMM sensitivity analysis consists of a total of 17 stand-alone model solutions. These model solutions consist of a reference case and 8 pairs of runs. Each pair of runs differs from the reference case only on one set of input variables and consists of a low and high value for the perturbed set of inputs. The reference case for this analysis is the output of a stand-alone run of PMM based on the reference case input data and assumptions for the *Annual Energy Outlook 1995* (*AEO95B*) as of September 15, 1994.

Table III lists the runs that were performed, the sets of variables that were perturbed and the percentage deviation from the reference case. Except for the reference case, the following notation is used for the runs: Caseij, where i = 1, ..., 8 refers to the set number of Table II; and j = L or H, where L corresponds to the case where the perturbed set of input variables takes the value of the reference case minus the percentage variation given in column 3 of Table III, and H corresponds to the case where the perturbed set of input variables takes the value of the reference case plus the same percentage variation.

Table III. PMM runs.

Run	Variables Perturbed	% Variation from Reference Case
Reference Case	N/A	N/A
Case 1L and 1H	RFG, TRG, RFH, and TRH demands.	±20%
Case 2L and 2H	DSL demands.	±20%
Case 3L and 3H	N6I, N6B, N67, and N68 demands.	±30%
Case 4L and 4H	RFG import prices.	± 10%
Case 5L and 5H	N2H import prices.	± 10%
Case 6L and 6H	DSL import prices.	± 10%
Case 7L and 7H	Crude oil import prices.	±10%
Case 8L and 8H	Petroleum product import prices.	± 10%

Each set of input variables that were varied is discussed below. The changes were made in forecast year 1995 and were held constant through 2010. Test changes were begun in forecast year 1995 to allow capacity expansion to take place in response to the demand and price changes.

Motor Gasoline Demands-Case 1L and 1H. Motor gasoline is the petroleum product in greatest demand in the United States. The impact of ±20 percent changes in gasoline demand is explored.

Distillate Transportation Demand-Case 2L and 2H. The introduction of low-sulfur fuel in the transportation sector has greatly affected petroleum markets. Low-sulfur distillate makes up about 80 percent of transportation distillate. Distillate transportation demand is varied ±20 percent.

Residual Fuel Demand-Case 3L and 3H. The proportion of residual fuel demand to total product demand has been declining as utilities and industrial establishments switch to natural gas and other fuels. Further reductions in residual fuel demand could require additional changes by refiners to upgrade residual into higher valued products. In this analysis, variations of ±30 percent are made.

Imported Reformulated Gasoline Prices-Case 4L and 4H. Imports are becoming a much more significant part of the U.S. market. As reformulated gasoline requirements begin in 1995,

the role of imports could be important. The impact of changing prices on reformulated gasoline imports by ± 10 percent is explored.

Imported Distillate Prices-Case 5L and 5H. The supplies of the distillate portion of the petroleum barrel are expected to become tighter in the future, primarily as a result of growth in foreign markets. This could result in higher prices for imports. Imported distillate prices are varied ± 10 percent.

Imported Low-sulfur Distillate Prices-Case 6L and 6H. The requirement to produce low-sulfur on-highway distillate is an additional strain on refiners. Imports could be an important supplement to domestic supplies. Imported low-sulfur distillate prices are varied ± 10 percent.

Prices of all Crude Oil Imports-Case 7L and 7H. With domestic crude production declining, crude oil imports are a vital source of supply. The sensitivity of PMM results to changes in crude oil import prices of ± 10 percent is explored.

Prices of all Imported Petroleum Products-Case 8L and 8H. Imports of petroleum products are expected to grow as increases in demand outpace refinery capacity additions. Imported product prices are varied ± 10 percent.

5. Sensitivity Results

The results of the PMM sensitivity analysis are displayed in a series of tables and a set of graphs. The tables are used to display the impact of an input change or a set of input changes as it affects each of the seven output variables. The graphs are useful for comparing the impact on a selected output variable across the test cases and across years. Not all test case graphs are shown since the variation was very small in several cases.

There are eight sets of tables, one for each input variable test. Each table contains the results for the years 2000 and 2010 in tables designated A, B, and C. Table iA shows the values of the selected output variables that correspond to a change in input variable i. The Low, Reference, and High case results are reported. Table iB reports the percentage changes in the selected output variables (relative to the reference case) for the input variable i model solutions. Table iC represents the ratio of the percentage change in the selected output variables relative to the percentage change in input variable i . The graphs exhibit the percentage difference between the test results and the reference case for each of the seven output variables as a function of time.

The selection of the input variables was based upon analyst judgement of variables that are considered important for various reasons as well as those that are considered to have a large impact on results. As can be seen in the next paragraphs, some of the perturbations had little or no effect on the selected output variables. The finding that some input variables have little effect on the output variables can be as valuable as the finding that a perturbed parameter has an impact on the output variables.

Motor Gasoline Demands (Cases 1L and 1H)

Motor gasoline is the petroleum product in greatest demand in the United States. The impact of 20 percent variation in the products that constitute motor gasoline is explored. This scenario produces the largest percentage changes for most of the output variables observed (Figures 1-7).

With an increase in gasoline demand of 20 percent (Case 1H), beginning in 1995 and extending to 2010, the PMM responds with increases in both domestic process unit capacity and product imports to meet these demands. Product imports respond to a greater degree, rising 1.24 million barrels per day (MMbbl/cd) in 2010 (Table 1A). Crude imports increase about 350,000 barrels per day (bbl/cd) along with a comparable rise in distillation capacity. On a percentage basis, product imports increase sharply in the early years and remain over 30 percent higher in 2010 (Figure 5).

Table 1A. ±20% Variation in RFG, TRG, RFH, and TRH demands.

	2000			2010		
Output Variable	Low	Reference	High	Low	Reference	High
Transportation Gasoline Price	122.38	129.47	144.03	130.11	137.06	147.43
Transportation Distillate Price	122.67	123.64	125.40	128.76	131.75	133.55
Residential Distillate Price	106.94	107.78	109.45	118.66	121.54	123.66
Crude Oil Net Imports	7.64	8.36	8.79	8.34	8.66	9.01
Petroleum Products Net Imports	1.45	2.32	3.46	2.63	3.96	5.20
Domestic Refining Capacity	15.03	15.33	15.61	15.34	15.34	15.72
Utilization Rate, %	85.90	88.90	90.00	87.88	90.00	90.00

Table 1B. Percentage Changes from Reference Case.

	2000		2010	
Output Variable	Low	High	Low	High
Transportation Gasoline Price	-5.48%	11.24%	-5.07%	7.57%
Transportation Distillate Price	-0.79%	1.42%	-2.27%	1.37%
Residential Distillate Price	-0.78%	1.54%	-2.37%	1.74%
Crude Oil Net Imports	-8.64%	5.07%	-3.69%	4.10%
Petroleum Products Net Imports	-37.61%	49.34%	-33.50%	31.40%
Domestic Refining Capacity	-1.96%	1.81%	0.05%	2.52%
Utilization Rate	-3.36%	1.24%	-2.36%	0.00%

Table 1C. Ratio of Percentage Change in Output Variables to Input Variables.

	2000		2010	
Output Variable	Low	High	Low	High
Transportation Gasoline Price	0.274	0.562	0.253	0.378
Transportation Distillate Price	0.039	0.071	0.113	0.068
Residential Distillate Price	0.039	0.077	0.118	0.087
Crude Oil Net Imports	0.432	0.254	0.184	0.205
Petroleum Products Net Imports	1.880	2.467	1.675	1.570
Domestic Refining Capacity	0.098	0.090	-0.002	0.126
Utilization Rate	0.168	0.062	0.118	0.000

Motor gasoline prices increase about 10 percent in most years (Figure 1). The largest price changes typically occur in the forecast years just prior to the availability of new capacity. Capacity expansion decisions are made every 3 years. Actual additions then take place throughout the 3-year period (Please refer to Chapter 4 of the Petroleum Market Model Documentation). The result is that gasoline prices rise, reflecting tight supply conditions, and then decline as new capacity is made available. This is especially true in 2006 when the percentage difference from the reference case is the greatest since 1995. Downstream capacity additions in 2007 provide expanded capability to produce the increase in gasoline demand. Product imports become relatively more cost effective in the last three years of the forecast which also contributes to prices reductions relative to the reference case. Distillate prices also rise, but by a much smaller amount than gasoline (Table 1B and Figures 2 and 3).

In the low gasoline demand case (1L), similar changes occur in crude and product imports but in the opposite direction. Product imports, the swing supply in the high demand case, are the bigger losers in this case, falling 1.3 MMbbl/cd while crude imports decline about 320,000 bbl/cd for 2010 (Table 1A). On a percentage basis, crude imports fall substantially in the early years, but the difference from the reference case becomes smaller over time (Figure 4). Gasoline prices fall by a smaller proportion than the increase in the high case, around 5 percent (Figure 1). Distillate prices also decline, but at a smaller percentage change than gasoline (Table 1B). The lower gasoline demand allows refiners to shift processing unit modes and blending streams, enabling them to produce distillate at a lower cost.

The 20 percent increase in gasoline demand put more stress on the market than the same size reduction relieved. It is much easier for refiners to cut back on gasoline yields than to squeeze more gasoline out of the crude barrel.

Transportation Distillate Demand (Cases 2L and 2H)

Increasing transportation distillate (low-sulfur diesel) demand by 20 percent has little impact on crude oil imports and capacity expansion. Product imports provide nearly the entire increase, rising about 400,000 bbl/cd in 2010 (Table 2A). Prices increase less than 2 percent (Table 2B). This is a situation where it is not cost effective to add capacity to produce more of just one product. Building capacity results in additional production of all products and the model chose to import the product rather than make it domestically. Reducing distillate transportation demand results in changes of nearly identical magnitude but in the opposite direction.

Table 2A. ± 20% Variation in DSL demands.

	2000			2010		
Output Variable	Low	Reference	High	Low	Reference	High
Transportation Gasoline Price	129.14	129.47	129.59	136.79	137.06	137.55
Transportation Distillate Price	122.25	123.64	125.10	129.25	131.75	133.46
Residential Distillate Price	106.63	107.78	109.24	119.19	121.54	123.13
Crude Oil Net Imports	8.27	8.36	8.42	8.60	8.66	8.68
Petroleum Products Net Imports	2.04	2.32	2.63	3.57	3.96	4.36
Domestic Refining Capacity	15.27	15.33	15.33	15.33	15.34	15.36
Utilization Rate	88.70	88.90	89.25	89.64	90.00	90.00

Table 2B. Percentage Changes from Reference Case.

	2010		2010	
Output Variable	Low	High	Low	High
Transportation Gasoline Price	-0.26%	0.09%	-0.19%	0.36%
Transportation Distillate Price	-1.13%	1.18%	-1.90%	1.30%
Residential Distillate Price	-1.07%	1.35%	-1.93%	1.31%
Crude Oil Net Imports	-1.08%	0.67%	-0.68%	0.27%
Petroleum Products Net Imports	-12.16%	13.56%	-9.71%	10.22%
Domestic Refining Capacity	-0.43%	0.01%	-0.03%	0.16%
Utilization Rate	-0.22%	0.40%	-0.40%	0.00%

Table 2C. Ratio of Percentage Change in Output Variables to Input Variables.

	2000		2010	
Output Variable	Low	High	Low	High
Transportation Gasoline Price	0.013	0.005	0.010	0.018
Transportation Distillate Price	0.056	0.059	0.095	0.065
Residential Distillate Price	0.053	0.068	0.096	0.066
Crude Oil Net Imports	0.054	0.033	0.034	0.013
Petroleum Products Net Imports	0.608	0.678	0.486	0.511
Domestic Refining Capacity	0.022	0.001	0.001	0.008
Utilization Rate	0.011	0.020	0.020	0.000

Residual Fuel Demand (Cases 3L and 3H)

The residual fuel demand cases show similar results as the distillate transportation case. Crude imports and capacity remain near the reference case levels while product imports respond to the demand changes (Table 3A). Gasoline and distillate price changes are very small, in the 0.5 percent range (Table 3B). The PMM is able to respond to these large changes in residual fuel demand simply through product import changes, without affecting the refinery expansion decisions. Additional imports are available on the import supply curves at prices lower than those required to provide an incentive to expand domestic capacity.

Table 3A. ±30% Variation in N6I, N6B, N67, and N68 demands.

	2000			2010		
Output Variable	Low	Reference	High	Low	Reference	High
Transportation Gasoline Price	129.38	129.47	129.45	137.02	137.06	137.10
Transportation Distillate Price	123.68	123.64	123.60	131.50	131.75	132.02
Residential Distillate Price	107.73	107.78	107.84	121.37	121.54	121.98
Crude Oil Net Imports	8.36	8.36	8.37	8.63	8.66	8.68
Petroleum Products Net Imports	1.96	2.32	2.67	3.55	3.96	4.36
Domestic Refining Capacity	15.33	15.33	15.33	15.33	15.34	15.36
Utilization Rate	88.85	88.90	88.93	89.81	90.00	90.00

Table 3B. Percentage Changes from Reference Case.

	2000		2010	
Output Variable	Low	High	Low	High
Transportation Gasoline Price	-0.07%	-0.01%	-0.03%	0.03%
Transportation Distillate Price	0.03%	-0.04%	-0.19%	0.21%
Residential Distillate Price	-0.05%	0.05%	-0.14%	0.37%
Crude Oil Net Imports	-0.09%	0.07%	-0.38%	0.26%
Petroleum Products Net Imports	-15.29%	15.17%	-10.33%	10.19%
Domestic Refining Capacity	0.00%	0.00%	-0.03%	0.16%
Utilization Rate	-0.06%	0.04%	-0.21%	0.00%

Table 3C. Ratio of Percentage Change in Output Variables to Input Variables.

	2000		2010	
Output Variable	Low	High	Low	High
Transportation Gasoline Price	0.002	0.000	0.001	0.001
Transportation Distillate Price	-0.001	-0.001	0.006	0.007
Residential Distillate Price	0.002	0.002	0.005	0.012
Crude Oil Net Imports	0.003	0.002	0.013	0.009
Petroleum Products Net Imports	0.510	0.506	0.344	0.340
Domestic Refining Capacity	0.000	0.000	0.001	0.005
Utilization Rate	0.002	0.001	0.007	0.000

Imported Reformulated Gasoline Prices (Cases 4L and 4H)

Increasing imported reformulated gasoline prices has little impact on refinery economics since most reformulated gasoline is supplied domestically. Capacity, crude imports, and product imports remain very close to reference case levels (Table 4A). The higher import prices do not provide sufficient incentives to cause the model to add capacity and shift away from product imports. The higher import prices are simply passed on, but have little impact on national average end-use price increases (Table 4A).

Lower prices on imported reformulated gasoline are also insufficient to take away market share from domestic suppliers. Virtually no changes are evident from the reference case (Table 4A).

Table 4A. ±10% Variation in RFG import prices.

Output Variable	Low	Reference	High	Low	Reference	High
Transportation Gasoline Price	128.50	129.47	129.82	136.58	137.06	137.25
Transportation Distillate Price	123.70	123.64	123.60	131.60	131.75	131.89
Residential Distillate Price	107.80	107.78	107.78	121.52	121.54	121.64
Crude Oil Net Imports	8.37	8.36	8.38	8.66	8.66	8.66
Petroleum Products Net Imports	2.31	2.32	2.30	3.95	3.96	3.96
Domestic Refining Capacity	15.33	15.33	15.33	15.33	15.34	15.34
Utilization Rate	88.95	88.90	89.00	90.00	90.00	90.00

Table 4B. Percentage Changes from Reference Case.

	2000		2010	
Output Variable	Low	High	Low	High
Transportation Gasoline Price	-0.75%	0.27%	-0.35%	0.14%

Transportation Distillate Price	0.05%	-0.04%	-0.11%	0.10%
Residential Distillate Price	0.01%	0.00%	-0.02%	0.08%
Crude Oil Net Imports	0.10%	0.19%	-0.05%	0.00%
Petroleum Products Net Imports	-0.34%	-0.73%	-0.10%	0.10%
Domestic Refining Capacity	0.00%	0.00%	-0.03%	0.00%
Utilization Rate	0.06%	0.11%	0.00%	0.00%

Table 4C. Ratio of Percentage Change in Output Variables to Input Variables.

	2000		2010	
Output Variable	Low	High	Low	High
Transportation Gasoline Price	0.075	0.027	0.035	0.014
Transportation Distillate Price	-0.005	-0.004	0.011	0.010
Residential Distillate Price	-0.001	0.000	0.002	0.008
Crude Oil Net Imports	-0.010	0.019	0.005	0.000
Petroleum Products Net Imports	0.034	-0.073	0.010	0.010
Domestic Refining Capacity	0.000	0.000	0.003	0.000
Utilization Rate	-0.006	0.011	0.000	0.000

Imported Distillate Prices (Cases 5L and 5H)

A 10 percent increase in imported distillate prices is not sufficient to affect refinery economic decisions. Slight movements away from product imports and toward crude imports are evident, but very small (Table 5A). Prices change very little. Decreasing distillate import prices by 10 percent also fails to provide incentives to change the import patterns seen in the reference case.

Table 5A. ±10% Variation in N2H import prices.

	2000			2010		
Output Variable	Low	Reference	High	Low	Reference	High
Transportation Gasoline Price	129.42	129.47	129.20	136.84	137.06	137.09
Transportation Distillate Price	123.56	123.64	123.86	130.57	131.75	132.97
Residential Distillate Price	107.49	107.78	108.21	120.29	121.54	123.11
Crude Oil Net Imports	8.37	8.36	8.38	8.64	8.66	8.67
Petroleum Products Net Imports	2.31	2.32	2.30	3.97	3.96	3.94
Domestic Refining Capacity	15.33	15.33	15.33	15.33	15.34	15.35
Utilization Rate	88.94	88.90	88.98	89.92	90.00	90.00

Table 5B. ±10%Variation in N2H import prices.

Output Variable	Low	High	Low	High
Transportation Gasoline Price	-0.04%	-0.21%	-0.16%	0.02%
Transportation Distillate Price	-0.07%	0.18%	-0.89%	0.93%
Residential Distillate Price	-0.27%	0.39%	-1.03%	1.29%
Crude Oil Net Imports	0.08%	0.18%	-0.18%	0.12%
Petroleum Products Net Imports	-0.31%	-0.65%	0.27%	-0.43%
Domestic Refining Capacity	0.00%	0.01%	-0.03%	0.07%
Utilization Rate	0.05%	0.09%	-0.08%	0.00%

Table 5C. Ratio of Percentage Change in Output Variables to Input Variables.

	2000		2010	
Output Variable	Low	High	Low	High
Transportation Gasoline Price	0.004	-0.021	0.016	0.002
Transportation Distillate Price	0.007	0.018	0.089	0.093
Residential Distillate Price	0.027	0.039	0.103	0.129
Crude Oil Net Imports	-0.008	0.018	0.018	0.012
Petroleum Products Net Imports	0.031	-0.065	-0.027	-0.043
Domestic Refining Capacity	0.000	0.001	0.003	0.007
Utilization Rate	-0.005	0.009	0.008	0.000

Imported Low-Sulfur Distillate Prices (Cases 6L and 6H)

As in cases 4 and 5, changing imported low-sulfur distillate prices by 10 percent has very little impact on decisions to import or build capacity (Table 6A). Price effects were also quite small.

Table 6A. ±10% Variation in DSL import prices.

	2000			2010		
Output Variable	Low	Reference	High	Low	Reference	High
Transportation Gasoline Price	128.43	129.47	129.49	136.71	137.06	137.87
Transportation Distillate Price	121.72	123.64	124.66	129.92	131.75	133.84
Residential Distillate Price	105.63	107.78	108.95	119.84	121.54	123.87
Crude Oil Net Imports	8.35	8.36	8.39	8.64	8.66	8.68
Petroleum Products Net Imports	2.33	2.32	2.30	3.97	3.96	3.93
Domestic Refining Capacity	15.33	15.33	15.33	15.33	15.34	15.35
Utilization Rate	88.82	88.90	89.04	89.90	90.00	90.00

Table 6B. Percentage Changes from Reference Case.

	2000		2010	
Output Variable	Low	High	Low	High
Transportation Gasoline Price	-0.80%	0.01%	-0.25%	0.59%
Transportation Distillate Price	-1.56%	0.82%	-1.39%	1.59%
Residential Distillate Price	-2.00%	1.08%	-1.39%	1.92%
Crude Oil Net Imports	-0.19%	0.26%	-0.22%	0.19%
Petroleum Products Net Imports	0.64%	-0.87%	0.38%	-0.59%
Domestic Refining Capacity	-0.04%	0.00%	-0.03%	0.12%
Utilization Rate	-0.08%	0.16%	-0.11%	0.00%

Table 6C. Ratio of Percentage Change in Output Variables to Input Variables.

	2000		2010	
Output Variable	Low	High	Low	High
Transportation Gasoline Price	0.080	0.001	0.025	0.059
Transportation Distillate Price	0.156	0.082	0.139	0.159
Residential Distillate Price	0.200	0.108	0.139	0.192
Crude Oil Net Imports	0.019	0.026	0.022	0.019
Petroleum Products Net Imports	-0.064	-0.087	-0.038	-0.059
Domestic Refining Capacity	0.004	0.000	0.003	0.012
Utilization Rate	0.008	0.016	0.011	0.000

Prices of All Crude Imports (Cases 7L and 7H)

Refinery economics are very sensitive to changes in crude oil import prices. A 10 percent increase in foreign crude prices, with import product prices remaining constant, results in 300,000 bbl/cd less capacity than the reference case (i.e., capacity remains at current levels, the only scenario where this occurred) (Table 7A and Figure 6). Product imports increase more than 500,000 bbl/cd in 2010 with no change in product demands from the reference case. Crude imports fall by a comparable amount. Product prices increase by about 1 to 2 percent (Table 7B and Figures 1-3).

Reducing foreign crude prices also has dramatic effects. Domestic capacity rises by over 400,000 bbl/cd while crude imports increase by about 380,000 bbl/cd in 2010 (Table 7A). Product imports fall by about 360,000 bbl/cd. Price decreases are very small, indicating that most prices are still set by product imports, which do not change in price by assumption.

Table 7A. ±10% Variation in all Crude Oil Import Prices.

	2000			2010		
Output Variable	Low	Reference	High	Low	Reference	High
Transportation Gasoline Price	127.56	129.47	130.97	136.48	137.06	139.50
Transportation Distillate Price	123.03	123.64	125.29	131.27	131.75	133.56
Residential Distillate Price	107.43	107.78	109.20	121.20	121.54	123.09
Crude Oil Net Imports	8.68	8.36	7.70	9.04	8.66	8.11
Petroleum Products Net Imports	2.01	2.32	2.95	3.60	3.96	4.47
Domestic Refining Capacity	15.50	15.33	15.03	15.75	15.34	15.03
Utilization Rate	90.00	88.90	86.32	90.00	90.00	88.22

Table 7B. Percentage Changes from Reference Case.

	2000		2010	
Output Variable	Low	High	Low	High
Transportation Gasoline Price	-1.48%	1.16%	-0.42%	1.78%
Transportation Distillate Price	-0.50%	1.33%	-0.36%	1.37%
Residential Distillate Price	-0.33%	1.31%	-0.27%	1.28%
Crude Oil Net Imports	3.83%	-7.88%	4.36%	-6.32%
Petroleum Products Net Imports	-13.41%	27.42%	-9.12%	13.06%
Domestic Refining Capacity	1.07%	-1.96%	2.67%	-1.98%
Utilization Rate	1.24%	-2.89%	0.00%	-1.97%

Table 7C. Ratio of Percentage Change in Output Variables to Input Variables.

	2000		2010	
Output Variable	Low	High	Low	High
Transportation Gasoline Price	0.148	0.116	0.042	0.178
Transportation Distillate Price	0.050	0.133	0.036	0.137
Residential Distillate Price	0.033	0.131	0.027	0.128
Crude Oil Net Imports	-0.383	-0.788	-0.436	-0.632
Petroleum Products Net Imports	1.341	2.742	0.912	1.306
Domestic Refining Capacity	-0.107	-0.196	-0.267	-0.198
Utilization Rate	-0.124	-0.289	0.000	-0.197

Prices of All Imported Products (Bases 8L and 8H)

As in case 7, changing the prices of all imported products has a significant impact on PMM outputs. In the higher price case, imported crude oil is relatively more attractive, and the model imports about 340,000 bbl/cd more than in the reference case in 2010 (Table 8A). About 360,000 bbl/cd of domestic capacity is added to process the additional crude oil. Product imports drop about 380,000 bbl/cd or nearly 10 percent lower than the reference case (Table 8B). Prices increase by nearly the same amount as the absolute increase in the imported product prices.

Reducing imported petroleum product prices by 10 percent has an even more dramatic affect. In 2010, crude imports drop and product imports increase by nearly 800,000 bbl/cd (Table 8A). Utilization rates remain lower than the reference case throughout the forecast, dropping off by a greater amount in the last two years (Figure 7). Cheaper imports can meet demand at lower cost, reducing the need to run domestic distillation capacity. Domestic crude production increases in the last three years of the forecast which, combined with the decline in utilization, results in falling crude oil imports at the end of the forecast (Figure 4). Gasoline and distillate prices decline by almost the same amount in 2010 as in the high imported product case.

Table 8A. ±10% Variation in all Imported Petroleum Product Prices.

	2000			2010		
Output Variable	Low	Reference	High	Low	Reference	High
Transportation Gasoline Price	124.78	129.47	133.20	132.56	137.06	143.36
Transportation Distillate Price	120.97	123.64	128.16	127.04	131.75	136.60
Residential Distillate Price	104.91	107.78	112.36	116.81	121.54	126.32
Crude Oil Net Imports	7.71	8.36	8.60	7.87	8.66	9.00
Petroleum Products Net Imports	2.97	2.32	2.07	4.75	3.96	3.58
Domestic Refining Capacity	15.03	15.33	15.41	15.21	15.34	15.70
Utilization Rate	86.39	88.90	89.92	85.60	90.00	90.00

Table 8B. Percentage Changes from Reference Case.

	2000		2010	
Output Variable	Low	High	Low	High
Transportation Gasoline Price	-3.62%	2.88%	-3.28%	4.60%
Transportation Distillate Price	-2.16%	3.65%	-3.57%	3.68%
Residential Distillate Price	-2.66%	4.24%	-3.89%	3.93%
Crude Oil Net Imports	-7.76%	2.77%	-9.10%	3.89%
Petroleum Products Net Imports	28.28%	-10.52%	19.99%	-9.56%
Domestic Refining Capacity	-1.96%	0.53%	-0.85%	2.39%
Utilization Rate	-2.82%	1.15%	-4.88%	0.00%

Table 8C. Ratio of Percentage Change in Output Variables to Input Variables.

	2000		2010	
Output Variable	Low	High	Low	High
Transportation Gasoline Price	0.362	0.288	0.328	0.460
Transportation Distillate Price	0.216	0.365	0.357	0.368
Residential Distillate Price	0.266	0.424	0.389	0.393
Crude Oil Net Imports	0.776	0.277	0.910	0.389
Petroleum Products Net Imports	-2.828	-1.052	-1.999	-0.956
Domestic Refining Capacity	0.196	0.053	0.085	0.239
Utilization Rate	0.282	0.115	0.488	0.000

6. Findings

The Model Developer's Report (MDR) analysis provides several significant insights into the performance of the PMM. The results conform to expectations regarding the direction of the change and the magnitude of the changes seem reasonable. These results need to be kept in perspective given the constraints of the one-at-a-time changes in input variables and stand-alone use of the module. The sensitivity analysis tests model responsiveness, and caution should be used in interpreting these results from a policy perspective.

Findings of the analysis include:

- Changes in crude and petroleum product import prices greatly affect domestic capacity expansion and importing decisions. End-use prices are also significantly affected.
- Petroleum product imports are the marginal supply of petroleum into the United States. Changing product import prices has the most dramatic impact on flows. The changes in end-use prices are also substantial, especially considering that crude prices do not change in this scenario.
- Changes in crude import prices do not change end-use prices as much as changing product import prices. This is due to the marginal supply nature of product imports. It must be remembered, however, that product imports are available at unchanged prices in this scenario, a situation that would probably not occur in the real world.
- Changes in gasoline demands have a bigger impact on refinery economics than changes in demands of other products.
- Changes in gasoline demands have a significant impact on prices. The largest price changes occur in this scenario.
- Capacity expansion responds as expected. Cheaper crude prices bring on more expansion; higher prices initiate less. The interaction between expansion and prices is also evident, especially in the gasoline demand case. Price differences with the reference case are greatest in the forecast years just prior to a new 3-year expansion cycle. Price differences then decline at the beginning of the cycle, indicating that the expansion mitigates the price pressures that built up during the 3-year period.
- Changing import prices of individual products has little impact on economic decisions to build capacity. Prices are little affected as well.

- Changing demands for low-sulfur diesel and residual fuel result primarily in changes in product imports. This may indicate a lack of sensitivity in the 3-step supply curves used in the model. A more robust representation of foreign refining may produce different results.
- Changes in three sets of input variables produce slight, unexpected variations in some of the output variables across the low, reference, and high cases. The input variables producing unexpected variations are residual fuel demand, imported reformulated gasoline prices, and imported distillate prices. Although these variations are slight, they will be reviewed carefully before the production of the Annual Energy Outlook 1996 to confirm that the model is properly specified.

Attachment A

Sensitivity of Selected Output Variables

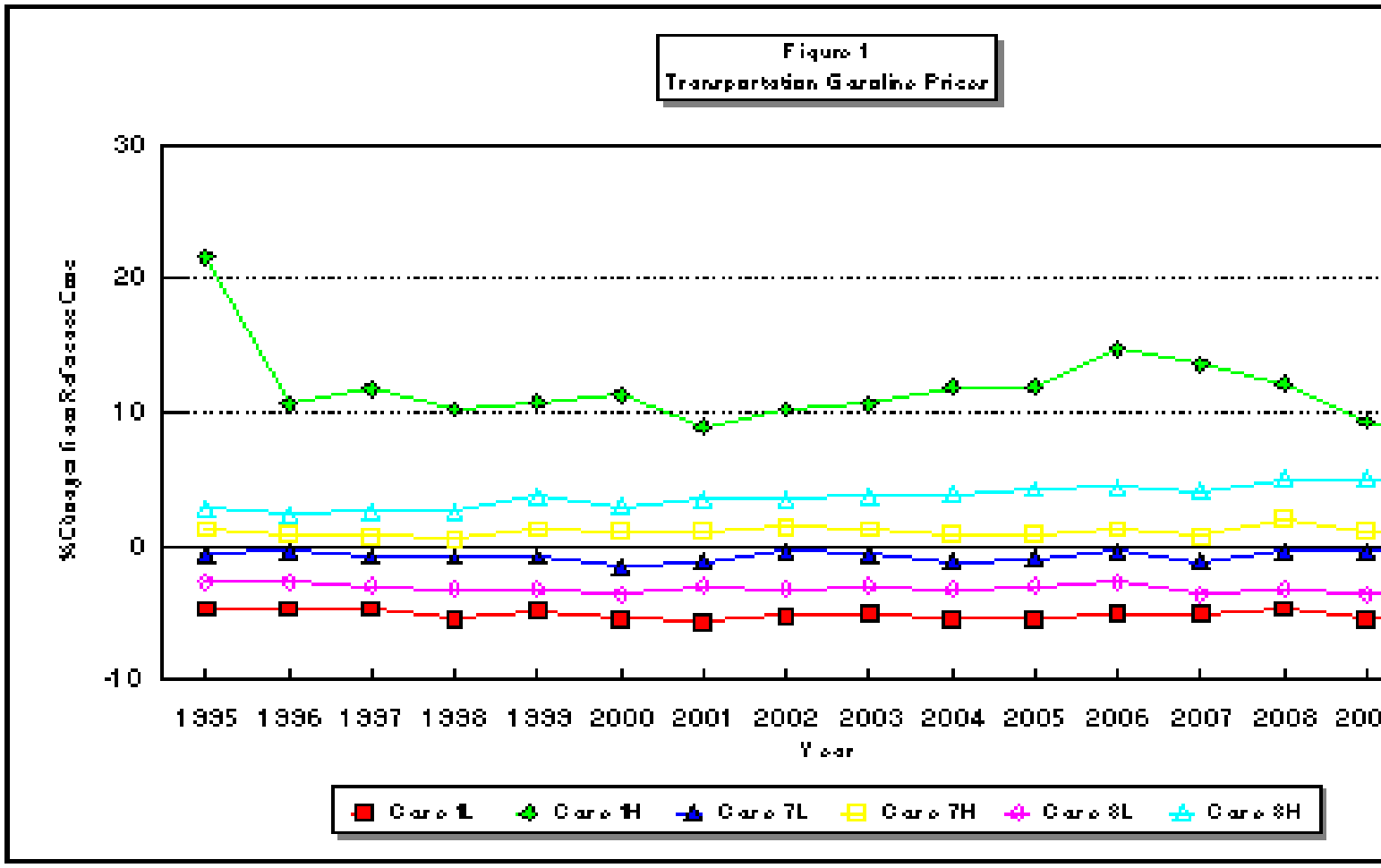
Figure 1
Transportation Gasoline Prices
30
20
10
0
-10
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
Year
Case 1L
Case 1H
Case 7L
Case 7H
Case 8L
Case 8H

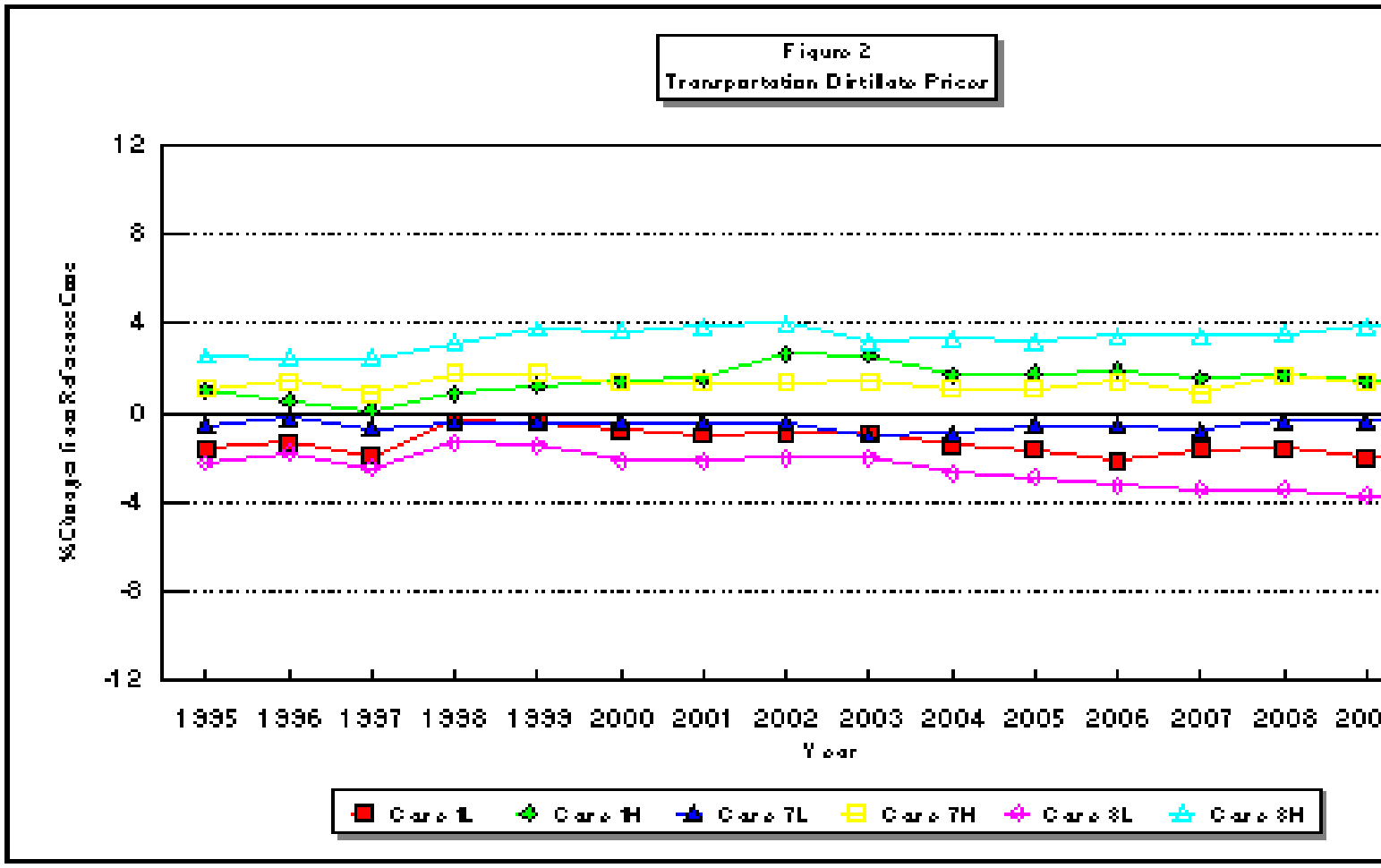
Figure 2
Transportation Distillate Prices
12
8
4
0
-4
-8
-12
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 200
Year
Case 1L
Case 1H
Case 7L
Case 7H
Case 8L
Case 8H

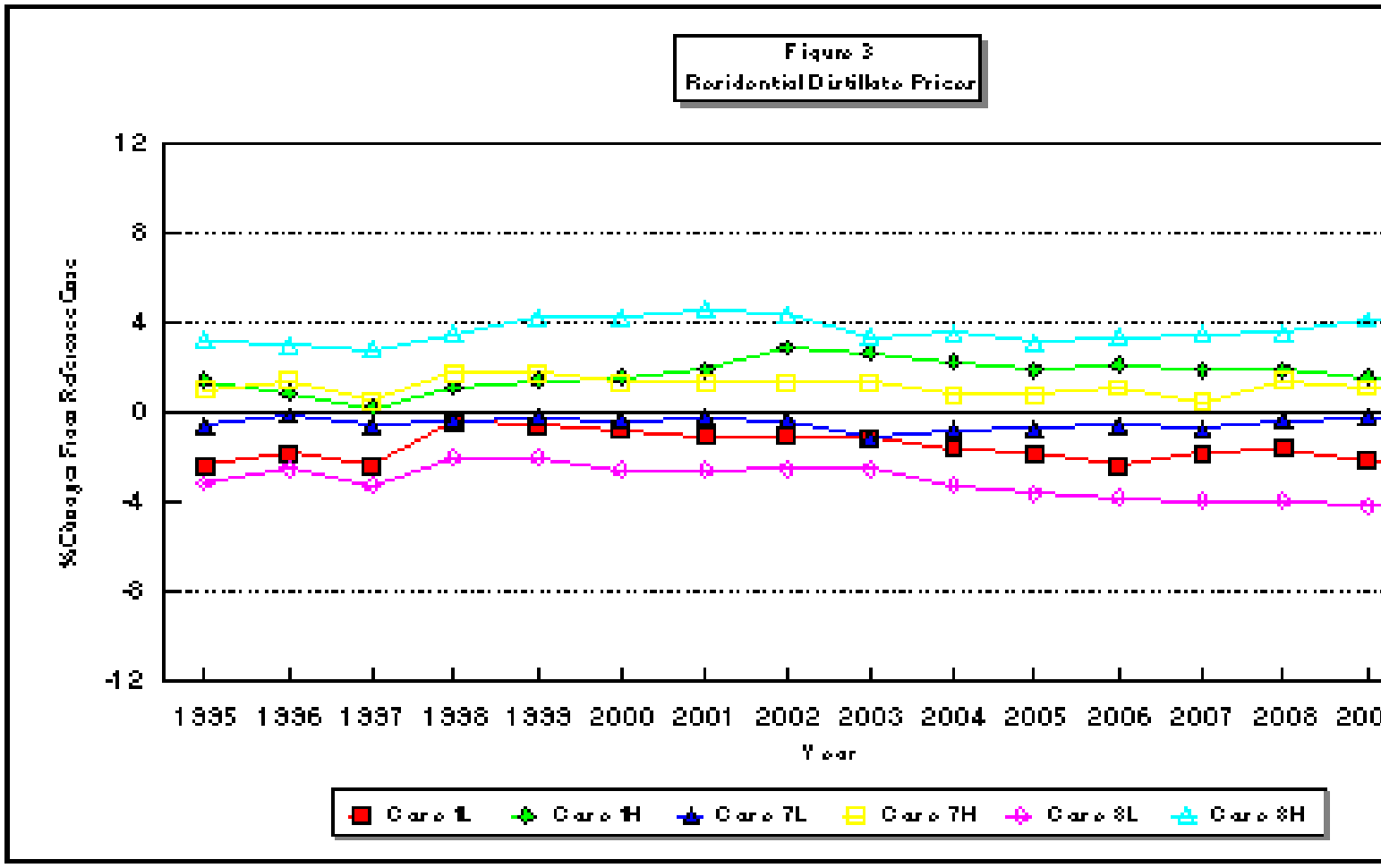
Figure 3
Residential Distillate Prices
12
8
4
0
-4
-8
-12
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
Year
Case 1L
Case 1H
Case 7L
Case 7H
Case 8L
Case 8H

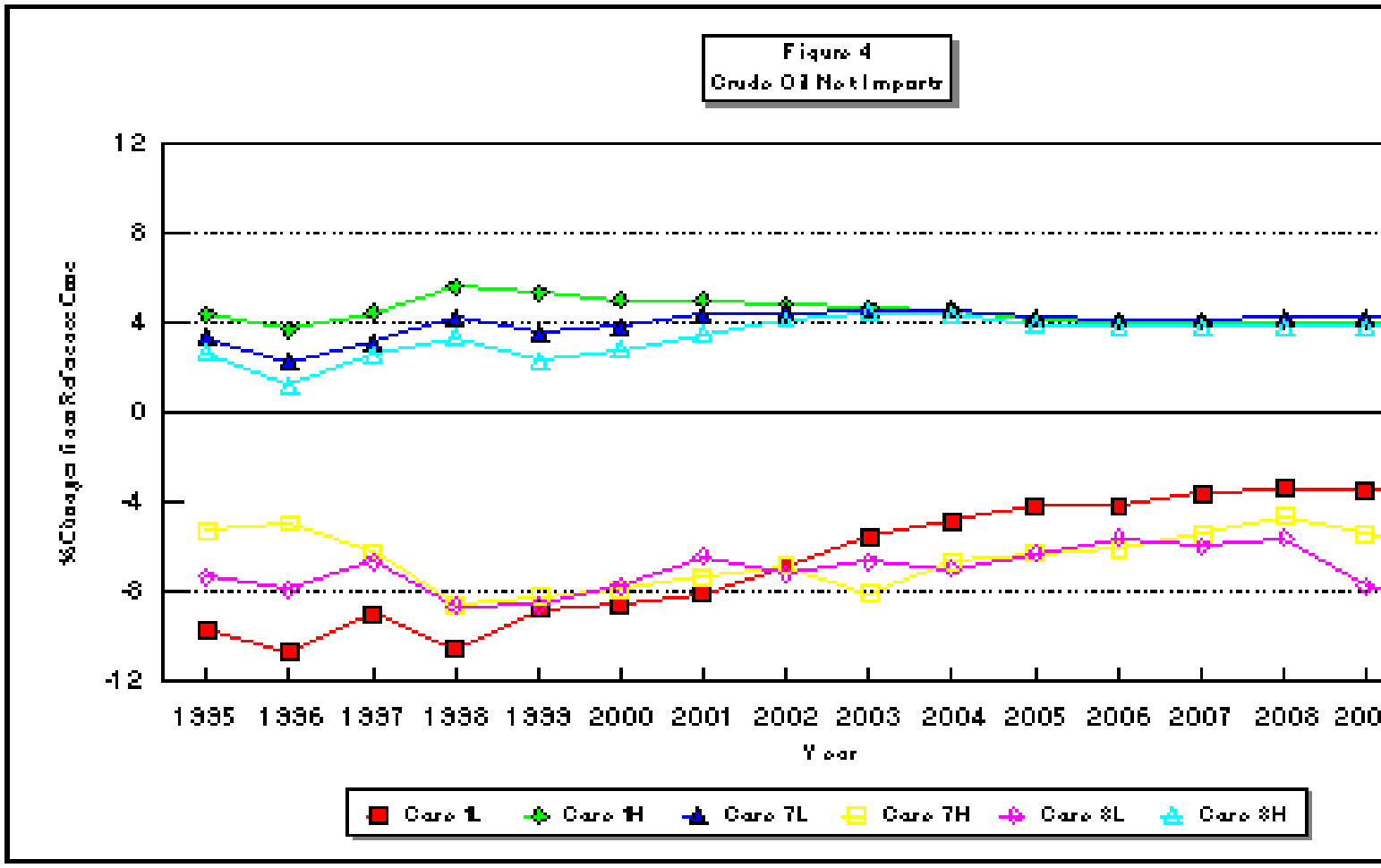
Figure 4
Crude Oil Net Imports
12
8
4
0
-4
-8
-12
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Year
Case 1L
Case 1H
Case 7L
Case 7H
Case 8L
Case 8H

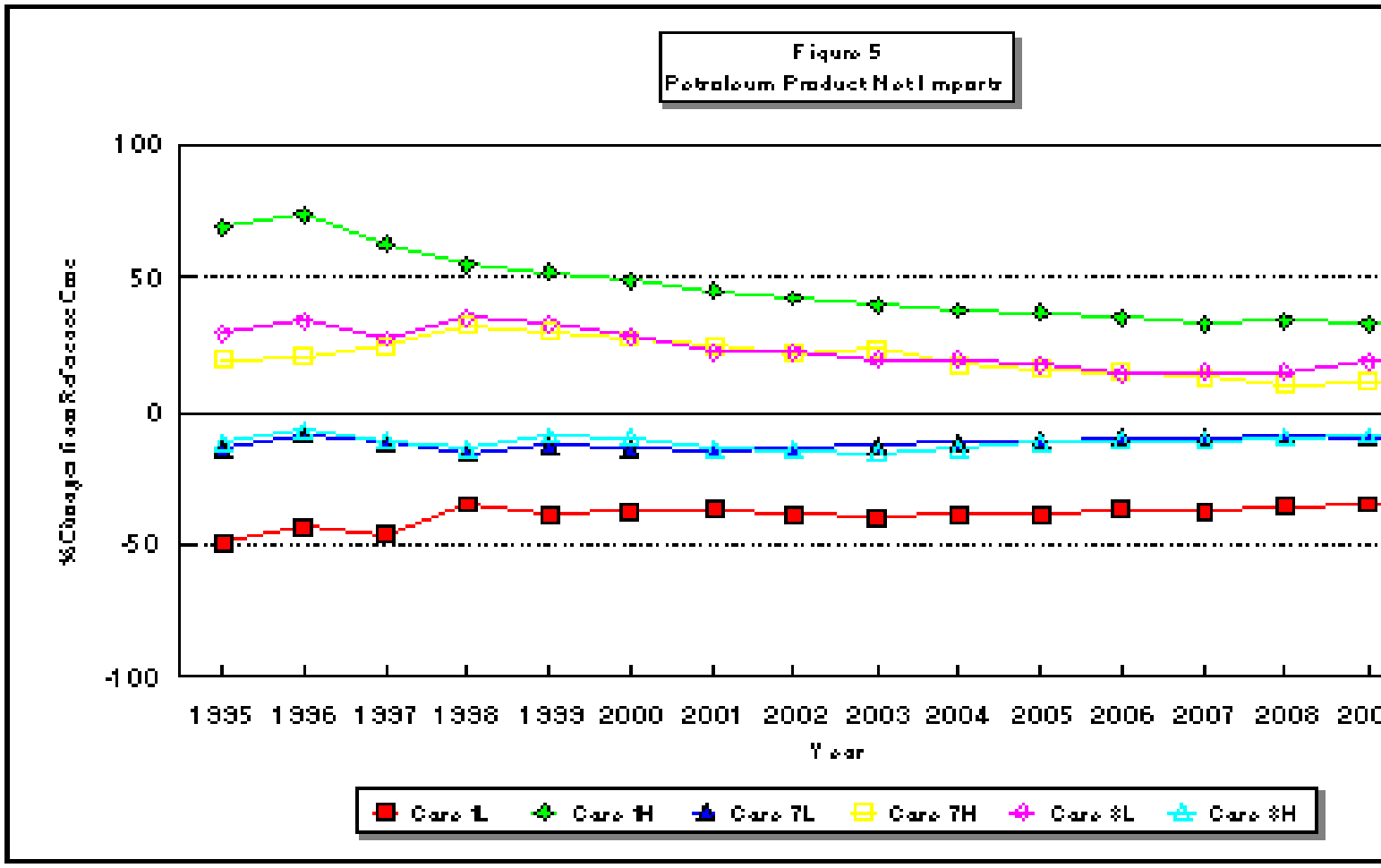
Figure 5
Petroleum Product Net Imports
100
50
0
-50
-100
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Year
Case 1L
Case 1H
Case 7L
Case 7H
Case 8L
Case 8H

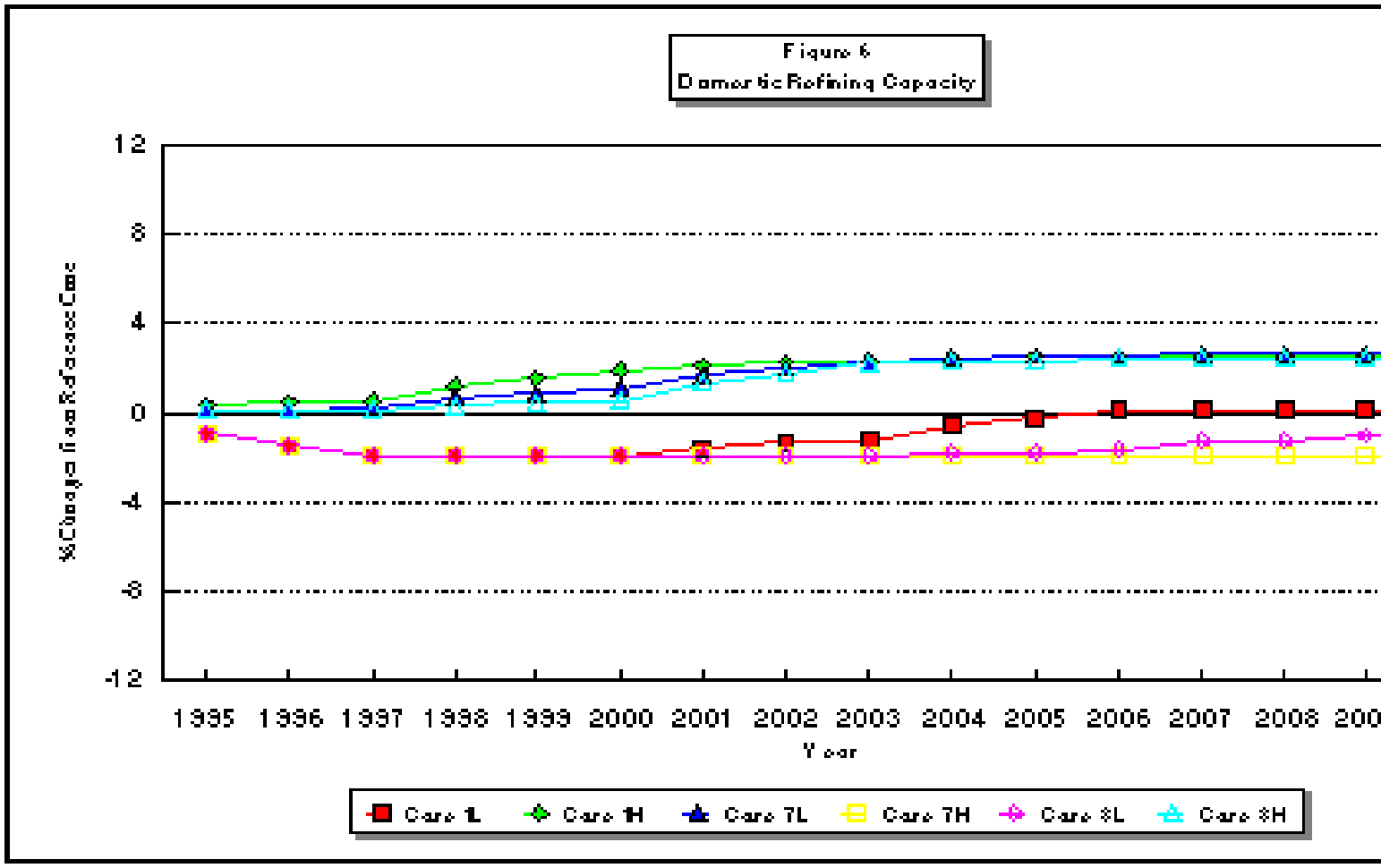
Figure 6
Domestic Refining Capacity
12
8
4
0
-4
-8
-12
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 200
Year
Case 1L
Case 1H
Case 7L
Case 7H
Case 8L
Case 8H

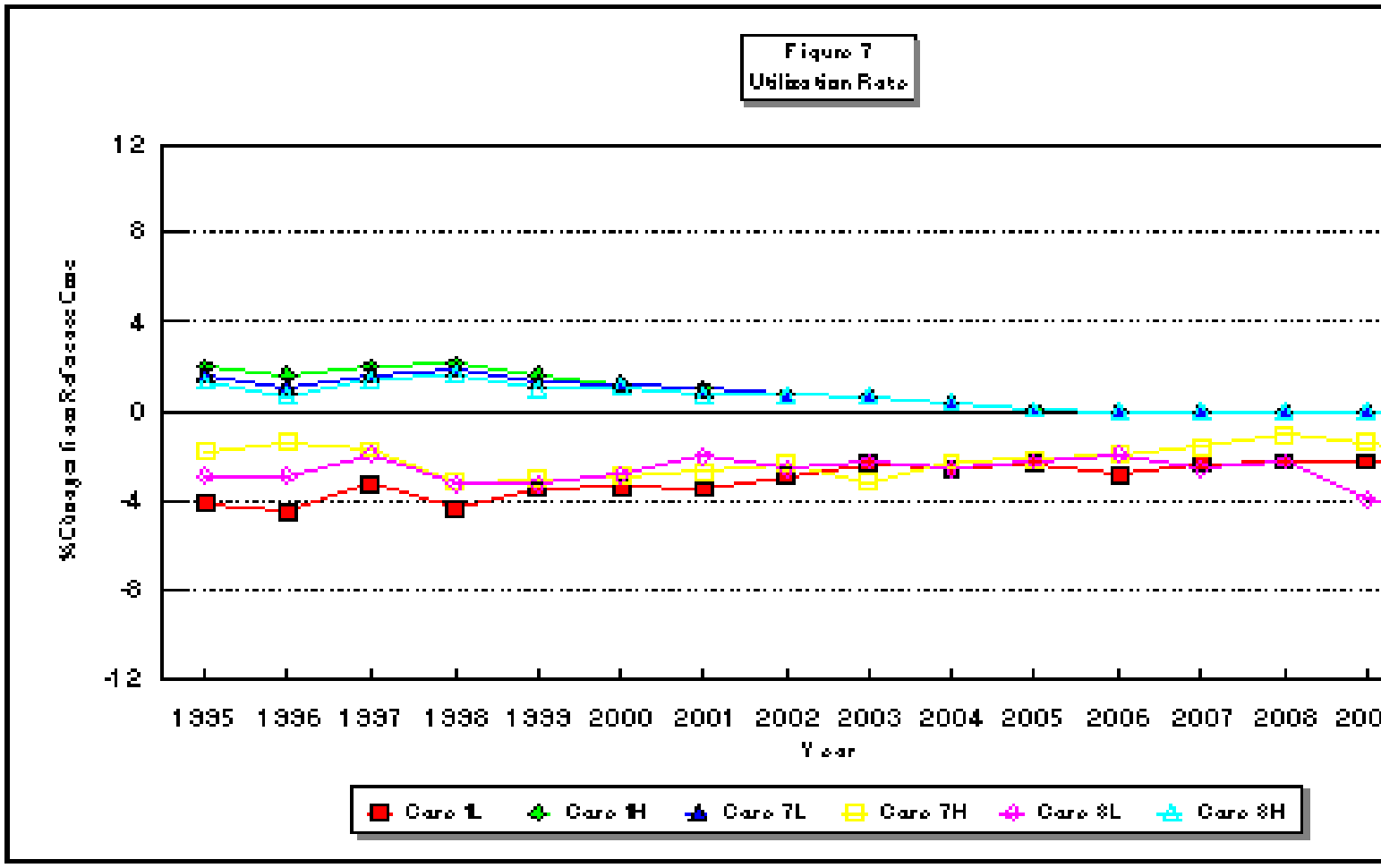
Figure 7
Utilization Rate
12
8
4
0
-4
-8
-12
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Year
Core 1L
Core 1H
Core 7L
Core 7H
Core 8L
Core 8H