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CRUDE OIL PRICING: CALIFORNIA GRAVITY DIFFERENTIALS

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ABSTRACT

Crude Oil Pricing:
California Gravity Differentials

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The relatively large price differential between crude oils of different gravity in California has been attributed to monopsonistic pricing. Qualitative assessment of this charge is shown to be inconclusive; and a previous quantitative assessment, which substantiated the charge, is shown to have serious shortcomings. A linear programming model of the California refining industry is used to simulate competitive market behavior given the refining capacities and other conditions facing the industry. The gravity price differentials implicit in the computed shadow prices are very close to those actually observed and do not lend support to allegations of non-competitive pricing.

CRUDE OIL PRICING: CALIFORNIA GRAVITY DIFFERENTIALS*

Introduction

Federal regulation of the United States petroleum industry has distorted pricing behavior since 1971. For years prior to the imposition of price regulation, however, it was alleged that the structure of California crude oil prices was distorted due to a lack of competition. Crude oil price fixing, beginning at a date unknown, is an offense charged under an ongoing State antitrust case.1/ That aspect of the price structure which has received the most criticism is the price spread between crude oils of different gravity. 2/

Crude oil is not a homogeneous product. An important qualitative feature of a crude oil is its gravity (measured in API degrees). When subjected to the simplest and least costly form of refining, a high gravity crude oil will yield a larger proportion of light, high value products such as gasoline than will a low gravity crude oil. Product yields of low gravity crude oil can be made to approach those of higher gravity crude, but this

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*This paper has been condensed from Chapter VI of the author's thesis, "The California Crude Oil Market" written at the University of California at Santa Barbara. The paper does not necessarily reflect the views of the Federal Trade Commission.

requires additional processing. As a result, high gravity crude oil has historically commanded a higher price than low gravity crude. In the major crude oil producing areas of the United States other than California, the price of crude oil generally decreases 2 cents per barrel for each degree decrease in gravity. The 2 cent gravity price differential has been common in these areas for decades. In California, the differential has typically been 4 to 7 cents per barrel for most of the post-war period. High gravity crude in California has been priced about the same as high gravity crude in other parts of the country, but low gravity California crude has been priced much lower than similar crude in other major producing areas. Independent crude oil producers and government agencies in California have argued that the large gravity price differential did not reflect market conditions and was a monopsonistic price structure imposed by the major integrated refiners. They argue that a competitive market would have yielded a 2 cent per degree price differential.[3/]

Although the various gravities of crude oil actually form a continuum, they are priced discretely and each may be thought of as an individual type of input.

Determining the appropriate gravity price differential, therefore, requires determination of the competitive relationship between a set of factor prices for a multifactor production process. In some respects, the petroleum refining industry and the crude oil inputs lend themselves ideally to such an analysis. The prices of various crude oils are not influenced by demands for their employment in other enterprises. In addition, variable factor inputs other than crude oil play a relatively minor role in the petroleum industry. This allows concentration on the crude oils without excessive concern with other variable factors of production. The difficulties of analyzing the relative factor prices are substantial, however. The petroleum industry is characterized not only by multiple variable inputs but also by jointly produced multiple outputs -- both of these aspects complicate analysis. In addition, although the various crudes are primarily substitutes in production, they may be complements over some ranges; and the production technology which conditions the patterns of substitutability and complementarity is intricate.

Qualitative Assessment

The price of an input to a production process is determined by the supply of the input, the demand for the output of the process and the production function which relates inputs to outputs. Economic justification of the large gravity price differential has usually been based on supply and demand determinants while critics have focused on technological factors.

The California crude oil market has historically been isolated from that of other areas. It has peculiar supply and demand conditions due to natural phenomena. On the supply side, the quantity of low gravity crude found in California has been exceptionally large relative to the quantity of high gravity crude found there. With only about 11 percent of the Nation's proved reserves in 1967, California had 66 percent of the reserves of less than 20^{o} gravity.[4/] In addition, low gravity crude oil has made up an increasing percentage of total production in the State over the past decade.[5/] This could be expected to depress the relative price of low gravity crude oil. On the demand side, the relatively mild winters enjoyed by the population centers of California practically eliminate the demand for heating oil without any corresponding decrease in the demand for gasoline. Also, natural gas has tended to displace fuel oil in many uses. Since fuel oils are most easily produced from low gravity crude, this also could be expected to adversely affect the price of low gravity crude.

Critics of the price structure point to advances in refining technology. Hydrocatalytic cracking and other new methods of upgrading the yields of low gravity crude oil came into widespread use during the 1960's, and older processes such as coking and conventional catalytic cracking became cheaper and more extensively used.[6/] The improved capability to obtain high value yields from low gravity crude should have tended to increase the relative value of such crude.[7/]

No conclusion can be drawn from qualitative arguments concerning the gravity price differential. There have been technological forces tending to decrease the differential, but there have also been supply and demand forces tending to increase it. Quantitative analysis is necessary to determine whether the competitive resolution of the conflicting forces is reflected by the observed price structure or by a price structure with a smaller gravity differential.

The Ben Holt Study

Quantitative analysis of the gravity price differential has been conducted by petroleum engineers. One of the most thorough attempts was made by the Ben Holt Company of Pasadena, California (subsequently referred to as B.H.).[8/] B.H. was commissioned by the Independent Oil and Gas Producers of California to determine the relative values of eight California crude oils with gravities ranging from 8.5° to 34.1°.

The B.H. evaluation was conducted as follows (selected computations from the evaluation process are presented in Table 1 and will be described below). It was assumed that a given quantity of each crude was processed in a refinery employing modern processing equipment. Crude oil assay information and knowledge of refinery process capabilities allowed the computation of the most valuable product mix which could be obtained from each crude.

The product yield was evaluated using Los Angeles prices to obtain the product realization in dollars per barrel. The cost of refining each crude was estimated based upon the total unit cost for each process and the number of units of each process used in refining the crude. The refining cost was subtracted from the product realization to get the value of the crude at the refinery gate. From this "delivered" value was subtracted a transportation cost which was dependent upon the source of the crude. The final figure thus obtained was to reflect the value of each crude at the wellhead and will subsequently be referred to as the B.H. price. The difference between the B.H. prices and the actual posted prices for the crude oils analyzed is shown on the bottom line of Table 1.

B.H. claimed no significance for the absolute level of their computed prices -- they are all considerably higher than the actual prices. They did, however, draw a conclusion about the relative prices of the different gravities. B.H. observed that the actual prices of the lower gravity crudes were much farther below the computed prices than were the prices of the higher gravity crudes.

They concluded, therefore, that low gravity crude oils were underpriced relative to high gravity crude oils. In other words, they concluded that the gravity price differential in California was too large. The study did not support an argument that the differential should be as small as 2 cents per degree. The B.H. prices decline at an average rate of over 4.4 cents per degree and at a rate of over 5.2 cents per degree between 21.3^{o} and 8.6^{o}. But, these differentials are markedly smaller than those actually observed.

The B.H. analytical method has potentially serious shortcomings. B.H. anticipated two criticisms. As the report states:

> A refiner could take the position that in a particular case he could not afford to pay as much for a heavy crude as indicated (by B.H. prices) because of limited capacity in his processing units or because of inability to market some of the products.

The second criticism concerning the refiner's inability to sell all of each product would not be valid. In a competitive milieu, every refiner should behave as if he could sell all of a particular good that he could produce at the market price. If a refiner restricts his output to the quantity that he can sell at any given price, it is a prima facia indication of non-competitive behavior. The first criticism, however, that the study did not take into account refinery capacity constraints, is valid. A market price is a short run phenomenon; and in the short run, available capital is fixed. As different gravities of crude compete for the use of a limited amount of capital, their relative prices are likely to be different than they would be if capital could be instantly acquired (and disposed of) in desired amounts. By failing to evaluate capacity constraints, B.H. ignored the possibility that some refinery capital may have been earning quasi rents as well as normal returns to capital. A final criticism which might be made is that possible complementarity in production among crudes was not taken into account. The value of each crude was determined without consideration of the quantities of other crudes available.

A Linear Programming Approach

Linear programming allows both the inclusion of capacity constraints and the interaction, both as complements and as substitutes, of the various crude oils being processed together. This method of analysis has been most successful in taking into account technological considerations in the short run behavior of the firm[9/] and is well suited to the production process found in the petroleum industry.

The generalized linear programming problem in matrix notation is to maximize

$$\text{Profit} = c'x$$

subject to

$$Ax \leq r$$

and

$$X \geq o.$$

The matrix A reflects the technological possibilities and each column describes a possible activity. The choice vector x tells the level at which each activity is conducted. The vector c gives the pay off from using a single unit of each activity. An activity which involves the sale of a product will have a positive pay off equal to the price of the product, while a processing activity will have a negative pay off equal to the marginal cost of operating the process. The vector r specifies the constraints on the use of each input and output of the activities including inputs of process capacity.

The dual problem is to minimize

$$P^* = r'y$$

subject to

$$A'y \geq c$$

and

$$y \geq o.$$

The solution of the dual problem is implicit in the solution of the maximization problem and the elements of the vector y have the interpretation of being the shadow prices (the marginal value) of the constrained inputs and outputs.

Since both factor prices and output prices are held constant throughout the solution of the program, the optimal decision generated by a linear programming solution is the decision of a price taker. The linear programming method, in this respect, simulates competition.

Let us assume that a perfectly accurate linear programming model of the California refining industry could be constructed for a point in time. In other words, let us assume an A matrix could be constructed which accurately reflected the technological possibilities available and that the relevant marginal costs and product prices could be ascertained for the construction of a c vector. If capital inputs were constrained to their existing levels, if the various crude oil inputs were constrained to the levels actually used, and, finally, if the industry were competitive, both in the sale of products and in the purchase of inputs, three statements could be made concerning the optimal solution of the linear program. First, the shadow prices generated for the constrained crude oil inputs should equal the observed market prices for those crude oils. Second, the x vector generated by the optimal solution should indicate the quantity of each product actually produced. And third, if the shadow price of any capital input exceeded the marginal cost of acquiring units of that input and if the decision makers in the industry expected the existing situation to persist, then the industry should be in the process of acquiring additional units of that type of capital. If the observed conditions were not as indicated by the solution of the linear program in the three respects mentioned, it would indicate that the refining industry behavior was not competitive.

The analytical method employed below will be to construct and solve linear programming models of the California petroleum refining industry which incorporate the historical market conditions of particular points in time. Assuming that the solution of each model simulates a competitive market outcome, the actual market outcome will be compared to the simulated outcome and conclusions will be drawn about the competitiveness of the market at that time. Of the three indicators of competitive behavior mentioned above, the shadow prices of the crude oil inputs are of primary interest in this study; but the shadow prices of capital units and the predicted product outputs will also be useful in both the evaluation of the market and of the model.

Since the assumption of a "perfectly accurate" model of the industry is undoubtedly presumptuous, especially in the case of the model which will be employed here, a less ambitious goal of the analysis will be to evalute the B.H. results and conclusions in light of the additional considerations (most especially capacity constraints) being introduced.

The linear program used in this study is of modest dimensions for a petroleum refinery model (40 rows and 100 columns); but it includes most of the major processes actually in use.* The B.H. process descriptions provided a basis for the linear program and additional processes and alternate process flows were included to allow flexibility in the face of capacity constraints.[10/] The possible outputs were gasoline, jet fuel, distillate fuel oils (stove oil and Number 2 fuel oil), residual fuel oil, refinery gases, and coke. The model was solved for two points in time, January of 1967 and January of 1970. The B.H. report was prepared on the basis of the 1967 time period, and 1970 was the last year of industry stability prior to the imposition of federal price controls. Product prices, process costs, process capacities, and crude oil availability were all estimated for those points in time.[11/] Two different sets of eight sample crude oil inputs were used, those studied in the B.H. report and eight with more evenly spaced gravities.[12/] Each of the sample crude oils was used to represent a range of crude oil gravities, and the availability of each was constrained to be equal to or less than the

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*Detailed specifications of the model and a description of its construction will be furnished by the author on request.

estimated number of barrels per day of crude in that gravity range which was actually processed by California refineries.

Solution I - Parallel to the B.H. Study

One solution of the model, Solution I, was computed to see how closely the B.H. results could be duplicated by making assumptions in the linear program which were implicit in the B.H. analytical method. In Solution I, the constraints on processing capacities were specified so that they would not be binding; and the pay off vector used average unit costs rather than variable costs. The time period was January 1967, as in the B.H. study; and the eight representative crude oils were those used by B.H. The shadow prices generated in Solution I are listed in Table 2 along with other figures to be discussed below. The shadow prices computed by the model were "delivered" values of the crudes and the transportation costs used by B.H. were subtracted to get the appropriate wellhead values.

The Solution I prices do not all closely match the B.H. prices -- probably due to the fact that the linear program includes additional processing options and took into account complementarity among the crudes. The Solution I results do, however, lead to the same conclusion as the B.H. prices -- that is, that the low gravity crudes are under-priced relative to the high gravity crudes. In fact, the Solution I results indicate that the average gravity price differential should be even lower than was indicated by the B.H. results. The drop in the shadow price from the highest gravity crude to the lowest gravity crude is at the rate of 4.0 cents per degree gravity versus over 4.4 cents per degree gravity for the B.H. prices.

It is interesting to observe the mix of refined products produced in Solution I. The output of each product as a percentage of the volume of crude oil input is shown in Table 3 along with P.A.D. District V's[13/] actual 1967 percentage output of the various products (and some other percentages which will be described below). Since the actual refinery output consisted of a much larger variety of products than the linear program allowed, some actual products are grouped under a single name. For example, gasoline includes both motor gasoline and aviation gasoline as well as various napthas. Residual fuel oil includes road oil, lube oils and asphalt as well as residual fuel oil. In this first solution, where process capacity constraints are ignored, the product yields predicted by the linear program bear no relation to those actually observed. Particularly notable is the extremely high predicted gasoline output of 81%. This is even higher than the 63% to 79% gasoline output that was indicated in the B.H. study.

Had Solution I been a simulated competitive outcome, the results would have clearly suggested non-competitive behavior on the part of refiners. First, the shadow prices especially for the lower gravities, were much higher than the actual posted prices. This would indicate that the refiners were depressing the prices of crude oil and, in particular, the prices of low gravity crude oil relative to high gravity crude oil. Second, the actual output of gasoline was much lower than the predicted output suggesting that refiners were attempting to maintain a non-competitively high price in the gasoline market.

Solution II - January 1967

In Solution II, the use of the major processes -- coking, visbreaking, thermal cracking, catalytic cracking and hydrocracking -- was constrained to be no greater than the capacities of those processes which were actually available in California in January 1967. Also, variable costs were used in the pay off vector rather than average costs. Solution II was meant to simulate a competitive outcome given existing process capacities.

The shadow prices computed in Solution II, corrected for transportation costs, are shown in Table 2 along with the B.H. and Solution I prices. The inclusion of capacity constraints decreased the value of all crude oils but it decreased the value of low gravity crude oils more than that of high gravity crude oils. In Solution II, the shadow prices decline at the average rate of 6.3 cents per degree. This refinement of the B.H. analysis yields a price differential very close to the 6.4 cent differential contained in the observed prices. There is no good statistical test which may be applied to the hypothesis that the actual prices are not significantly different from the computed prices. Given the very limited sophistication of the model, however, the shadow prices of Solution II seem close to the actual posted prices.

The computed prices cannot be labeled estimated "competitive" prices without the qualification "given the existing process capacities." This is because the process capacities themselves may not have been at competitive levels. A colluding group of refiners may have agreed to limit refinery facilities and then behaved competitively under those limitations. For this reason, while an observed deviation from the computed prices would be evidence of non-competitive behavior, a correspondence between the computed and observed prices can only be described as a result which does not contradict competitive behavior.

Capacity constraints were binding for coking visbreaking, catalytic cracking and hydrocracking. Only thermal cracking had excess capacity. The shadow prices for the fully used processes are shown in Table 4. Also shown is the estimated unit construction cost for each process. The estimated construction costs are subject to wide error; but even if construction costs were considerably higher than those estimated, the marginal daily value of the processes, as indicated by their shadow prices, imply very high returns to an investment in additional capacity. It appears that these capital processes were earning substantial quasi rents. In a competitive milieu, refiners should have been planning to add additional capacity in these processes unless they expected a dramatic change in the market situation. In fact, over the three years from January 1967 to January 1970, while crude oil charging capacity rose by about 14%, hydrocracking capacity did rise by over 65% and coking capacity rose by over 94%. Catalytic cracking capacity, on the other hand, rose by a slightly smaller percentage than did crude oil charging capacity and visbreaker capacity actually declined in absolute amount. There is a possible reason why catalytic cracking capacity and visbreaking capacity were not expanded despite their high shadow prices. Catalytic cracking is a substitute for hydrocracking and visbreaking is a substitute for coking. The high shadow prices for these two substitute processes may have been generated because of overflow from the other two processes; and if hydrocracking and coking were considered superior, the decision may have rationally been made to add capacity only in superior processes. There is no objective way to judge whether or not the observed capacity expansion was of the competitive magnitude. A competitive response may have involved even larger capital additions. Such a determination would require knowledge of the subjective decision making processes of the firms involved. It should be pointed out, however, that agreement on a detailed plan of allowed construction would have been necessary if the non-uniform refinery expansion actually observed had occurred under a collusive agreement.

The predicted product outputs for Solution II are shown in Table 3. The correspondence with the actual output is not perfect; but is much closer than that given by Solution I. Again, the lack of any good statistical test makes it difficult to evaluate the significance of differences between the actual and predicted outputs; but, given the limitations of the model, the actual behavior seems reasonably close to the predicted competitive behavior.

Solutions III and IV - January 1970

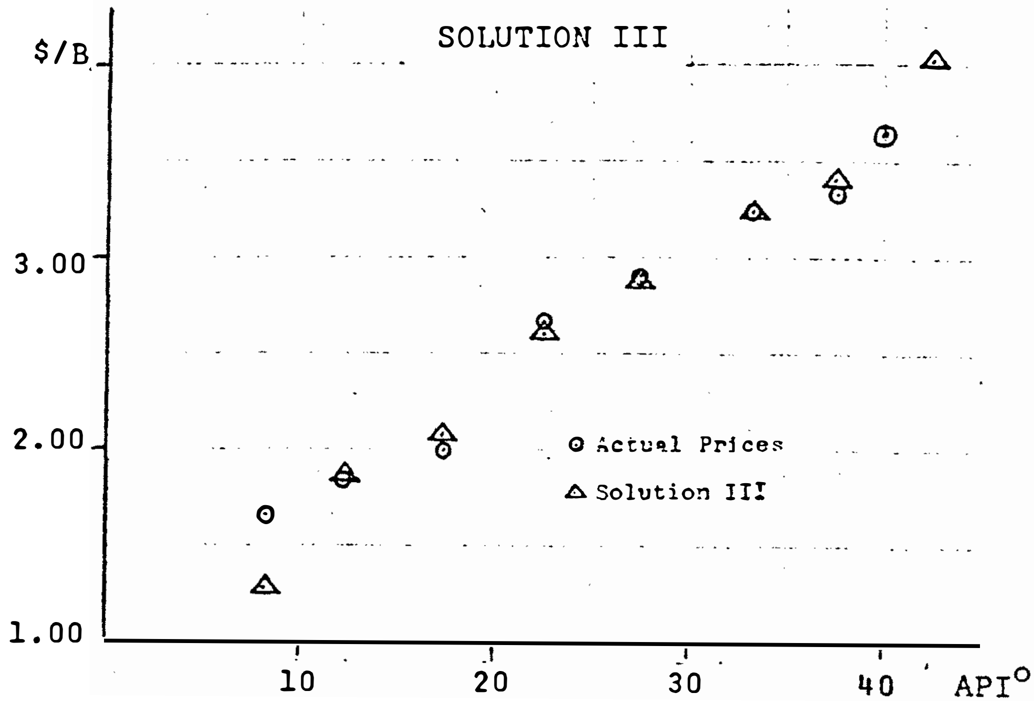
The linear program was also applied to another point in time, January 1970, to see if the relationship between predicted and actual behavior observed in Solution II would prove consistent. A different set of representative crude oils was also used, six of them different from those used by B. H., to test the sensitivity of the model to different crude oil aggregations. The new crudes were chosen to achieve a more even distribution of sample gravities than was given by the B. H. crudes. Process descriptions, other than crude distillation, were not changed; but crude oil availabilities, process capacities, operating costs and product prices were all updated to reflect the 1970 conditions. Two widely varying prices were reported for residual fuel oil in the Los Angeles area. The price given in Platt's Oil Price Handbook for residual fuel oil was $1.55/B while that given in The Oil and Gas Journal for residual was $2.25/B until October 1970. The model was solved for both prices to test the sensitivity of the results to such a price change. A sharp increase in the relative price of a heavy product such as residual fuel oil might be expected to increase the relative price of low gravity crude oil.

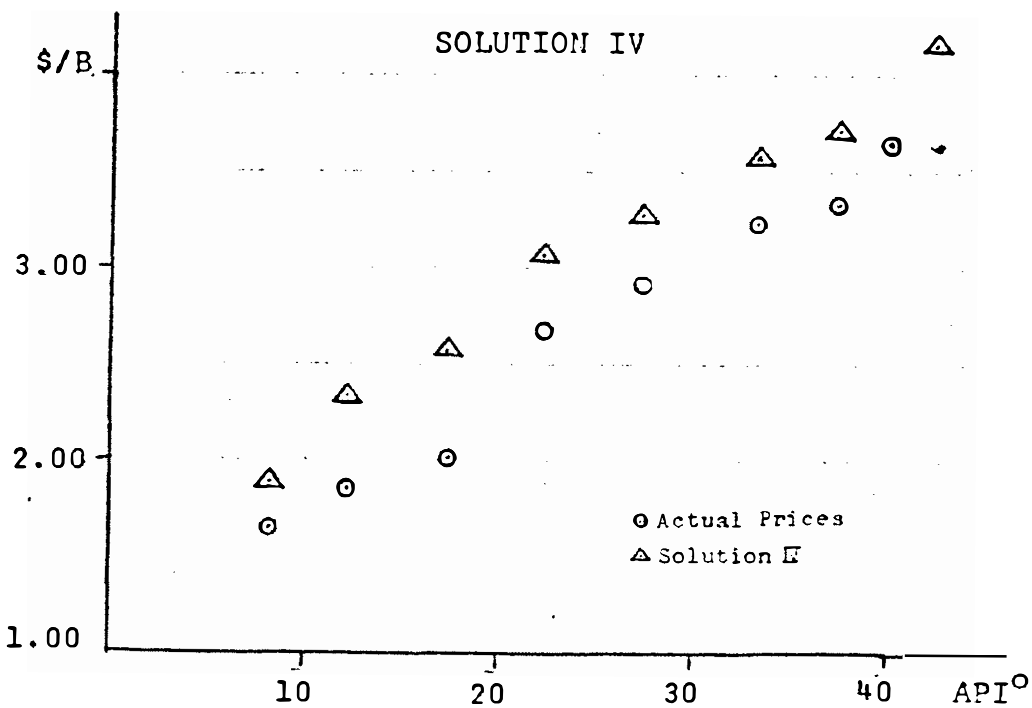
Solution III was computed assuming the lower price for residual fuel oil and Solution IV the higher price. Table 5 presents the actual posted prices and the computed shadow prices, corrected for transportation, for each solution. For the lowest and highest gravities, there were no posted prices and the prices shown are for the closest gravity whose price was posted at the relevant field.

It can be seen that with the Solution III prices (which assume the lower price for residual fuel oil) the computed prices and actual posted prices (except for the two extreme gravities) are quite close. The gravity price differential indicated by the shadow prices is, if anything, greater than that actually prevailing. From the next-to-highest gravity to the next-to-lowest gravity, the computed price falls at the average rate of about 6.4 cents per degree while the actual posted price falls at the rate of only 5.9 cents per degree.

The dominant effect of assuming a higher price for residual fuel oil was a shift up in the values of all of

FIGURE 2


SOLUTION III
$/B
3.00
2.00
1.00
10
20
30
40
API°
Actual Prices
Solution III


SOLUTION IV
$/B
3.00
2.00
1.00
10
20
30
40
API°
Actual Prices
Solution IV

the crude oils. There was also an increase in the computed value of the heavy crudes relative to the light crudes, but except for the extreme high and extreme low gravities, it was modest. The rate of decrease in the shadow price from the next-to-the-highest gravity to the next-to-the-lowest gravity crude fell from 6.4 cents per degree in Solution III to about 5.4 cents per degree in Solution IV. Again, these gravity price differentials can be compared to the 5.9 cents per degree drop in the actual posted price over these same gravities.

The results of Solutions III and IV reinforce the notion that a gravity price differential, at least very close to that contained in the actual posted price structure and certainly much greater than two cents per degree, may have been justified in 1967 and 1970. It is also interesting to note, in light of the gap between the computed prices of Solution IV and actual posted prices, that there was an across the board increase in posted prices of 25 cents per barrel in November of 1970.

The refined product mix predicted in Solutions III and IV is shown in Table 6 along with the actual 1970 District V output. Compared to the product percentages for Solution II (Table 3), the actual and predicted percentages of residual fuel oil are somewhat closer in this case; and the distillate fuel oil percentages are considerably closer. The jet fuel percentages are somewhat farther apart, however; and the gap between the actual and predicted gasoline percentages is much larger. There is some indication that either the linear programming model is more efficient at producing gasoline than are actual refineries or else gasoline output has been restricted below the competitive level. Since the model did not constrain all capacities, the former possibility cannot be dismissed; but an in-depth study of the refined goods market might consider further investigation along this avenue.

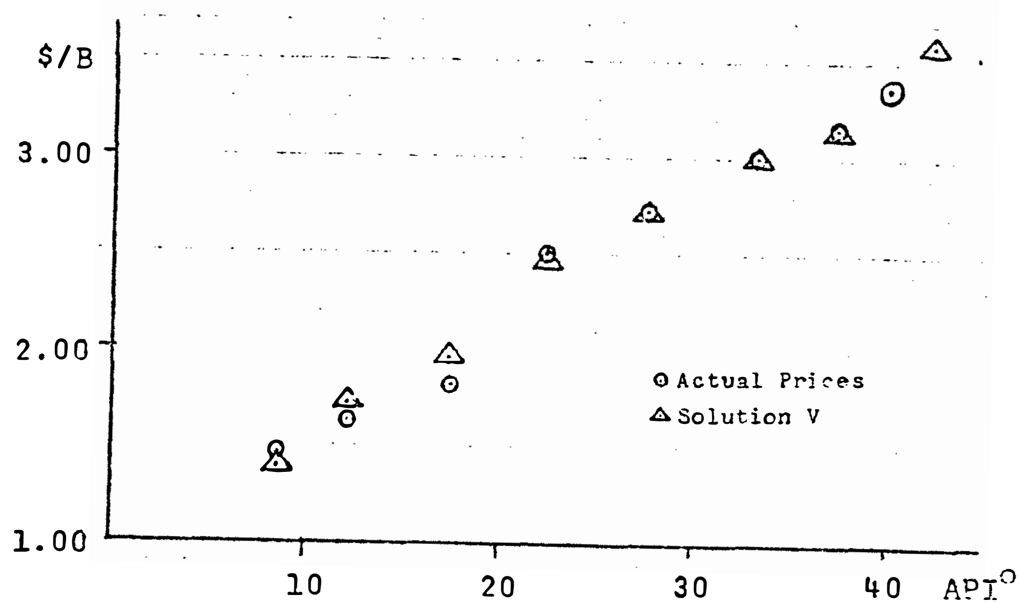
The shadow prices for process capacities are shown in Table 4. The changes from Solution II are mixed and no obvious conclusions can be drawn. The shadow price which increased the most between 1967 and 1970 was that for coking, whose capacity increased most. The shadow price for hydrocracking capacity, which also underwent major expansion, markedly declined. More interesting is the difference between the shadow prices of Solutions III and IV. The magnitude of the changes indicates that the value of specialized refinery equipment may be quite sensitive to changing market conditions. This leads to two observations. First, a large part of the return to refinery investment may be a risk premium rather than rents. Second, shadow prices may be a poor indicator of future investment; expected changes may dominate decision making.

Solution V

A final solution of the model was computed for January 1967 using the set of sample crude oils adopted for Solutions III and IV. The actual and computed prices are presented in Table 7. There is no indication that the gravity price differential should have been significantly greater than it was. The predicted product output mix for Solution V is shown in Table 3 along with the other 1967 results and is fairly close to that estimated in Solution II.

FIGURE 3

SOLUTION V



Summary

Previous arguments and evidence presented in support of the contention that California's large gravity price differential was a monopsony phenomenon were shown to have serious shortcomings. A linear programming analysis was adopted to correct these shortcomings. A model of the California refining industry was employed to simulate competitive prices for comparison with observed prices. The results obtained cast serious doubt on the hypothesis that California's large gravity price differential was the result of monopsony pricing. They do not, however, conclusively rule out the possibility. It is possible, for example, that California refiners colluded to restrict additions of certain types of refining capacity below the competitive level and then acted as competitors in other respects. Although it was not possible to determine whether or not the capacities of refining facilities were at a competitive level, given this limitation, the results generated by the linear program appeared to be consistent with a hypothesis that the observed California price differentials were the result of competitive pricing.

NOTES

1/ The State of California v. Standard Oil of California, et. al., C-75-1322SC, June 25, 1975.

2/ The Wall Street Journal, August 10, 1973, p. 26.

3/ For example, see Pacific Oil World, December 1971, p. 2 and City of Long Beach, Fiscal 1972/1973 Annual Report, p.22.

4/ Computed from data in U.S. Bureau of Mines, Heavy Crude Oil, Bureau of Mines Information Circular 8352, 1967.

5/ Conservation Committee of California Oil Producers, Annual Review of California Crude Oil Production (Los Angeles: Conservation Committee of California Oil Producers, 1972), Part I, Section II.

6/ The Oil and Gas Journal, April 15, 1974, p. 66.

7/ Rene Pierre Manes, "The Quality and Pricing of Crude Oil," Journal of Industrial Economics, Vol. XII, No. 2 (March, 1964), pp. 151-162.

8/ Ben Holt Company, Job 6711 (Pasadena, California: December 20, 1967). Unpublished but widely circulated in the industry. Its results were summarized in "Heavy California Oil Claimed Too Cheap," The Oil and Gas Journal, July 8, 1968, pp.36-37.

9/ A.A. Walters, "Production Functions: An Econometric Survey," Econometrica, Vol. 31, No. 1-2 (January-April 1973), pp. 1-65.

10/ Supplementary process information was taken from Bonner and Moore Associates U.S. Motor Gasoline Economics (Houston: Bonner and Moore, 1967), Volume I; Alan S. Manne, "A Linear Programming Model of the U.S. Petroleum Refining Industry," Econometrica, January 1958, pp. 67-104; and R. J. Hengstebeck Petroleum Processing (New York: McGraw-Hill Books, Co., Inc., 1959).

11/ Refinery process capacities were obtained from The Oil and Gas Journal, April 3, 1967, p. 153 and 183-184; and April 6, 1970, pp. 160-161. Process costs were taken from Wilbur L. Nelson, Guide to Refinery Operating Costs, (Tulsa, Oklahoma: The Petroleum Publishing Co., 1970) updated by information from The Oil and Gas Journal, June 5, 1967, p. 132 and June 1, 1970, p. 69. Product prices were taken from B.H.; Platt's Oil Price Handbook and Oilmanac, (New York: McGraw-Hill, Inc., 1967 and 1970); and The Oil and Gas Journal. Crude oil availability estimated based on data in the Conservation Committee's Annual Review, 1967 and 1970; and import data from the Bureau of Mines Mineral Industry Surveys and The Oil and Gas Journal, July 20, 1970, pp. 64-65.

12/ Crude oil assays were obtained from B.H.; E. L. Garton and C.M. McKinney, Analysis of Crude Oils from Some California Fields, Bureau of Mines Report of Investigation 5249, 1956, pp. 16 and 52; and C.M. McKinney and O.C. Blade, Analysis of Crude Oils from 283 Important Oil Fields in the U.S., Bureau of Mines Report of Investigation 4289, 1948, pp. 8, 13, and 17.

13/ PAD V is a Bureau of Mines accounting area which includes in addition to California, Alaska, Arizona, Hawaii, Nevada, Oregon and Washington. Refinery output data were not available for California alone, but California accounted for about 90 percent of PAD V refining.

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TABLE 1

BEN HOLT CALCULATIONS

Crude Oil Gravity	34.1°	30.3°	21.3°	18.1°	14.8°	13.7°	12.7°	8.6°
Product Realization	5.47	5.35	5.18	5.02	5.18	5.07	4.75	4.54
Operating Cost	1.22	1.38	1.45	1.43	1.57	1.59	1.50	1.38
Transportation	0.10	0.05	0.05	0.10	0.15	0.10	0.15	0.15
Net Realization (B.H. Price)	4.15	3.92	3.49	3.56	3.38	3.10	3.10	3.01
Actual Posted Price	3.12	2.92	2.37	2.10	1.88	1.70	1.63	1.48
B.H. Price-Actual Price	1.03	1.00	1.12	1.46	1.50	1.40	1.47	1.53

TABLE 2

ACTUAL AND COMPUTED CRUDE OIL PRICES, 1967

Crude Oil Gravity	Actual Posted Price ($/B)	B.H. Price ($/B)	Solution I ($/B)	Solution II ($/B)
34.1°	3.12	4.15	3.34	2.98
30.3°	2.92	3.92	3.27	2.81
21.3°	2.37	3.49	3.01	2.42
18.1°	2.10	3.56	2.79	2.14
14.8°	1.88	3.38	2.78	2.08
13.7°	1.70	3.10	2.53	1.75
12.7°	1.63	3.10	2.47	1.69
8.6°	1.48	3.01	2.31	1.37

TABLE 3

PRODUCT YIELDS - 1967

(Volumetric Percentage Of Crude Oil Input)

	Actual Dist. V	Solution I	Solution II	Solution V
Gasoline	42.8	81.1	44.1	42.7
Jet Fuel	12.4	12.7	13.1	11.1
Distillate Fuel Oils	11.8	0.7	3.7	6.6
Residual Fuel Oil	24.5	0.0	34.5	35.6
Coke	2.6	9.4	3.9	3.6
Dry Gases	5.2	13.1	8.0	5.9
Liquid Gases	2.6	0.0	0.0	0.0
Other	0.8	N/A	N/A	N/A
Total	102.7	117.0	107.3	105.5

SOURCE: Actual Yield Percentages Computed From U.S. Bureau of Mines, <u>Mineral Industry Survey</u>

TABLE 4

CAPITAL COSTS AND SHADOW PRICES

(Dollars Per Daily Barrel)

	Construction Cost		Shadow Price, Solution		
	1967	1970	II	III	IV
Coking	411	432	.88	1.73	1.34
Visbreaking	131	138	.17	.42	.13
Catalytic Cracking	439	445	.41	.81	.37
Hydrocracking	602	609	1.29	.18	.22

Source: Construction costs constructed from information found in W.L. Nelson, "Cost of Processing Units," The Oil and Gas Journal, March 25, 1974, p. 120; April 1, 1974, pp. 118-119; April 8, 1974, p. 74; and April 15, 1974, p. 66. Based on average sized processing units found in California.

TABLE 5

SOLUTIONS III AND IV

Gravity	Actual Prices ($/B)	Solution III ($/B)	Solution IV ($/B)
42.6°	3.57[a]	4.02	4.16
37.6°	3.32	3.40	3.70
33.2°	3.24	3.23	3.57
27.7°	2.90	2.88	3.28
22.6°	2.68	2.60	3.08
17.5°	2.00	2.07	2.58
12.2°	1.83	1.77	2.33
8.6°	1.74[b]	1.28	1.89

[a] Posted price for 40° gravity

[b] Posted price for 9° gravity

TABLE 6

PRODUCT YIELDS - 1970
(Volumetric Percentage Of Crude Oil Input)

	Actual Dist. V	Solution III	Solution IV
Gasoline	48.0	61.6	60.1
Jet Fuel	14.2	12.6	12.1
Distillate Fuel Oils	10.9	9.2	7.6
Residual Fuel Oil	19.0	11.2[a]	15.6
Coke	4.1	6.9	6.9
Dry Gasses	5.6	8.3	7.5
Liquid Gasses	3.1	0.0	0.0
Other	0.7	N/A	N/A
Total	104.9	109.8	109.8

[a]Includes visbreaker tar.

SOURCE: Actual yield percentages computed from U.S. Bureau of Mines, Mineral Industry Surveys.

TABLE 7

SOLUTION V

Gravity	Actual Prices ($/B)	Solution V ($/B)
42.6°	3.37[a]	3.59
37.6°	3.12	3.12
33.2°	2.98	2.99
27.7°	2.70	2.71
22.6°	2.48	2.47
17.5°	1.80	1.92
12.2°	1.63	1.72
8.6°	1.48	1.40

[a]Posted price for 40° gravity