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REFINERY CLOSINGS AND THE REGIONAL DISTRIBUTION OF REFINING CAPACITY

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Introduction

During the past several years, the United States refining industry has suffered severe problems of excess operating capacity and low operating margins. These problems have several origins. Higher prices and sluggish economic activity have reduced the overall demand for petroleum products in the United States. Decontrol of crude prices and elimination of the entitlements program have removed some explicit and implicit subsidies for many refiners, resulting in substantially higher costs. This is particularly true for small refiners who enjoyed the advantages of additional subsidies referred to as the "small refiner bias."

Changing crude slates and product yield patterns have exacerbated the problem. Petroleum product demand has become increasingly concentrated in lighter products, such as unleaded gasoline, at the expense of heavier products, such as residual fuel oil. Producing these lighter products requires complex and costly refining processes, or necessitates the use of light and sweet (i.e. low sulfur) crude oils as refinery input. However, the light sweet crudes sell at a premium relative to heavy and sour (i.e. high sulfur) crudes, which are available in greater relative supply.

A third alternative for refiners is to specialize in the production of heavier products using less complex and lower cost refining techniques. However, refiners choosing this alternative may experience reduced revenues, due to the lower relative demand for heavy products. Each of the three alternatives suggests squeezed profit margins as long as excess capacity exists in the refining industry. Because of these conditions, it seems inevitable that the domestic refining industry will undergo a competitive shakeout during the next several years.

This study examines the domestic refining industry to identify the types of refineries most likely to shut down in this current economic climate. The analysis is done at the individual refinery level in an attempt to identify resulting changes in the regional distribution of refining capacity by Petroleum Administration for Defense District. It should be noted that this study is not "location analysis" in the traditional sense of examining the impact of specific regional location factors on refinery location. Rather, it assesses the hypo-

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thetical profit potential of individual refineries and the regional distribution of refining capacity which would result from failure of the hypothetically least economic units. This distribution then can be considered as a possible input into a more traditional and sophisticated regional location analysis.

The Data

The primary source of data used in the study is the Bonner and Moore Aggregator for 1980.[1] The Aggregator contains a list of all domestic refineries at year end 1979, including a quantitative description of their crude oil distillation capacities and the capacities of their other refining processes. These data were used to calculate all refining indexes in the study.

One such index computed from these data is called the refinery complexity index, a statistic attributable to W. L. Nelson.[2] To calculate the index, each refinery operation is assigned a complexity factor relating its cost and technical sophistication to those of crude oil distillation. For example, catalytic reforming has a complexity factor of 5, indicating that it is five times as complex as crude oil distillation. The complexity index for a refinery is the weighted sum of these complexity factors, the weights being the ratios of various process capacities to the total crude oil distillation capacity. Constructed in this fashion, the complexity index provides a good summary measure of the sophistication of the total refinery.

Other sets of data utilized in the study are average crude oil slates and product yield patterns for refineries of different size and complexity. These data were obtained for 1978 from the National Petroleum Council [7, 8]. The averages were available for six size classifications ranging from the smallest refineries with a capacity less than or equal to 10,000 barrels per day, to the largest with refining capacity in excess of 175,000 barrels per day. They also were available for six complexity classifications ranging from the least sophisticated refineries with complexity factors less than or equal to 3, to the most sophisticated with factors greater than 11. Crude slates were apportioned into five crude oil types varying by weight and sulfur content, and product slates were formed into six product yield fractions.

Price data were the final pieces of information utilized in the study. Product prices were measured by IPAA wholesale prices for 1980 [2]. Prices for each crude oil type also were obtained for 1980, using the price of a particular type

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[1] The Aggregator is a set of refinery data published by the Bonner and Moore Company of Houston, Texas. It was available to me through the auspices of Marathon Oil Company.

[2] For a complete description of the index, its calculation and interpretation, refer to a series of articles by Nelson in the *The Oil and Gas Journal* [3, 4, 5, 6].

of crude oil corresponding to each density and sulfur classification.[3] Given these various sets of data, it was possible to construct "hypothetical gross profit margins" for individual refineries and to assess refiners' "hypothetical profitability" under 1980 market conditions.

Hypothetical Gross Margins

Several steps were necessary to analyze hypothetical refinery profitability. First, a value of output per barrel was constructed for each refinery. This was computed as the weighted sum of the refinery's hypothetical product yield fractions multiplied by the price per barrel of each product. Two such market values per barrel were constructed for each refinery, one according to its size classification (VALUES) and the second based on its complexity classification (VALUEC). Next, hypothetical crude costs per barrel were computed for each refinery as the weighted sum of average crude slates multiplied by the price per barrel of each crude type. SLATES measured the per barrel crude cost according to the size of the refinery, the SLATEC measured crude cost according to refinery complexity.

These indexes then were used to compute hypothetical gross profit margins for each refinery using 1980 prices. MARGINS = VALUES − SLATES represented a gross margin based on a refinery's size. Its values ranged from $-3.68 to $1.36. Similarly, MARGINC = VALUEC − SLATEC depicted gross margins based on complexity characteristics, with values ranging from $-4.41 to $2.20. Even though these gross margins were calculated in a very crude fashion, some of the negative values suggest the severity of the market conditions confronting many refiners.

It should be emphasized that these gross margins are strictly hypothetical. Every refinery is different and its refining decisions are made by different groups of individuals. In particular, regional price variations and deviations from the average product yield pattern would affect the revenue of each refinery. Ideally, regional variations in average product slates would have been incorporated into the analysis if the data were available. Variations from the average crude slate and from the mix of crude oils used by a refinery would affect crude costs as measured by SLATES and SLATEC. Consequently, no gross margin based on crude costs and product values accurately represents

[3] These data were supplied by the economics department of Marathon Oil Company. The specific crude oils used in the study are as follows: sweet — Bonny Light; light, medium sulfur — Murban; heavy, medium sulfur — North Slope; light, high sulfur — Arabian Light; heavy, high sulfur — Bachequero. There are two reasons for using these crude oils. First, they represent the examples used by the National Petroleum Council in its refinery study [8]. Second, since the slate is dominated by foreign crudes, the prices more accurately reflect the post-decontrol set of crude costs faced by refiners. The only exception is North Slope crude, and a deregulated price was used for this category. Since the purpose of the study is to analyze the hypothetical profit potential of refiners in a deregulated market, this set of prices is considered appropriate even though most refiners may not use a crude slate as heavily weighted toward foreign crudes. My thanks to Gary R. Bishop for these price data.

the actual profit position of a given firm. The best that can be obtained is a representation of the relative competitive position of various categories of refineries.[4]

The specific values of MARGINS and MARGINC must be considered in light of these caveats. In order to summarize the information contained in these gross margins and to organize the data in a more appropriate ordinal fashion, an index number representing the size, complexity, and gross margins of each refinery was calculated. The index number, designated as RANKSUM, was computed in several steps. First, 1980 gross margins were ranked for the six refinery size classifications, 1 representing the classification with the lowest margin and 6 representing the classification with the highest margin. Next, a similar ranking was performed for the six refinery complexity classifications, 1 representing the lowest and 6 the highest. Finally, the ranks on these criteria were summed for each refinery to form an index number from 2 to 12. Lower numbers represented refineries with lower hypothetical profitability; high numbers represented refineries with greater hypothetical profitability.

Three general groups of refineries were constructed based on RANKSUM:

Group 1 = small size, low complexity; RANKSUM less than or equal to 4; average gross margins ranging from $-4.04 to $-1.36 per barrel.

Group 2 = medium size, medium complexity; RANKSUM greater than or equal to 5 and less than or equal to 9; average gross margins ranging from $-2.46 to $0.59 per barrel.

Group 3 = large size, high complexity; RANKSUM greater than or equal to 10; average gross margins ranging from $0.84 to $1.78 per barrel.

Although groups 1 and 3 are relatively homegenous, group 2 contains a range of different refinery types. Based on each refinery's capacity to process heavy and sour crude, group 2 was divided into several distinct subsets:

2A = lube refineries; complexity greater than 11 indicating sophisticated lube oil capabilities.

2B = no heavy, no sour; refineries incapable of processing heavy crude (*except* for possible asphalt capacity) or sour crude.

2C = no heavy, sour; sour processing capacity, but no heavy (except asphalt).

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[4] Adjustments to crude oil acquisition costs for the entitlements and small refiner bias programs have not been made in the data. The primary rationale for this exclusion is the desire to represent crude costs and product values in a deregulated market. Even if it were desirable to include these adjustments, the data are unavailable. Payments and subsidies under both programs were allocated on a company basis, and the unit of analysis in this study is the individual refinery.

2D = heavy, no sour; heavy processing capacity beyond asphalt, but no sour capacity.

2E = heavy, sour; capacity to process heavy and sour crudes.

Because of expected refining market conditions described above, it is hypothesized that group 1 refineries will face the most severe competitive pressures and are the most likely to shut down. Their small refining capacities and unsophisticated refining techniques contribute to their relatively low/negative profitability. Most of the so-called "bias babies," which sprang up during the decade of the 1970s and which largely owe their existence to the small refiner bias, are in this group. Group 2B refineries are hypothesized to be the next most likely candidates for shutdown, due to their inability to process heavy and sour crude slates. Refiners capable of processing some heavy and/or sour crude (groups 2C, 2D, 2E) are hypothesized as less likely to fail. Groups 3 and 2A are considered the least likely to fail, due to the higher gross margins attributable to their size and sophistication (group 3) and the specialized nature of their products (group 2A).

These hypotheses are meant to pertain on a general or average basis, and should not be interpreted as having implications for any specific refinery. For example, while many small refiners may have benefited substantially from the small refiner bias program, they certainly may be capable of surviving on their own. They may be efficient at producing limited product slates, or they may exist in isolated markets or in areas where there is a lack of market density necessary to support larger refineries. Refineries also need not possess the ability to process heavy and sour crude to stay in business. However, it is likely that they will be faced with the alternatives of modernizing and retrofitting refining capacity, using premium priced crude oils, or producing relatively lower priced products. The survival of any particular refinery will depend on the timing and astuteness of the business decisions made by its managerial staff.

Discriminant Analysis

To analyze the likelihood of refinery closings from a different perspective, and to provide additional impressionistic evidence regarding the hypotheses stated above, discriminant analysis was applied to the 1979 year end stock of refineries. The specific purpose of this task was to classify each refinery into one of two groups ("closed" or "open") based on refinery process capacities. Having classified refineries in this manner, the regional distribution of refining capacity resulting from these "shutdowns" can be analyzed. The discriminant analysis program from SAS [9] was applied to the refinery data contained in the Bonner and Moore Aggregator to accomplish this task.

The data sample used in the first step to estimate the discriminant function contained 47 refineries owned by six major oil companies which had announced refinery closings prior to June 1, 1981. These six companies included Amoco, Texaco, Gulf, Conoco, Mobil, and Ashland. Status 0 included the seven refineries whose closings had been announced; status 1 contained the remaining 40 refineries owned by the same companies.

Five variables describing refiners' process capacities were used to classify refineries into status 0 or status 1. These variables are described as follows:[5]

CRUDE = crude oil distillation capacity, thousands of barrels per day

FACTOR = refinery complexity factor, Nelson refinery index

GOTREAT = gas oil hydrotreating; proportion of refinery capacity capable of processing sour crude oil

HEAVY1 = proportion of refinery capacity capable of processing heavy crude oil (excluding any asphalt capacity)

CATREF = catalytic reforming; proportion of refinery capacity capable of producing unleaded gasoline.

The means of these variables for status 0 (closed) and status 1 (open) refineries are contained in Table 1. The descriptive data suggest that shut down refineries are generally smaller and slightly less sophisticated than other refineries owned by the same companies. Although the proportionate processing capacities for producing unleaded gasoline appear similar for each group, the capability of the closed refineries to process heavy and sour crude appears to be only half as great as its counterparts.

The SAS program utilizes the measure of generalized squared distance based on the pooled covariance matrix or the within-groups covariance matrices. Because the test of homogeneity of the within-group covariance matrices indicated rejection of the null hypothesis at the .01 level (chi-square value = 31.2), the within-group covariance matrices were used in the discriminant function. The prior probabilities of a refinery being in either group were treated as equal.

Table 1. Means of Discriminating Variables for Sample Refineries

Variable	**Status 0**	**Status 1**
CRUDE	49.7	112.9
FACTOR	6.4	7.9
GOTREAT	0.24	0.50
HEAVY1	0.21	0.48
CATREF	0.22	0.23

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[5] The specific details of computing the values of these variables are rather lengthy and complex. These details are available on request from the author. It could be argued that other variables should be included in the discriminant function. Specific candidates might include a variable measuring the degree of dependence on entitlement subsidies, a measure of market density, or a regional measure of self sufficiency. Since the primary purpose of the analysis was to obtain a reasonable classification scheme based strictly on refinery process characteristics, these other variables were excluded.

Table 2. Classification Summary for Sample Data

Number and Percent of Observations Classified

From \ Into	Status 0	Status 1	Total
Status 0	7 100%	0 0%	7 100%
Status 1	7 17.5%	33 82.5%	40 100%
Total	14 29.8%	33 70.2%	47 100%

Based on the estimated discriminant function, each observation was classified into the group (0 or 1) which provided the smaller generalized squared distance. The generalized squared distance criterion also can be converted into a posterior probability of classification into each group. The classification summary for the sample of 47 refineries is contained in Table 2. The results suggest that discriminant analysis based on the five refinery variables satisfactorily describes the potential status of a refinery for the purposes of this study. Of particular importance is the fact that all seven closed refineries were classified correctly based on the estimated discriminant function. This is crucial since the purpose of the analysis is to provide insights regarding the types of refineries most likely to shut down. Also important is the fact that the lowest posterior probability of classification into status 0 for the seven closed refineries was .798. Five of them had posterior probabilities greater than .936.

The estimated discriminant model then was applied to the entire stock of refineries to provide impressionistic insights into the types and locations of refineries likely to fall into status 0. The number and percent of "closings" for each refinery group as suggested by the model are contained in Table 3. These results reinforce the hypotheses stated above. In particular, the most likely groups of refineries to be classified as "closed" are the small unsophisticated refineries (group 1) and those incapable of processing either heavy or sour crude (group 2B). Refineries capable of processing heavy and/or sour crude (groups 2C, 2D, 2E) have a much lower incidence of

Table 3. Hypothetical Refinery Closings by Group

		Status 0	
Refinery Group	Total Number	Number	Percent
1	127	100	78.7
2A	18	0	0.0
2B	40	24	60.0
2C	44	6	13.6
2D	11	0	0.0
2E	20	3	15.0
3	35	1	2.9

closure according to the discriminant model. Nine of the 75 (12 percent) refineries in these groups were classified as status 0. Finally, complex lube oil refineries (group 2A) and the large, highly complex refineries (group 3) had a very low incidence of closure according to the discriminant model. Only one such refinery was classified as status 0.

An interesting question raised by the results concerns the regional distribution of refining capacity which would result from these hypothetical closures. This question was analyzed briefly at the level of Petroleum Administration for Defense Districts (PADs). PADs represent five product supply districts in the U.S. and are used frequently in petroleum industry supply analysis. These districts can be described succinctly as follows: PAD 1 - east coast; PAD 2 - midwest; PAD 3 - gulf coast and southwest; PAD 4 - mountain states; PAD 5 - far west. Refinery closings by region using the results of the discriminant model are contained in Table 4.

PAD 1 is predicted to have the lowest incidence of refinery closure (33.3%), and all other PADs are approximately equal in this respect. The regions with the greatest number of closings and the largest amount of shut down capacity are PADs 2 and 3. These two regions dominate refining activity at the current time. Except for PAD 4, where the model suggests closure of almost one third of total refining capacity, the impressions provided by the model do not seem entirely unreasonable.

Several additional sets of information were combined with the impressions in Table 4 to derive a final forecast of regional refining capacity. First, the stock of refineries was updated using year end 1980 figures obtained from the *The Oil and Gas Journal* in place of the 1979 data contained in the Aggregator [10]. This had the effect of altering slightly the number and capacity of refineries in each PAD. Second, previously announced planned additions to refining capacity were added to the totals. This also raised net refining capacity. Third, the *Hydrocarbon Processing* refinery construction boxscore was consulted to identify refiners undertaking upgrading and retrofitting [1]. In those cases where the upgrading was of major proportions and would alter substantially the ability to process heavy and sour crude or produce unleaded

Table 4. Hypothetical Refinery Closings by PAD

	PAD 1	PAD 2	PAD 3	PAD 4	PAD 5	TOTAL
# Refineries*	30	69	113	29	57	298
# Closed	10	32	55	13	27	137
% Closed	33.3	46.4	48.7	44.8	47.4	46.0
Total Capacity+	1,937	4,288	7,771	576	3,150	17,722
Capacity Closed	207	788	961	189	486	2,631
% Closed	10.7	18.4	12.4	32.8	15.4	14.8

* Year end 1979 data contained in Bonner and Moore Aggregator used as the base.

\+ Capacity measured in thousands of barrels per day.

gasoline, the refineries were reclassified subjectively as "open." This procedure decreased the amount of shutdown capacity in several PADs.

Finally, several refineries in PAD 4 and Alaska (PAD 5) were reclassified as "open," despite the discriminant analysis results. These somewhat arbitrary reclassifications were made to account for the fact that there were no measures of market density or regional self sufficiency included in the discriminant function. A judgment was made that several relatively small, unsophisticated refineries were more likely to survive in these regions than if they were located in more densely populated regions, such as PAD 2 or PAD 3. This had the effect of reducing the closures in PAD 4 and PAD 5. The final pattern emerging from these considerations is contained in Table 5.

The general picture drawn from this forecast is that of a leaner refining industry in all regions of the United States. The industry will lose many of its smaller and less sophisticated plants, and will be dominanted by a smaller number of larger and more flexible production facilities. This would leave the industry in a position of being able to respond more quickly to changes in the composition of demand, especially with regard to producing lighter products, such as unleaded gasoline. Refiners remaining in PAD 2 should be in a relatively good position to utilize their capacity efficiently because of the greater relative decline in refining capacity in that midwest region. If all planned additions to capacity are completed, refiners in PADs 1 and 3 may be forced to operate with less than desired capacity utilization rates or be forced to experience greater numbers of plant closings than suggested currently.

Table 5. Adjusted Regional Distribution of Refining Capacity

	PAD 1	PAD 2	PAD 3	PAD 4	PAD 5	TOTAL
# Refineries	30	68	117	30	59	304
# Closed	10	27	49	9	21	116
% Closed	33.3	39.7	41.9	30.0	35.6	38.2
Capacity	1,888	4,285	8,408	592	3,293	18,466
Capacity Closed	199	697	884	46	294	2,120
% Closed	10.5	16.3	10.5	7.8	8.9	11.5
Planned Additions	161	50	440	25	46	722
Net Capacity	1,850	3,638	7,964	571	3,045	17,068
% of Initial Capacity	98.0	84.9	94.7	96.4	92.5	92.4

Summary Comments

This study represents a first attempt to quantify the competitive shakeout currently underway in the refining industry. Although based on firm level analysis, the study provides some impressions regarding the regional distribution of refining capacity likely to result from the spate of plant closures. What remains to be done is a more straightforward regional location analysis to complement the impressions provided by the gross profit margin and discriminant analyses.

Certainly the individual refinery results obtained from the discriminant analysis, which were not reported in this article, should be taken with more than a modicum of salt. However, the set of "predictions" regarding the disposition of individual refineries is not the important aspect of the study. Rather it is the overall impressions with respect to the types of firms most subject to competitive pressures, and the broad regional distribution pattern implied by the analysis which are important. If these insights prove useful, then the study has value for the regional analyst.

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