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The Determinants of Plant Exit: The Evolution of the U.S. Refining Industry

by

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Abstract:

This paper analyzes factors that affect the exit and expansion of U.S. petroleum refineries using plant-level capacity data from 1947 to 2013. We find that larger refineries are less likely to close and that refineries owned by a multi-plant firm are more likely to close. If a multi-plant firm closes a refinery, it is likely to close its smaller refineries. In contrast to previous literature, we find weak evidence that refineries owned by firms with higher market shares are less likely to close. In specifications with more control variables, this relationship is statistically insignificant.

JEL Classifications: L11; L71
Keywords: Refining, Multinomial Probit, Plant Exit, Multi-plant Coordination

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I. Introduction

The petroleum refining industry has undergone significant changes since the late 19th century as new technologies have altered how petroleum products are manufactured, transported, and consumed. Refineries began as relatively simple plants that distilled crude oil into different products including kerosene for lighting. Other products were used for heating and lubrication. With the growth of internal combustion engines, gasoline became a higher-valued product. As gasoline consumption grew, refineries added new technology to "crack" crude oil to increase the percentage of crude oil that could be refined into gasoline and reduce the production of less valuable byproducts. Over time, higher performing engines required fuels that met more stringent specifications, such as higher octane. Government regulations also began to influence the products that refineries produced, such as Clean Air Act regulations phasing out lead and later regulations requiring reductions in sulfur in gasoline and diesel. These changes in the demand for the types of petroleum products often led refineries to add additional equipment to alter the types of products that they produced as well as remove contaminants from the final products.[2] At the same time, technology to move crude oil and petroleum products also improved as crude, and then product pipelines lowered shipping costs.

As the market for petroleum products has changed, the optimal number, type, and location of refineries has likely also changed. These changes may lead a refinery to exit, or may lead a refinery to expand. This dynamic process is not unique to petroleum refineries, and many other manufacturing industries have undergone similar changes. In this paper, we analyze what factors make it more likely that a refinery survives in these changing market conditions. Several

[2] For a more in depth discussions of the evolution of refining processing and complexity see Nguyen, Saviotti, Trommetter and Bourgeois (2005) and Leffler (2008).

authors have previously analyzed factors that influence plant exit, mostly in other industries during periods of consolidation and exit. This paper contributes to that literature by utilizing a much longer data set that tracks annual changes in refinery capacity during periods of both capacity expansion and exit. Refinery exit and lack of refinery entry have also been posited as explanations for more recent increases in gasoline prices. Over the last decade, many industry observers have pointed to two industry facts: (1) A large number of refineries have closed since the 1980s; (2) No new refinery has been built since 1976.[3] While the number of refineries has been decreasing since 1940, the focus on closures and lack of new construction misses the main source of current refinery capacity, the expansion of existing refineries.

In our empirical section, we find that larger refineries are less likely to close and that refineries owned by a multi-plant firm are more likely to close. If a multi-plant firm closes a refinery, it is likely to close its smaller refineries. In contrast to previous literature, we find weak evidence that refineries owned by firms with higher market shares are less likely to close. In specifications with more control variables, this relationship is statistically insignificant.

In the remainder of the introduction, we give a brief overview of how refineries operate and a brief review of related literature. Section II describes the data set and discusses factors that could influence refinery exit and expansion decisions. Section III presents the empirical methodology and results. Section IV offers some concluding observations.

[3] The second statement is not quite true. A number of refineries have been built since 1976, but that was the year that the last large refinery in the continental United States was built. This was the Marathon refinery in Garyville, Louisiana. Ten additional refineries opened between 1976 and 2008, with two more opening in 2015 after the end of our data. For some examples of observers linking these statements to high gasoline prices, see James Surowiecki, "Pumped Up," *The New Yorker*, June 12, 2006 (http://www.newyorker.com/magazine/2006/06/12/pumped-up retrieved 11/13/2015); Daniel Gross, "The Great Refinery Shortage," *Slate*, June 8, 2004 (http://www.slate.com/articles/business/moneybox/2004/06/the_great_refinery_shortage.html retrieved 11/13/2015); Mark J. Perry, "No New Oil Refineries Since 1976," Carpe Diem Blogpost June 02, 2008, (http://mjperry.blogspot.com/2008/06/no-new-oil-refineries-since-1976.html retrieved 11/13/2015).

A. Institutional Detail

Crude oil is a mixture of many different hydrocarbons. Refineries are complex manufacturing facilities that separate and recombine those hydrocarbons into various refined products. The main products produced today are gasoline, distillate (mainly diesel), and jet fuel. In the past, fuel oil and kerosene were also significant products, but over time, production of these products has decreased significantly. A typical refinery consists of various processing units. Crude oil is initially processed by the crude distillation unit, which separates the crude oil into various groups of hydrocarbons based on their boiling points. These separate groups are then processed further in one or more downstream units. These units include vacuum distillation, fluid catalytic cracking, delayed coker, hydrotreater, catalytic reformer, and alkylazation, among others. Figure 1 shows a schematic of the various units of a hypothetical refinery.

Since the 1930s, there have been many changes in the petroleum refining industry, as well as in the production and distribution of crude oil and the distribution and marketing of refined products. For example, refiners developed new technologies to increase the portion of crude oil that could be refined into higher value products, especially for more difficult to refine types of crude oil.[4] Refined products markets also evolved as advances in engine technology and changes in environmental regulations altered the specifications for finished petroleum products.[5] As a result, refiners that continued to manufacture fuels often needed to upgrade their refineries to meet these new specifications. Changes in transportation infrastructure also have influenced where refiners choose to operate. For example, crude oil pipelines became viable before refined

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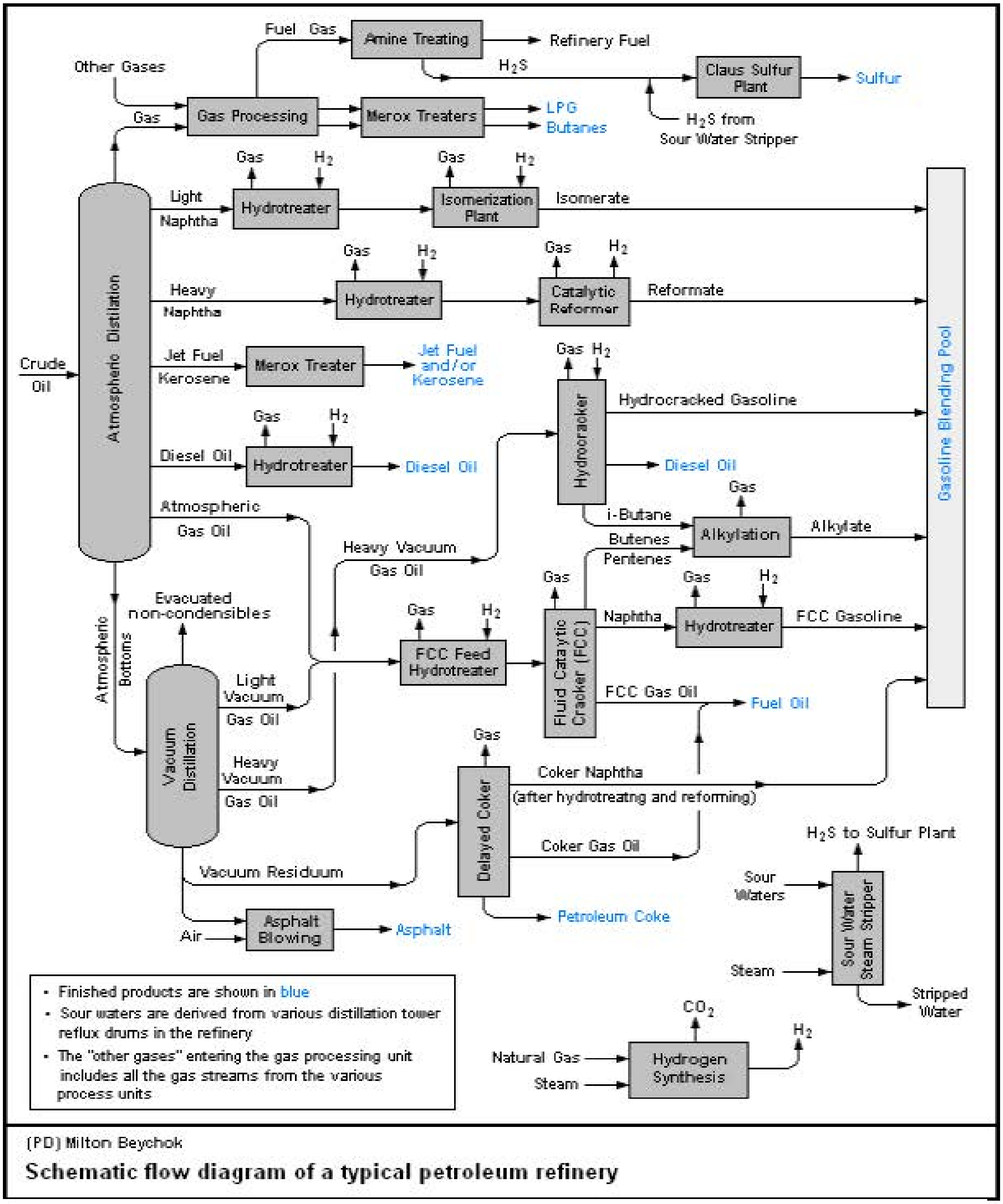
[4] Over time, the average crude oil has become heavier and more sour. In a simple refinery, heavier crude oil generally produces significantly less gasoline, distillate, and jet than lighter crude oil. Sour crude oil has more sulfur, most of which must be removed from finished fuels to meet environmental regulations.

[5] Besides reducing sulfur, regulations required the removal of gasoline additives such as lead and MTBE (methyl tertiary-butyl ether), and reduced the ability to blend more volatile blendstocks into finished gasoline.

product pipelines, so that in some locations it was more efficient to build refineries near the source of finished product demand and ship the crude oil there, rather than refine the crude oil near where it was produced or imported and ship the finished product there. While we do not have good data on many of these factors affecting how refineries developed, we are able to make some inferences based on the refinery capacity data.

Figure 1 - Hypothetical Refinery Schematic*



* Beychok, M. (2012). Petroleum refining processes. Retrieved from http://www.eoearth.org/view/article/169791

B. Literature Review on Plant Exit and Refinery Exit Modeling

A number of previous studies have looked at how plant and firm characteristics influence the probability that a plant will close. Gemawat and Nalebuff (1985), Reynolds (1988) and Whinston (1988) look at theoretical models of which firms would exit first in declining industries. In Gemawat and Nalebuff's model, each firm has one plant, and larger plants exit first. Reynolds and Whinston allow multi-plant firms, and show under certain conditions, firms with more capacity will close plants before firms with less capacity.

There are a number of empirical papers that examine factors that increase the likelihood that a manufacturing or processing plant will close. These studies either review a broad range of industries using data from a survey of manufacturing plants or they concentrate on an industry. Both of these types of studies inform our empirical specification.

First, we review the cross industry studies. Dunne, Roberts and Samuelson (1989) use the U.S. Census of Manufacturers at the four-digit level to look at growth and exit rates, and find that size, owning multiple plants, and age all affect the probability of closure for the years 1963-1982. Disney, Haskel, and Heden (2003) use the UK Census of Production to look at how size, age, and owning multiple plants affect plant survival with data from 1986-1991. Bernard and Jensen (2007) use the US Census of Manufacturers, from 1987-1997, to look at the effect of owning multiple plants, whether the firm is a multinational, whether the plant has been sold in the last five years, along with the effect of plant level controls including plant employment, age, capital intensity, factor productivity, and whether it is a multi-product plant. They also use measures based on input costs. Kneller, McGowan, Inui, and Matsuura (2012) use data from the Japanese Census of Manufacturers and the Basic Survey of Japanese Business Structure and Activities, for 1994 through 2005, to look at the impact of whether a plant is owned by a multinational firm, and also control for the number of employees, capital per worker, factor productivity, input costs, entry and exit rates. All of these studies examine a cross section of industries for a 10 to 20 year period.

Next, we review studies examining plant exit in specific industries. Baden-Fuller (1989) uses profitability, diversification, closure experience, share information, and the number of employees to explain exits in the U.K. Steel Castings industry. He examines exit from this declining industry from 1975 through 1983. He finds that multi-plant diversified firms are the most likely to close a plant. Lieberman (1990) uses data on 30 different types of chemical plants to look at the impact of size, owning multiple plants, diversification, economies of scope, and capacity utilization. Lieberman uses data from roughly 1960 through 1980. He finds that small plants and plants of multi-plant firms are more likely to exit. He also finds that multi-plant firms with higher market shares are more likely to close a plant. Deily (1991) looks at data on integrated steel companies during a period of consolidation between 1977 and 1987. She analyzed the impact of plant and firm size, geographic location, plant technology, and customer market segments on which plats exit. She finds that small plants are the most likely to close. Muth, Karns, Wohlgenant and Anderson (2002) examine data on meat slaughter plants and find that smaller, older and higher costs plants are more likely to close. This study was conducted using data from 1996 through 2000, a period when new regulations would change the cost of production. All of these studies examine plant closing during a relative short period, usually a decade or less during which the industry in question was consolidating.

There are two papers examining refinery closures during a short period in the 1980s when the petroleum industry was consolidating. Chen (2002) examines the probability of survival of U.S. petroleum refineries from 1981-1986, a period of many refinery closures due to the removal of price controls and allocations of crude oil. He uses duration analyses, both parametric and non-parametric duration models, to estimate which factors affect the probability that a refinery existing in 1980 is still operating in 1986. He finds plant size, age, complexity, and whether the refinery is part of a multi-plant firm affects the survival probabilities. Chen (2003) examines the same issue with a similar data set but uses probit analyses. Once again examining yearly data from 1981-1985, he estimates the relationship of surviving each year as a function of the size, age, complexity, location and multi-plant nature of each refinery. He also uses an ordered probit to examine which refineries exit, which refineries remain open but stay the same size, and those that remain open and grow. He finds that larger and older refineries are most likely to survive. It is important to note that regulatory changes in the early 1980's, including the deregulation of crude oil, and the subsequent restructuring, may make this time period unique.

While we do not have data on all the relevant characteristics used in these previous studies that examine exit, we have data on a number of variables that these studies found had an impact on that probability. For example, several papers have found that smaller plants and single-firm plants are more likely to exit, but after controlling for size, some of these papers find that plants owned by multi-plant firms were more likely to close than a plant that was the only one owned by a firm.[6] Other variables that that these papers include are the age of the plant (older plants are less likely to close)[7] and measures of changes in capacity. One of these papers also found that a plant was more likely to close in years with lower capacity utilization, and that firms with higher market shares were more likely to close a plant.[8]

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6 Dunne, Roberts, and Samuelson (1989), Lieberman (1990), Chen (2002), Bernard and Jensen (2007), and Kneller, McGowen, Inui, and Matsura (2012)

7 Dunne, Roberts, and Samuelson (1989), Muth, Karns, Wohlgenant, and Anderson (2002), Bernard and Jensen (2007)

8 Lieberman (1990)

II. Data and Discussion of Factors Influencing Expansion and Exit

Since at least 1928, the federal government has reported annually (with a few exceptions) refinery capacity for most U.S. refineries.[9] Over time, the level of detail of this data has increased, but for each year of data that we have been able to locate, the government reported crude distillation capacity for these refineries. Using the location and characteristics of the refinery, we were able to track changes in individual refinery capacity from 1947 through 2013.[10] For this time range, we have operating and shut down atmospheric crude tower capacity for 627 different refineries: 592 refineries operated at least one year and 35 were shut down for each year in the data. Unfortunately, there is a long gap in the data during World War II so that for many refineries we were not able to match the 1930s data with post-1947 data. However, there are several observations that we make using the data from 1929 to 1935 as well.[11]

We can also use this data to put the two observations on refinery closures and lack of new refinery construction into a broader context. As discussed more below and shown in Table 3, there has been a steady exit of refineries since the beginning of our data set in 1947.[12] As the number of refineries fell, however, total industry capacity continued to increase other than after the second oil shock in the early 1980s. Early in our data, this was due to a combination of existing refineries expanding along with new refinery construction. Since 1976, much more of the increase in capacity has been due to the expansion of existing refineries. Two recent examples of very large refinery expansions were Marathon's Garyville, Louisiana, refinery,

[9] Currently, the Energy Information Administration publishes this data. Prior to the formation of the Department of Energy, the Bureau of Mines published the data. Initially, the Bureau of Mines was part of the Department of Commerce, and later was part of the Department of Interior.
[10] There are two years of missing data. The Energy Information Administration did not release data in 1996 or 1998.
[11] We currently have data for 1929, 1930, 1933, 1934, and 1935.
[12] This trend began in 1940. We do not have individual refinery data for 1940 to 1946, but early reports include historical summary data that show a decrease in the number of operating refineries and increase in capacity for this period.

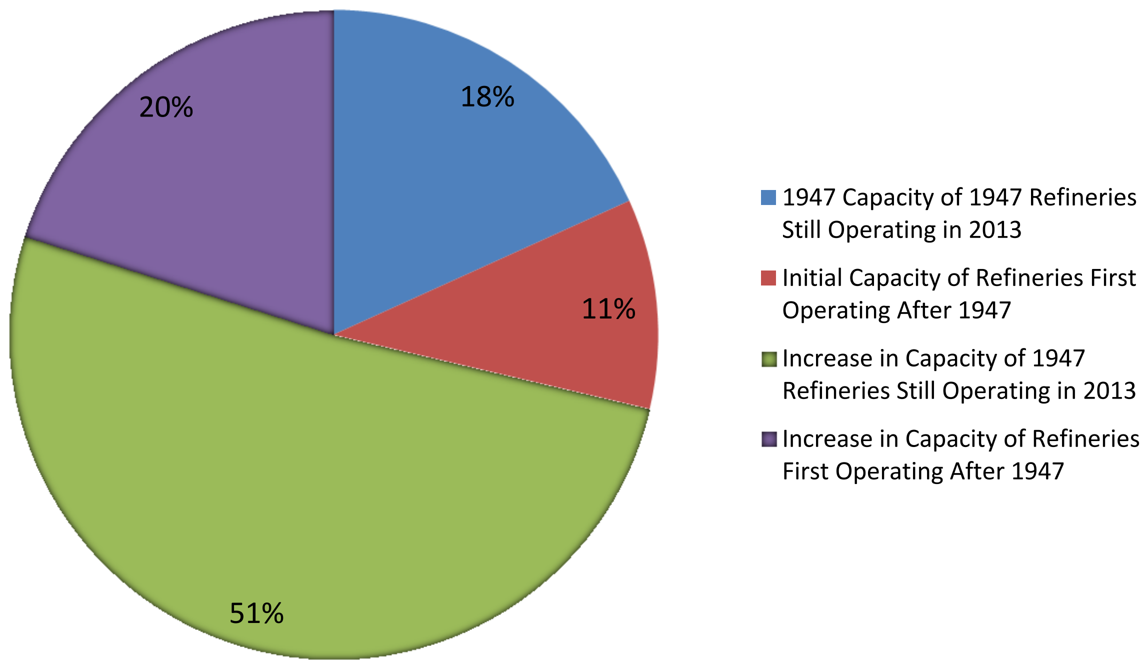
which expanded from 256,000 barrels per day to 522,000 barrels per day between 2009 and 2013, and Motiva's Port Arthur, Texas, refinery, which expanded from 285,000 barrels per day to 600,000 barrels per day in 2012.[13] If these refinery expansions of 266,000 barrels per day and 315,000 barrels per day were new refineries, they would be the 9th and 13th largest refineries in the United States. Furthermore, each of these expansions is larger than the initial size of any refinery built in the United States.[14] It is interesting to note that these two refinery expansions demonstrate that both old and new refineries expand. The Motiva refinery, originally built by The Texas Company (which later became Texaco), began operating in 1903, while Marathon completed its Garyville refinery in 1976.

These two expansions demonstrate how large an impact expansions can have on an individual refinery. To see the broader impact of expansions, consider the 2013 refinery capacity of operating refineries.[15] Of the 134 operating refineries in 2013, 82 were built prior to 1947, with an additional 52 that were constructed in 1948 or later so that we know their initial capacity. The total capacity of the 82 refineries initially in the dataset grew from 3,104 thousand barrels per day in 1947 to 11,826 thousand barrels per day in 2013. For the 52 refineries that began operations during the dataset, their initial combined capacity was 1,776 thousand barrels per day, which grew to 5,195 thousand barrels per day by 2013. As shown in Figure 2, over 70% of 2013 refinery capacity was due to expansions of existing refineries, with at most 30% of capacity due to the original refinery capacity since most refineries in 1947 likely had much smaller initial

[13] On January 1, 2013, this expansion was not online, so the 315,000 barrel per day expansion is listed as shutdown capacity in that year of the data and is not included in most of the data in this paper. Shortly after the expansion came on line May 31, 2012, it was shut down for repairs and restarted in March 2013.
[14] Marathon's Garyville refinery was the largest initial capacity of a U.S. Refinery, at 200,000 barrels per day.
[15] One of those 52 that was still operating on January 1, 2013, but no longer had a crude tower and therefore was no longer in the dataset.

capacities. All refineries that operated in both 1947 and 2013 increased their operating capacities, and only 6 of the 84 refineries failed to double in size over that time frame.

Figure 2: 2013 Refinery Capacity Source



A. Data

We have many variables similar to the prior studies on plant exit discussed above. Table 1 lists a brief description of the variables, while Table 2 gives summary statistics for most of these variables. Table 3 shows the number of refinery entry and exits for each five-year period. Entry slowed significantly after 1985, and exit has slowed since 1995.

Table 1: Variables

Variable	**Description**
Plant Open Next Year	1 if open in following observation, 0 otherwise
Size	the operating capacity of the atmospheric crude distillation tower in barrels per day[16]
Quartile	the quartile of refinery size for that year[17]
Age	for plants built after 1947, the age of the plant broken into categories of 0 to 5 years old and 5 to 10 years old[18]
Multi-plant	1 if the owner also owns other refineries, 0 otherwise[19]
Firm Share	the firm's share of industry capacity[20]
Plant Share	The plant's share of the firm's capacity
Growth+	1 if growth over the last five years >0, 0 otherwise[21]
Capacity Utilization	Estimate of industry-wide capacity utilization. Combined refinery output of gasoline, distillate, and residual, divided by total capacity in prior year.[22]
Market Growth	Percentage increase in total U.S. consumption of gasoline
PADD	Controls for which geographic region the refinery is located in[23]
Gulf Coast	1 if on Gulf Coast, 0 if inland.[24] This variable splits PADD 3 into two distinct sub regions.
Cracking	For refineries operating in 1949, 1 if the refinery had a cracking unit in 1949, 0 otherwise
Year Group	Controls for half decades
Small Built 1974 to 1980	1 if the refinery was below 50,000 barrels per day and built between 1974 and 1980[25]

[16] We also looked at linear and quadratic measure of capacity, but natural log had better fit.
[17] If multiple refineries have the quartile value, all ties go to the lower quartile.
[18] In addition, we added a group for 10 to 15 years, but there was no significant gain. For plants built prior to 1947, *Age* is missing. The dummy variable for the 0 to 5 years old age category is set to zero after 1951, and the dummy variable for the 6 to 10 years old age category is set to zero after 1956.
[19] While the Bureau of Mines and EIA list the name of an owner, there are many instances of a firm operating under multiple names. Some of the data from the Bureau of Mines includes summaries provided by the National Petroleum Refining Association (NPRA) that helped to find some of these combinations. Other combinations were found by looking at company histories. However, it is likely that we missed some of these combinations. This would also potentially lead to measurement error in the Firm Share and Plant Share variables.
[20] Firm share and market shares in this paper refer to the firm's share of national refining capacity, and do not purport to be shares of an antitrust market, which may be narrower (or broader) than a national market.
[21] We also looked at growth in barrels, or percentage growth, but best fit was from a dummy variable equal to one if growth is positive.
[22] EIA has data on refinery and blender output of these three products back to 1948, but not for other products. Since 1983, EIA has total refinery and blender output of petroleum products. Gasoline, distillate, and residual output in those years is 71% to 75% of the total. The largest missing product is jet fuel. Others significant missing products include liquid petroleum gases, petroleum coke, asphalt and still gas. Since we do not have production data for 1947 and capacity data for 1946, there is no observation for 1947.
[23] PADD refers to Petroleum Administration for Defense Districts. Roughly, PADD 1 is the East Coast, PADD 2 the upper Midwest, PADD 3 the Gulf Coast states, PADD 4 the Rocky Mountains, and PADD 5 the West Coast.
[24] The Bureau of Mines used to break down refineries in Texas and Louisiana into Gulf Coast and Inland. We used similar methodology for refineries in Mississippi and Alabama.

Table 2: Summary Statistics

Variable	Average	Minimum	Maximum
Plant Open Next Year	0.969	0	1
Size	56,756	30	640,000
Age 0 to 5	0.069	0	1
Age 6 to 10	0.055	0	1
Multi-plant	0.607	0	1
Growth+	0.568	0	1
Firm Share	0.023	0.000	0.134
Plant Share	0.251	0.000	1
Capacity Utilization	0.716	0.553	0.807
Market Growth	0.022	-0.081	0.127
PADD 1	0.112	0	1
PADD 2	0.266	0	1
PADD 3	0.328	0	1
PADD 4	0.110	0	1
PADD 5	0.184	0	1
PADD 3 - Gulf Coast	0.158	0	1
PADD 3 – Inland	0.170	0	1
Cracking	0.702	0	1

[25] Small refineries built in this time range were beneficiaries of various government programs that reduced their acquisition cost of crude oil. We test whether these refineries are more likely to close after these programs were removed.

Table 3: Exit of Refineries

	Exit	
Year Group	**Number**	**Average Size**
1947-1950	57	4,176
1951-1955	64	4,702
1956-1960	31	5,101
1961-1965	50	6,334
1966-1970	27	12,626
1971-1975	18	17,342
1976-1980	16	6,917
1981-1985	109	19,627
1986-1990	24	13,085
1991-1995	33	22,738
1996-2000	9	23,028
2001-2005	4	23,149
2006-2010	7	58,400
2011-2013	3	64,933
All years	**452**	**13,019**

B. Factors Affecting Decision to Close or Expand

Several factors influence a refiner's decision to close or expand a refinery. These factors include (1) the size of the refinery, (2) complexity of the refinery, (3) changes in local crude oil supply conditions (such as depletion of local reserves or the ability to ship those reserves to other refineries), and (4) changes in local refined product supply or demand conditions (such as new refined product supply options via pipeline or population changes). All of these factors have evolved over time, so that the optimal size, complexity, and location of refineries in 1947 are very different from what is optimal in 2013. However, since it is costly to move refineries, existing refineries may continue to operate even though that refinery may not be optimally located given today's supply and demand factors. Our dataset allows us to look more closely at the first factor, size, but there is only anecdotal evidence on the last three factors, complexity, crude markets, and product markets. We are also able to look at the growth of refineries, which can be thought of as an indication of the combined impact of all the factors that could influence a refinery shutting down.

i. Size

Most refineries that exit are smaller refineries. These smaller refineries are arguably less efficient, and likely are also less complex in that they have fewer downstream refinery units to increase the percentage of higher-value products that the refinery can produce. While a smaller refinery does not have the same economies of scale as a larger refinery, that was also true when it was originally constructed.[26] So, why were these small refineries built? One possibility is that when the refinery was built, other market conditions were more important than scale economies. For example, these market conditions could include proximity to crude oil or finished product demand, or the production of specialty petroleum products. Another possibility is that the initial capacity was the first stage of a longer construction process of a planned larger refinery. Finally, as discussed in Chen (2002, 2003), some of these refineries may have been built due to distortions caused by government regulations.

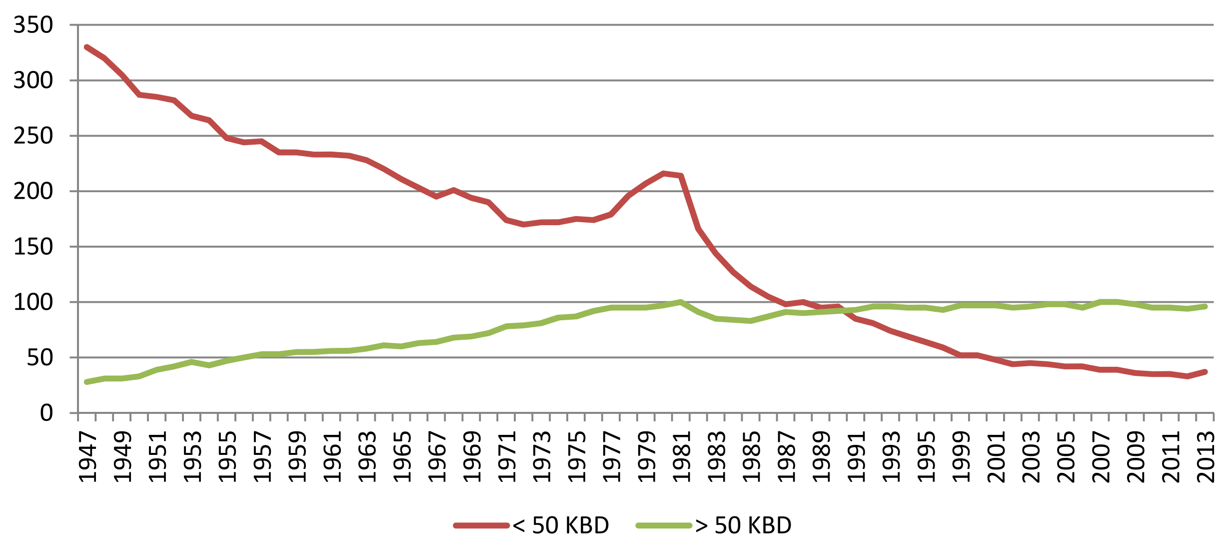
Over time, there are many reasons to believe that economies of scale have increased as refineries have become much more complex with the adoption of new refining technology. For example, in the 1930s refineries began to "crack" crude oil to increase the yield of gasoline.[27] Later, units were developed to increase the octane of gasoline. More recently, refineries have added units to remove more of the sulfur from the final fuel products to meet cleaner fuel regulations. Decreases in transportation costs for crude oil and finished petroleum products could also allow refiners to increase their size by removing logistical constraints. For example, as

[26] A refinery unit that has double the capacity will typically require less than double the materials to build it, so that larger units have a lower cost per barrel of capacity.
[27] For a brief description of the evolution of the refining industry, see the first chapter of Leffler (2008).

transportation costs fall, an isolated refinery processing 10,000 barrels per day of local crude to meet local refined product demand may close with that 10,000 barrels per day of crude shipped to a much larger distant refinery that then shipped back the finished products to meet the local demand near the crude production.

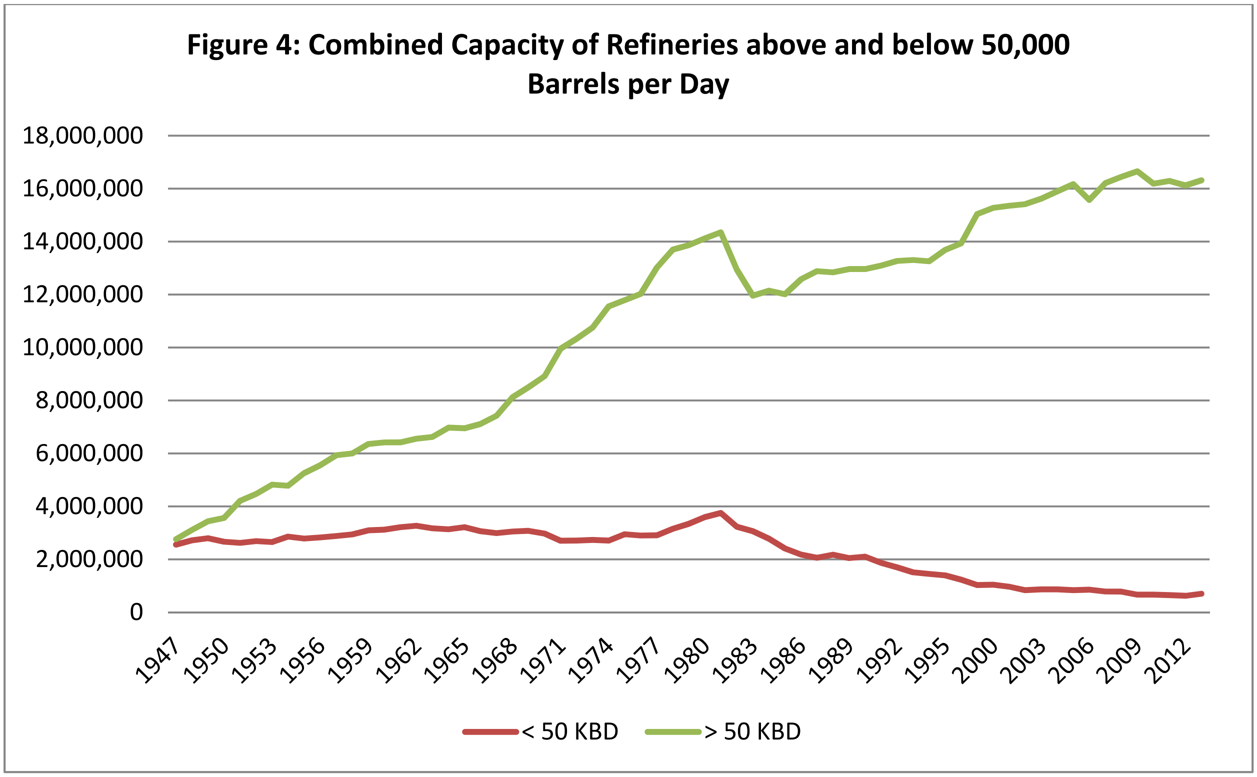
For the 330 refineries smaller than 50,000 barrels per day operating in 1947, only 61 (18%) were still operating in 2013, while 21 of 28 (75%) refineries that were at least 50,000 barrels per day were still operating. For the 234 refineries that first operated after 1947, the results are similar. Forty-three of 223 (19%) refineries whose initial operating capacity was less than 50,000 barrels per day were still operating in 2013, while 9 of 11 (82%) of refineries whose initial operating capacity was at least 50,000 barrels per day were still operating. Figure 3 shows that while over time the number of refineries with less than 50,000 barrels per day has fallen steadily (other than a few years in the late 1970s), the number of refineries with more than 50,000 barrels per day has generally increased or held steady.

Figure 3: Number of Refineries with Greater than and Less than 50,000 Barrels per Day



Most of the refineries that were still operating in 2013 grew from their capacity in 1947 or from its first year of operation. While 78% of refineries operating in 2013 were smaller than 50,000 barrels per day in the first operating year in the data, only 28% were still less than 50,000 barrels per day in 2013. With the exit of small refineries and the growth of remaining refineries, the share of refineries with capacity greater than 100,000 barrels per day increased from 3% to 47%. While there were no refineries over 200,000 barrels per day in 1947, by 2013, 23% of refineries were at least this size. From a slightly different perspective, of the 447 refineries that shutdown with a positive operating capacity, 415 (93%) had a peak operating capacity of under 50,000 barrels per day. However, of the 136 refineries still reporting data in 2013, only 37 (27%) had a peak capacity under 50,000 barrels per day.

Over time, the exit or expansion of small refineries has marginalized their combined impact on the overall refinery sector. While in 1947, the combined capacity of refineries under 50,000 barrels per day accounted for around 48% of total capacity, by 1971, that had dropped to 25%, and by 2013, less than 5%. In absolute terms, there was a small amount of growth of small refineries in the 1970s, but since the removal of price controls and crude oil allocations in the early 1980s, the combined capacity of the small refineries has decreased significantly. Figure 4 shows the combined capacity of refineries above and below 50,000 barrels per day.



ii. Complexity

We currently do not have systematic data on refinery complexity. However, in 1949, we have the type of refinery that the Bureau of Mines categorized the refineries in operation that year.[28] These categories indicate whether a refinery had cracking capacity or not, with cracking capacity indicating a more sophisticated refinery. Eighty-eight of the 336 refineries operating in 1949 were still operating in 2013, with five refineries having been absorbed by adjacent refineries. However, 35% (71 of 205) of refineries with cracking abilities remained open, while only 13% (17 of 126) of refineries without cracking abilities remained open. For the complex

[28] For each refinery, it listed whether it had skimming, asphalt, lube, or cracking units. Most refineries had at least two types of units, with 51 having all four.

refineries (those with cracking, lube, and asphalt units), 51% (26 of 51) refineries remained open also were larger on average than those that closed.

iii. Crude Oil Supply Market Conditions

While we do not have comprehensive data on crude supply conditions for the various refineries, there is some anecdotal evidence that illustrates how these changes can influence refinery entry and exit. For example, oil was discovered in Muskegon, Michigan, in the late 1920s. In 1930, four refineries appear in the historical data in this area, one of which is already listed as shutdown. One of these refineries shut down in 1934, while the remaining two were still operating at the beginning of 1935, the last year we have complete data before 1949. The remaining two refineries closed in 1966 and 1968.

Another example was in Gladewater, TX, where oil was discovered in 1931 within the large East Texas Field. We do not have data on 1932, but by 1933, five refineries were operating there, with four more under construction and two already shutdown. In 1934, there were 20 operating refineries, one still under construction, and another two refineries had shut down. All these refineries were very small, simple refineries without any cracking capabilities. One year later, only 10 of these refineries were still operating, and the data lists 14 shutdown refineries. By 1947, the next year that we have data for, only one of these small refineries was still operating, and it last operated in 1957. There are several reasons these refineries may have closed down. It is possible that some of these refineries helped hide oil production exceeding quotas set by the Texas Railroad Commission and Federal Government. These production quotas were adopted to prevent price wars and avoid damage to the field by extracting the oil too quickly. By the end of 1934, much of the illegal oil production in East Texas was successfully curtailed, and overall production from the field fell from the previous year.[29] Without the need to hide excess oil production, some of these small refineries may have shut down. Another significant change later in that time gap was the construction of a large crude oil pipeline from the East Texas Field to New York. Before World War II, crude oil was primarily transported from the Texas Gulf Coast to the East Coast by ship. However, to avoid German U-Boats, the pipeline was built during World War II to provide secure land transportation.[30] With the new source of demand from the East Texas field, there would have been additional pressure on small, less efficient refineries like those in Gladewater.

iv. Refined Product Market Conditions

There is some evidence that smaller refineries close after new product pipelines bring finished petroleum products from more distant refinery hubs that have numerous larger (and likely more efficient) refineries. For example, in 1964, the Colonial pipeline linking the large refineries on the Gulf Coast to the Mid-Atlantic States and New York Harbor opened up. By 1966, four small refineries near the path of the pipeline closed in Baltimore, Maryland, Brooklyn, New York, Charleston, South Carolina and Linden, New Jersey. Another refinery just outside Boston in Everett, Massachusetts, also closed. While not on the pipeline, the area around this refinery can be supplied by barge from the end of the pipeline in New York Harbor.

v. Growth

Refineries that grow faster are more likely to continue to operate than those that shrink, hold steady, or grow more slowly as shown in Table 4. It is likely that refinery growth is affected by the similar factors that influence whether a refinery will remain open. Refinery growth likely

[29] For a discussion of the regulatory history of the East Texas field, see https://www.tsl.texas.gov/exhibits/railroad/oil/page1.html and https://tshaonline.org/handbook/online/articles/doh04.
[30] For a discussion of the pipeline construction, see https://en.wikipedia.org/wiki/Big_Inch.

indicates that a refiner is investing more in the refinery, signaling that the refinery is more likely to be profitable. Over time, refiners, especially those producing gasoline and diesel, need to continue to make investments. Aside from maintenance, fuel specifications have become more stringent while average crude oil quality has decreased. Both trends require additional investments to maintain the yield of higher value products. For example, as regulations have decreased the amount of sulfur allowed in gasoline and diesel, refiners have had to add equipment to remove additional sulfur from these fuels. Whenever new equipment is added, refiners typically "debottleneck" the refinery, which adds additional capacity. This phenomenon is also known as capacity creep. Also, since most, if not all, refinery units experience increasing returns to scale, whenever a new unit is added the refiner may make other investments to increase overall capacity.

There is some evidence that refineries that grew more quickly were more likely to remain open. For the 586 refineries that did not merge with an adjacent refinery, those still operating in 2013 grew by 682% from the first year in the data, while those that closed down before 2013 grew by only 136%. These numbers may be misleading because it is possible that refineries still operating in 2013 grew more simply because they operated for a longer period of time. However, the annual average rate of growth for refineries still operating is 12%, and only 8% for those that have shut down.

To make a more accurate comparison, we also looked at subsets of refineries that were operating over a ten-year period, and then compared the growth over those ten years for refineries that remained open for an additional ten years compared with those that shut down over the next ten years. First, consider the 220 refineries that operated in both 1949 and 1959. Of these, 185 were operating in 1969, while 45 shut down before then. Comparing the capacity growth of these two subsets of refineries between 1949 and 1959, those still operating grew by an average of 86% while those that shutdown grew only by an average of 57%. This difference is even more noticeable when looking at larger refineries. Of the 96 refineries with capacity over 10,000 barrels per day, those still operating in 1969 grew by an average of 80% between 1949 and 1959, while those that closed down between 1959 and 1969 on average did not grow at all. Second, consider the 224 refineries that operated in 1959 and 1969. Of these, 201 were still operating in 1979, while 23 had shut down by then. The refineries that were still open in 1979 grew by 45%, while those that shut down grew by only 11%. With the same exercise starting in 1969, overall the refineries that closed actually grew by more, but that is likely due to distortions from the price controls and crude oil allocations of the 1970s discussed more below. Table 4 summarizes the differences in growth rates for refineries that stayed open and those that closed.

Table 4: 10 Year Growth of Refineries Open or Closed 20 Years Later

	Refinery Size	Number	% Growth Open	% Growth Closed
Growth 1949 to 1959, Open/Closed 1969	**All**	**230**	**86%**	**57%**
	> 10,000 Barrels Per Day	96	80%	0%
	< 10,000 Barrels Per Day	134	91%	66%
Growth 1959 to 1969, Open/Closed 1979	**All**	**224**	**45%**	**11%**
	> 10,000 Barrels Per Day	142	36%	12%
	< 10,000 Barrels Per Day	82	63%	11%
Growth 1969 to 1979, Open/Closed 1989	**All**	**220**	**77%**	**84%**
	> 10,000 Barrels Per Day	147	50%	11%
	< 10,000 Barrels Per Day	73	187%	142%

Looking at the 220 refineries operating in 1969 and 1979, those that closed grew by an average of 84%, while those that remained open grew by 77%. However, this is driven by differences in the distribution of sizes of those refineries that stayed open versus those that closed down. Over half of the 83 refineries that closed down had a capacity less than 10,000 barrels per day, compared to approximately 20% of refineries that remained open. In percentage terms, smaller refineries have tended to grow faster than larger refineries, but this was even more noticeable in the 1970s. Small refineries received preferences for lower-cost crude oil under various government programs, which likely led to the larger growth between 1969 and 1979. Overall, refineries below 10,000 barrels per day grew by 158%, while refineries above 10,000 barrels per day grew by 40%. For both sets of refineries, the average growth of refineries that remained open was higher than those that closed. For refineries with capacity of less than 10,000 barrels per day, those that remained open grew by 187%, while those that closed grew by 142%. Similarly, for refineries over 10,000 barrels per day, those that remained open grew by 50%, while those that closed grew by only 11%.

III. Methodology and Results

We now present our empirical methodology to estimate the joint effects of the above refiner attributes on the probability that a refinery closes. First, we estimate how various factors affect the probability that a refinery exits using a probit model. For the second set of results, we estimate a multinomial probit model to look at how these same factors influence whether a refinery chooses to exit, grow, or stay the same size.[31] The third set of results analyze how small refineries built in the 1970s may have had distorted incentives due to government programs granting them preferential access to lower priced crude oil. The last set of results look at the robustness of the assumption that size affects refineries in all regions similarly.

[31] Refineries that have reduced capacity are treated as staying the same size.

A. Methodology

Every period a firm owning a refinery decides either to continue operating, invest in expanding the refinery, or close. The decision to continue operating a refinery, expand the refinery, or exit depends on the attributes of the refinery as well as the current market characteristics, e.g. current level of refinery capacity utilization and the costs of local crude oil. Effectively each refinery in the United States could be ranked by its attributes and the expected profit of the refinery. Refineries below a given level of future profitability, δ, would close.[32]

$$\Pi_t^* = B^{'} X_i + \varepsilon_i \quad \text{for } i = 1 \text{ to n} \qquad (1)$$

Π is the expected profit refinery level profit, X is a set of plant, firm and demand characteristics, and ε is an iid error term. We estimate equation (1) as a probit. When $\Pi > \delta$ then the refinery remains open and the dependent variable equals 1, otherwise the refinery closes and the dependent variable equals 0. Using our data on refinery capacity, we ran probit regressions to estimate the probability that a plant closes in the following year.

When looking at the decision to whether to close, continue operating without expansion, or expand the refinery, the dependent variable is 0 for close, 1 for continue operations and 2 for expanding the refinery. We reestimate the above multivariable exit analysis with a multinomial probit analysis looking at the probability of exit, continued operations, and expansion.

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[32] This model follows the discussion of the exit and investment decision model presented in Deily, 1991.

B. Exit Probit Regressions

Using our data on refinery capacity, we ran probit regressions to estimate the probability that a plant closes in the following year.[33] We began with simple regressions to estimate the isolated effect of the variables available in our data. Individually, the variables have the expected impact on the probability that a refinery closes. We present these results in Table 5. Larger refineries are less likely to close, as are refineries that have survived five or ten years. In isolation, refineries owned by firms with multiple plants are less likely to close, however the variable changes sign when combined with other variables.[34] Newer refineries are more likely to close, while refineries that are growing are less likely to close. In isolation the higher the firm's overall share of national refinery capacity, the less likely the refinery is to close. However, when we control for other features of the refinery, this variable becomes statistically insignificant.[35] A firm with multiple refineries is more likely to close its smaller refineries so that the larger the share of firm capacity that a plant accounts for, the less likely it is to close.[36]

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[33] The dependent variable is the probability that the refinery closes, or the probability that the variable *open next year* = 0.

[34] Similar to the observation noted in previous literature, on average multi-plant refineries are significantly larger than those where the firm only owns a single refinery, so that without other control variables, multi-plant is likely picking up some of the estimated impact of the size variable.

[35] Similar to multi-plant, firms with larger shares are multi-plant, and in isolation, this variable is likely picking up some of the estimated impact of the size variable.

[36] The simple probit with the share of plant capacity either needs to include a dummy variable for multi-plant, or needs to drop observations for firms that operate only one plant. Otherwise, the 100% share of these plants distorts the impact of the variable.

Table 5: Estimated Marginal Effects on the Probability of Refinery Exit (Single Variable Regressions)

	1	2	3	4	5	6	7
ln(Size)	**-0.0141**						
	(0.00095)						
Multiplant		**-0.0235**					
		(0.00285)					
Firm Share			**-0.454**				
			(0.0577)				
Plant Share				**-0.0722**			
				(0.00895)			
Age 0 to 5					**0.0283**		
					(0.00450)		
Age 6 to 10						**0.0168**	
						(0.00556)	
Growth+							**-0.0261**
							(0.00304)
Observations	15,064	15,630	15,630	15,246	13,860	12,454	12,901
Pseudo R^2	0.0766	0.0172	0.0185	0.0219	0.0102	0.0026	0.0272

Significant at 5% Level *Significant at 10% Level*

Estimates the probability that a refinery closes. Reported coefficients are the marginal effects evaluated at the mean, with standard errors in parenthesis assuming that the error terms are i.i.d. normal.

The first set of regressions that we run include three combinations of the above variables, with no other control variables. The first four variables are in each regression, then with either the age variables or the growth variable.[37] These results are reported in columns 1 through 3 of Table 6. We then add various sets of control variables. The first of these are PADD controls, including the Gulf Coast variable that splits PADD 3 into two regions, with the results in columns 4 through 6. The PADD controls are included in all the remaining regressions. Columns 7 through 9 include the market controls that capture a rough estimate of capacity utilization and annual changes in consumption of gasoline.[38] Columns 10 through 12 replace the market controls with five-year time period dummies. Columns 13 through 15 replace the market controls and

[37] The age and growth variables cannot both be included in the same regression since the growth variable is defined for refineries that have been open for five years; there are no observations of refineries less than five years old.
[38] The two variables included as market controls are capacity utilization and market growth, described in Table 1.

five-year time period dummies with annual year dummies. Columns 16 through 18 include both the market controls and the five-year time period dummies. Qualitatively, the regressions have similar results for most of the variables.

For the size variable, evaluated for the average refinery in natural logs, increasing the natural log of capacity by 10% would decrease the probability of a refinery closing the next year by between 0.11% to 0.20% across the regression results reported in Table 6. A 10% increase the natural log of capacity corresponds to increasing the capacity from 19,975 barrels per day to 53,770 barrels per day.[39] To put this in context, on average 3.1% of refineries close each year. Whether the owner of the refinery owns other refineries has a much larger impact on the chances that a refinery will close in the next year, increasing the probability by between 1.5% to 2.2%. Increasing the firm's market share is not significant once controls beyond region controls are included. Increasing the plant's share of the firm's capacity by 10% decreases the probability of closing by between 0.59% to 0.75% for the average refinery which accounts for 25.1% of the firm's capacity. Positive growth over the previous five years decrease the probability of closing by between 1.3% to 2.0%. The age variables are almost always insignificant once controls are included. Occasionally, the coefficient on refineries age zero to five is positive, indicating that once plants survive for five years, they may be slightly more likely to stay open.

[39] The average natural log of the refinery size is 9.902241, so an increase of 10% would increase be 10.89247. Exp(9.902241) is 19,975, while Exp(10.89247) is 53,770.

Table 6: Estimated Marginal Effects on the Probability of Refinery Exit (Multi Variable Regressions)

	1	2	3	4	5	6
ln(Size)	**-0.0129**	**-0.0113**	**-0.0110**	**-0.0143**	**-0.0125**	**-0.0116**
	(0.00109)	**(0.00124)**	**(0.00116)**	**(0.00117)**	**(0.00131)**	**(0.00121)**
Multiplant	**0.0153**	**0.0172**	**0.0176**	**0.0171**	**0.0179**	**0.0176**
	(0.00486)	**(0.00539)**	**(0.00484)**	**(0.00491)**	**(0.00544)**	**(0.00490)**
Firm Share	**-0.1641**	**-0.2371**	**-0.1831**	*-0.1556*	**-0.2204**	**-0.1685**
	(0.0819)	**(0.0911)**	**(0.0812)**	*(0.0819)*	**(0.0912)**	**(0.0817)**
Plant Share	**-0.0620**	**-0.0623**	**-0.0643**	**-0.0649**	**-0.0655**	**-0.0671**
	(0.0121)	**(0.0131)**	**(0.0124)**	**(0.0122)**	**(0.0132)**	**(0.0126)**
Age 0 to 5		**0.00995**			*0.00889*	
		(0.00458)			*(0.00467)*	
Age 6 to 10		0.00740			0.00784	
		(0.00543)			(0.00544)	
Growth+			**-0.0198**			**-0.0199**
			(0.00295)			**(0.00295)**
Region Controls	N	N	N	Y	Y	Y
Market Controls	N	N	N	N	N	N
Year Group Controls	N	N	N	N	N	N
Year Controls	N	N	N	N	N	N
Observations	15,064	12,043	12,537	15,064	12,043	12,537
Pseudo R^2	0.0850	0.0872	0.1068	0.909	0.0946	0.1108

Significant at 5% Level *Significant at 10% Level*

Estimates the probability that a refinery closes. Reported coefficients are the marginal effects evaluated at the mean, with standard errors in parenthesis assuming that the error terms are i.i.d. normal.

Table 6: Estimated Marginal Effects on the Probability of Refinery Exit
(Multi Variable Regressions continued)

	7	8	9	10	11	12
ln(Size)	**-0.0163**	**-0.0140**	**-0.0129**	**-0.0185**	**-0.0167**	**-0.0155**
	(0.00123)	**(0.00134)**	**(0.00125)**	**(0.00131)**	**(0.00144)**	**(0.00139)**
Multiplant	**0.0177**	**0.0169**	**0.0174**	**0.0191**	**0.0206**	**0.0201**
	(0.00492)	**(0.00539)**	**(0.00489)**	**(0.00485)**	**(0.00535)**	**(0.00488)**
Firm Share	-0.0605	-0.1301	-0.1186	-0.0418	-0.1112	-0.0859
	(0.0823)	(0.0918)	(0.0822)	(0.0808)	(0.0889)	(0.0807)
Plant Share	**-0.0650**	**-0.0592**	**-0.0659**	**-0.0631**	**-0.0643**	**-0.0682**
	(0.0124)	**(0.0130)**	**(0.0126)**	**(0.0121)**	**(0.0130)**	**(0.0125)**
Age 0 to 5		0.00607			**0.00975**	
		(0.00466)			**(0.00496)**	
Age 6 to 10		0.00340			0.00533	
		(0.00539)			(0.00539)	
Growth+			**-0.0179**			**-0.0132**
			(0.00292)			**(0.00291)**
Region Controls	Y	Y	Y	Y	Y	Y
Market Controls	Y	Y	Y	N	N	N
Year Group Controls	N	N	N	Y	Y	Y
Year Controls	N	N	N	N	N	N
Observations	14,706	12,043	12,537	15,064	12,043	12,537
Pseudo R^2	0.1226	0.1346	0.1328	0.1536	0.1718	0.1639

Significant at 5% Level *Significant at 10% Level*

Estimates the probability that a refinery closes. Reported coefficients are the marginal effects evaluated at the mean, with standard errors in parenthesis assuming that the error terms are i.i.d. normal.

Table 6: Estimated Marginal Effects on the Probability of Refinery Exit (Multi Variable Regressions continued)

	13	14	15	16	17	18
ln(Size)	**-0.0195**	**-0.0180**	**-0.0165**	**-0.0182**	**-0.0167**	**-0.0154**
	(0.00138)	**(0.00153)**	**(0.00148)**	**(0.00132)**	**(0.00143)**	**(0.00139)**
Multiplant	**0.0206**	**0.0223**	**0.0220**	**0.0197**	**0.0205**	**0.0199**
	(0.00511)	**(0.00573)**	**(0.00521)**	**(0.00487)**	**(0.00533)**	**(0.00487)**
Firm Share	-0.0462	-0.1279	-0.1014	-0.0436	-0.1078	-0.0871
	(0.0859)	(0.0965)	(0.0870)	(0.0809)	(0.0888)	(0.0807)
Plant Share	**-0.0678**	**-0.0699**	**-0.0753**	**-0.0671**	**-0.0633**	**-0.0678**
	(0.0127)	**(0.0139)**	**(0.0134)**	**(0.0123)**	**(0.0129)**	**(0.0125)**
Age 0 to 5		0.0072			*0.0092*	
		(0.00546)			*(0.00498)*	
Age 6 to 10		0.00510			0.0048	
		(0.00577)			(0.00538)	
Growth+			**-0.0139**			**-0.0132**
			(0.00310)			**(0.00291)**
Region Controls	Y	Y	Y	Y	Y	Y
Market Controls	N	N	N	Y	Y	Y
Year Group Controls	N	N	N	Y	Y	Y
Year Controls	Y	Y	Y	N	N	N
Observations	14,267	11,186	11,754	14,706	12,043	12,537
Pseudo R^2	0.1634	0.1848	0.1728	0.1580	0.1747	0.1663

Significant at 5% Level *Significant at 10% Level*

Estimates the probability that a refinery closes. Reported coefficients are the marginal effects evaluated at the mean, with standard errors in parenthesis assuming that the error terms are i.i.d. normal.

There are some interesting observations from the control variables.[40] Based on regressions 7 through 9 with market controls but no year group or year controls, higher utilization decreases the likelihood that a refinery will close. While increases in gasoline demand are insignificant, these two variables are highly collinear, and when utilization is not included, increases in gasoline demand also decrease the likelihood of exit. Based on regressions 10 through 12, there are two five-year periods that significantly increase the chances that a refinery

[40] To simplify the presentation of results, these coefficients are not reported in the tables.

will close, 1981 to 1985 and 1991 to 1995. It is possible that removal of the various oil regulations favoring small refineries helps explain the large increase in the probability of closure between 1981 and 1985. We discuss this possibility more below.

The above regressions do not look at refinery complexity. While we currently only have data electronically on complexity for refineries operating in 1949, we can use these rough measures to look at whether more complex refineries are less likely to close. Without any other explanatory variables, or even with just the control variables, the presence of cracking equipment in the refinery decreases the likelihood of closing. However, when our other explanatory variables are included, the variable changes signs and is no longer statistically significant. One possible reason for the change is that the average size of refineries with cracking capabilities are much larger than those without, so that the size variable may be capturing some of the effect that having cracking equipment has in decreasing the likelihood of closing. To help control for this, we interact our cracking variable with our size variable. The coefficient on the cracking variable becomes significantly positive at the 10% level, while coefficient on the cracking variable interacted with size is negative, but not significant. We present these results in Table 7.

The combined impact of these two coefficients based on the point estimates is that all else equal, small refineries with cracking equipment are more likely to close than small refineries without cracking equipment, but the opposite is true for large refineries. The positive coefficient for cracking is offset by the larger negative impact that increased size has from the coefficient on the crackingXsize at around 40,000 barrels per day based on the estimates from equation 5. One possible explanation for this result is that small refineries that make specialty products may be more likely to survive than small refineries that are attempting to make fuels. However, since the demand for most specialty products is small, large refineries without cracking equipment are less likely to be able to specialize in these specialty products.

Table 7: Estimated Marginal Effects on the Probability of Refinery Exit Including Refinery Complexity

	1	2	3	4	5
Cracking	**-0.0202**	**-0.0193**	0.0064	*0.0343*	*0.0403*
	(0.00309)	**(0.00323)**	(0.0039)	*(0.0204)*	*(0.213)*
Cracking ln(Size)*				-0.0031	-0.0038
				(0.00230)	(0.00236)
ln(Size)			**-0.0188**	**-0.0152**	**-0.0172**
			(0.00186)	**(0.00197)**	**(0.00208)**
Multiplant			**0.0162**		**0.0146**
			(0.00525)		**(0.00532)**
Firm Share			0.1198		*0.1593*
			(0.0862)		*(0.0896)*
Plant Share			**-0.0573**		**-0.0532**
			(0.0136)		**(0.0136)**
Region Controls	N	Y	Y	Y	Y
Market Controls	N	Y	Y	Y	Y
Year Group Controls	N	Y	Y	Y	Y
Observations	11,391	11,037	10,739	10,739	10,739
Pseudo R^2	0.0169	0.0690	0.1526	0.1334	0.1536

Significant at 5% Level *Significant at 10% Level*

Estimates the probability that a refinery closes. Reported coefficients are the marginal effects evaluated at the mean, with standard errors in parenthesis assuming that the error terms are i.i.d. normal.

C. Exit and Growth Multinomial Probit Regressions

We are also able to analyze which of the factors studied above help to predict which refineries expand. We reran the above specifications with a multinomial probit with three possible outcomes, close, expand, or continue operating without expanding. We present the results of this analysis in Table 8. The results for closing are very similar to the above regressions, while the results for expand are roughly opposite those for closing. One notable difference is that the age variables are significantly positive for expansion, indicating that newer refineries are more likely to expand than older refineries. These variables are also positive, although not significant, for closure. As mentioned above, one possible explanation would be that new plants begin operations before reaching planned capacity. There are potential problems with the indicator variable for expansion. If a refinery temporarily reduces capacity due to maintenance, then goes back to normal capacity, the refinery will appear to have expanded.[41]

Table 8: Multinomial Probit Regressions Estimating the Marginal Effects on Refinery Closure and Expansion

		1			2	
	Close	Expand	Open without Expanding	Close	Expand	Open without Expanding
ln(Size)	**-0.0162**	**0.0156**	0.00058	**-0.0139**	**0.0143**	-0.0004
	(0.00123)	**(0.00302)**	(0.00317)	**(0.00134)**	**(0.00352)**	(0.00368)
Multiplant	**0.0180**	*-0.0251*	0.00710	**0.0175**	-0.0177	0.0002
	(0.00491)	*(0.01310)*	(0.01362)	**(0.00539)**	(0.0146)	(0.01521)
Firm Share	-0.0594	-0.2311	0.2904	-0.1298	-0.2831	*0.4129*
	(0.0822)	(.1921)	(0.2014)	(0.0916)	(0.2090)	*(0.2192)*
Plant Share	**-0.0647**	**0.0553**	0.0094	**-0.0595**	0.0264	0.0331
	(0.0123)	**(0.0246)**	(0.0262)	**(0.0129)**	(0.0275)	(0.0291)
Age 0 to 5				0.00656	**0.0885**	**-0.0950**
				(0.00463)	**(0.0148)**	**(0.0153)**
Age 6 to 10				0.00399	**0.0703**	**0.0743**
				(0.00536)	**(0.0167)**	**(0.0172)**
Region Controls		Y			Y	
Market Controls		Y			Y	
Year Group Controls		N			N	
Year Controls		N			N	
Observations		14,706			12,043	

Significant at 5% Level *Significant at 10% Level*

[41] One possible change to address the measurement error would be to replace the expand variable with a variable that equals 1 if the refinery capacity is larger than the maximum capacity for the previous five years, 0 otherwise. The results for close are very similar to the results in Table 8, but there are a couple small differences for expand and stay open without expanding. With the new measure of growth, higher firm share leads to an increased likelihood of staying open without expanding and a reduced likelihood of growing. Both variables are significant at the 5% level. Higher plant share no longer lead to an increased likelihood of expanding, but does lead to an increase in the likelihood of staying open without expanding. This last result is only significant at the 10% level.

Estimates the probability that a refinery closes, expands, or remains open without expanding. Reported coefficients are the marginal effects evaluated at the mean, with standard errors in parenthesis assuming that the error terms are i.i.d. normal.

D. Regulations Promoting Small Refineries

During the 1970s, a combination of government regulations gave small, independent, refineries a competitive advantage. The long-run trend of decreasing number of refineries stopped and even reversed for several years. In 1981, the government removed most of these regulatory distortions at the same time as the second oil shock significantly reduced demand.[42] Chen (2002) argues that distortions towards small refineries existed primarily between 1974 and 1980. We created a dummy variable for small refineries built between 1974 and 1980, and added it to the above regressions.[43] We show the results in Table 9. In all three specifications, small refineries built in this period are significantly more likely to close. Chen (2003) noted that some of the small refinery programs were most generous for those below 10,000 barrels per day, and somewhat more generous for those between 10,000 and 30,000 barrels per day. Column two separates the dummy variable for small refineries built between 1974 and 1980 into three categories. We find that all three sets of refineries are more likely to close, but we do not find that the coefficients are significantly different from each other.

[42] See Chen (2002) for a description of two of these programs, the Crude Oil Entitlements Program and the Buy-Sell program.
[43] We also included a variable for small refineries built in years other than 1974 to 1983. The coefficient on that variable was not significantly different from zero, and none of the other variables significantly changed.

Table 9: Estimated Marginal Effects on the Probability of Refinery Exit Including Variable on Small Refineries Built 1974 to 1980

	1	**2**	**3**
ln(Size)	**-0.0162**	**-0.162**	**-0.0143**
	(0.00123)	**(-0.00123)**	**(0.00134)**
Multiplant	**0.0178**	**0.0175**	**0.0163**
	(0.00490)	**(0.00493)**	**(0.00537)**
Firm Share	-0.0497	-0.0471	-0.1112
	(0.0820)	(0.0822)	(0.0912)
Plant Share	**-0.0633**	**-0.0626**	**-0.0565**
	(0.0124)	**(0.0124)**	**(0.0129)**
Age 0 to 5			0.00002
			(0.00509)
Age 6 to 10			0.00058
			(0.00559)
Small built ’74 to ‘80	**0.0171**		**0.0176**
	(0.00523)		**(0.00560)**
0 to 10 kbd built ’74 to ‘80		*0.0136*	
		(0.00693)	
10 to 30 kbd built ’74 to ‘80		**0.0216**	
		(0.00921)	
30 to 50 kbd built ’74 to ‘80		**0.0203**	
		(0.01024)	
Region Controls	Y	Y	Y
Market Controls	Y	Y	Y
Year Group Controls	N	N	N
Year Controls	N	N	N
Observations	14,706	14,706	12,043
Pseudo R^2	0.1253	0.1254	0.1377

Significant at 5% Level *Significant at 10% Level*

Estimates the probability that a refinery closes. Reported coefficients are the marginal effects evaluated at the mean, with standard errors in parenthesis assuming that the error terms are i.i.d. normal.

E. Robustness Checks

The models above assume that the region that the refinery is located in only affects the intercept term. However, it is possible that the coefficient on the size variable could also vary across regions. We rerun several of the regressions from Table 6 replacing the size variable with interactions of the size variable and the regional variables for each PADD, with PADD 3 split between the gulf coast and inland regions. The new regression results are reported in Table 10, columns 19 through 21, and for comparison purposes, the comparable results from Table 6 are reproduced here. While the coefficients are noticeable closer to zero for PADDs 1, 2 and inland PADD 3, depending on the specification, these differences sometimes are not statistically significant. Interacting the *Size* with the regional variables has minimal impact on the remaining variables. While the coefficient of the size variable increases in absolute value, the region dummy decreases in absolute value. Therefore, all else equal, for smaller refineries on the Gulf Coast, the net impact is to increase the likelihood that it closes relative to a PADD 1 refinery, while for large refineries, the net impact will be to decrease the likelihood it closes relative to PADD 1.

The creation of both the growth variable and the age variables lead to a number of missing variables. The growth variable creates missing variables for the first five years of data for each refinery, as well as all data from 1947 to 1951. Similarly, the age variables create missing variables for refineries built before 1947 until 1952 for Age 0 to 5, and until 1957 for Age 6 to 10. We repeat the set of regressions with region, market, and year group controls dropping all data before 1957, which removes any potential issues from not knowing the age of refineries built before 1947. We report the results of these new regressions in Table 11, columns

22 through 24, again with the comparable results included from Table 6. There are small differences to some of the explanatory variables, but none are statistically different.

Table 10: Estimated Marginal Effects on the Probability of Refinery Exit Checking Robustness of Size Variable

	6.16	19	6.17	20	6.18	21
ln(Size)	**-0.0182**		**-0.0167**		**-0.0154**	
	(0.00132)		**(0.00143)**		**(0.00139)**	
ln(Size) x PADD1		**-0.0138**		**-0.0122**		**-0.0096**
		(0.00301)		**(0.00321)**		**(0.00297)**
ln(Size) x PADD2		**-0.0159**		**-0.0147**		**-0.0139**
		(0.00175)		**(0.00190)**		**(0.00180)**
ln(Size) x PADD3-Inland		**-0.0151**		**-0.0163**		**-0.0126**
		(0.00246)		**(0.00275)**		**(0.00257)**
ln(Size) x PADD3-Gulf Coast		**-0.0226**		**-0.0195**		**-0.0181**
		(0.00273)		**(0.00289)**		**(0.00315)**
ln(Size) x PADD4		**-0.0202**		**-0.0179**		**-0.0196**
		(0.00237)		**(0.00270)**		**(0.00252)**
ln(Size) x PADD5		**-0.0242**		**-0.0223**		**-0.0196**
		(0.00291)		**(0.00304)**		**(0.00306)**
Multiplant	**0.0197**	**0.0200**	**0.0205**	**0.0204**	**0.0199**	**0.0211**
	(0.00487)	**(0.00494)**	**(0.00533)**	**(0.00543)**	**(0.00487)**	**(0.00493)**
Firm Share	-0.0436	-0.0421	-0.1078	-0.1070	-0.0871	-0.1067
	(0.0809)	(0.0832)	(0.0888)	(0.0913)	(0.0807)	(0.0829)
Plant Share	**-0.0671**	**0.0663**	**-0.0633**	**-0.0620**	**-0.0678**	**-0.0696**
	(0.0123)	**(0.00125)**	**(0.0129)**	**(0.0132)**	**(0.0125)**	**(0.0127)**
Age 0 to 5			*0.0092*	0.00802		
			(0.00498)	(0.00500)		
Age 6 to 10			0.0048	0.00424		
			(0.00538)	(0.00539)		
Growth+					**-0.0132**	**-0.0132**
					(0.00291)	**(0.00291)**
PADD controls	Y	Y	Y	Y	Y	Y
Market Controls	Y	Y	Y	Y	Y	Y
Year Group Controls	Y	Y	Y	Y	Y	Y
Year Controls	N	N	N	N	N	N
Observations	14,706	14,706	12,043	12,043	12,537	12,537
Pseudo R^2	0.1580	0.1622	0.1747	0.1778	0.1663	0.1705

Significant at 5% Level *Significant at 10% Level*

Estimates the probability that a refinery closes. Reported coefficients are the marginal effects evaluated at the mean, with standard errors in parenthesis assuming that the error terms are i.i.d. normal.

Table 11: Estimated Marginal Effects on the Probability of Refinery Exit
Checking Robustness Dropping pre-1957 Data

	6.16	22	6.17	23	6.18	24
ln(Size)	**-0.0182**	**-0.0171**	**-0.0167**	**-0.0167**	**-0.0154**	**-0.0154**
	(0.00132)	**(0.00142)**	**(0.00143)**	**(0.00144)**	**(0.00139)**	**(0.00145)**
Multiplant	**0.0197**	**0.0186**	**0.0205**	**0.0198**	**0.0199**	**0.0175**
	(0.00487)	**(0.00524)**	**(0.00533)**	**(0.00529)**	**(0.00487)**	**(0.00509)**
Firm Share	-0.0436	-0.0877	-0.1078	-0.1024	-0.0871	-0.0718
	(0.0809)	(0.0870)	(0.0888)	(0.0878)	(0.0807)	(0.0828)
Plant Share	**-0.0671**	**0.0606**	**-0.0633**	**-0.0610**	**-0.0678**	**-0.0598**
	(0.0123)	**(0.00128)**	**(0.0129)**	**(0.0128)**	**(0.0125)**	**(0.0126)**
Age 0 to 5			*0.0092*	0.0082		
			(0.00498)	(0.00504)		
Age 6 to 10			0.0048	0.0028		
			(0.00538)	(0.00547)		
Growth+					**-0.0132**	**-0.0098**
					(0.00291)	**(0.00299)**
PADD controls	Y	Y	Y	Y	Y	Y
Market Controls	Y	Y	Y	Y	Y	Y
Year Group Controls	Y	Y	Y	Y	Y	Y
Year Controls	N	N	N	N	N	N
Observations	14,706	11,845	12,043	11,825	12,537	11,124
Pseudo R^2	0.1580	0.1773	0.1747	0.1794	0.1663	0.1711

Significant at 5% Level *Significant at 10% Level*

Estimates the probability that a refinery closes. Reported coefficients are the marginal effects evaluated at the mean, with standard errors in parenthesis assuming that the error terms are i.i.d. normal.

IV. Conclusions

We make several observations about the refining industry based on historical refinery capacity data. While many recent industry observers have focused on the lack of new refinery construction or the significant decrease in the number of refineries, the focus should be on overall refining capacity. Focusing on the lack of new refinery construction obscures the fact that over two thirds of 2013 capacity is due to expansion of an existing refinery. Similarly, focusing on the number of refineries obscures the fact that refineries that close are on average smaller and less complex than those that remain in operation. Furthermore, as the larger, more complex refineries have expanded, they have typically more than made up for any lost capacity from the exit of the smaller, less complex refineries.

This paper expands on the literature analyzing the types of plant characteristics that influence whether or not a plant closes. Some of our results are similar to those of earlier studies. Larger plants are less likely to close, while plants owned by a firm with multiple plants are more likely to close. If a firm owns multiple plants, it is more likely to close smaller plants. Increased demand or increased refinery utilization leads to a lower probability of refineries closing. Unlike several previous studies, we are unable to show that higher market shares are associated with an increased likelihood of closure. In our regressions, higher market shares lead to a decreased probability that a refinery closes, but for the main specifications, these results are not statistically significant. Not surprisingly, refineries that have grown in recent years are less likely to close than those that have not grown. We also show that the removal of regulations favoring small refiners that were put in place in the 1970s led to an increased probability that small refineries built in the mid to late 1970's once the regulatory regime changed. Finally, the impact of complexity was not consistent across all refineries. Small refineries with cracking capacity, additional equipment that increases production of higher-valued fuels, are more likely to close, while large refineries with cracking capacity are less likely to close.

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