WORKING PAPERS

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

David W. Meyer
Christopher T. Taylor

WORKING PAPER NO. 328

November 2015

BUREAU OF ECONOMICS
FEDERAL TRADE COMMISSION
WASHINGTON, DC 20580

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

by

David W. Meyer and Christopher T. Taylor[1]

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

[1] We thank Matthew Chesnes, Jeffrey Fischer, Daniel Hosken, Nicholas Kreisle, and Nathan Wilson, for helpful comments and Elisabeth Murphy and Thomas Sharon for research assistance. The views expressed are those of the authors and do not necessarily represent those of the U.S. Federal Trade Commission or any individual Commissioner.

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 se 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

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]

[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 (w 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]

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.

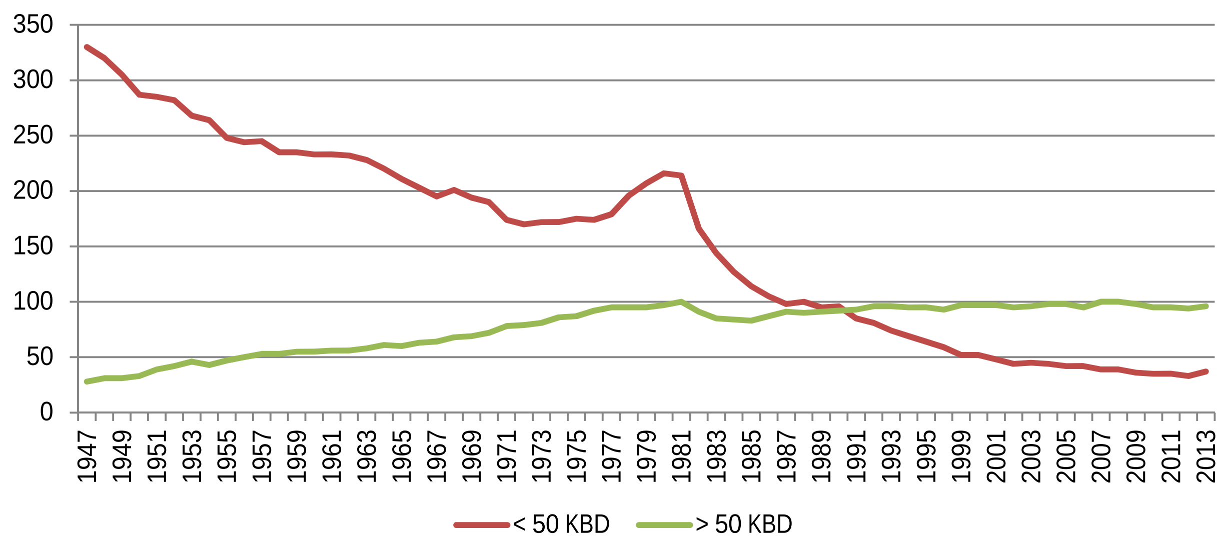
Over time, there are many reasons to believe that economies of scale have increased as refineries have become much more complex with the adoption of new refining technology. For example, in the 1930s refineries began to "crack" crude oil to increase the yield of gasoline.[27] Later, units were developed 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 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 th 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 indicates that a refiner is investi

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.

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

A. Methodology

Every period a firm owning a refinery decides either to continue operating, invest in

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

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)*	

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 longe 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

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 sma

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			

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 knodn1ues nrsdroppinowth variab3T

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	evalu81.3(ize))]norr2]T6	
			(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 assu.0002 h.2( )9el

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.

Works Cited

Baden-Fuller, C., 1989, “Exit from Declining Industries and the Case of Steel Casings,” The Economic Journal, 99, 949-961.

Bernard, A. and Jensen, J., 2007, “Firm Structure, Multinationals, and Manufacturing Plant Deaths,” Review of Economics and Statistics, 89(2), 193-204.

Chen, M., 2002, “Survival Duration of Plants: Evidence from the US Petroleum Industry,” International Journal of Industrial Organization, 20, 517-555.

Chen, M., 2003, “The Survival and Growth of U.S. Petroleum Refineries in Response to Changes in Market Conditions,” The Journal of Energy and Development, 29(1), 115-146.

Deily, M., 1991, “Exit Strategies and Plant-Closing Decisions: The Case of Steel,” Rand Journal of Economics, 22(2), 250-263.

Disney, R., Haskel, J. and Heden Y, 2003, “Entry, Exit and Establishing Survival in UK Manufacturing,” Journal of Industrial Economics, 51(1), 91-113.

Dunne, T., Roberts, M. and Samuelson, L., 1989, “The Growth and Failure of US Manufacturing Plants,” Quarterly Journal of Economics, 104(4), 671-698.

Gemawat, P. and Nalebuff, B., 1985, “Exit,” Rand Journal of Economics, 16, 184-194.

Kneller, R., McGowan, D., Inui, T., and Matsuura, T., 2012, “Closure within Multi-plant Firms: Evidence from Japan,” Review of World Economics, 148(4), 647-668.

Leffler, W., *Petroleum Refining in Nontechnical Language*, 4th ed., Tulsa, OK: Pennwell, 2008.

Lieberman, M., 1990, “Exit from Declining Industries: ‘Shakeout or stakeout’,” Rand Journal of Economics, 21, 538-554.

Muth, M., Karns, S., Wohlgenant, M. and Anderson, D., 2002, “Exit of Meat Slaughter Plants During Implementation of the PR/HACCP Regulations,” Journal of Agricultural and Resource Economics, 27(1), 187-203.

Nguyen, P., Saviotti, P., Trommetter, M. and Bourgeois, B., 2005, “Variety and the Evolution of Refinery Processing,” Industrial and Corporate Change, 14(3), 469-500.

Reynolds, S., 1988, “Plant Closings and Exit Behavior in Declining Industries,” Economica, 55, 493-503.

Whinston, M., 1988, “Exit with Multiplant Firms,”Rand Journal of Economics, 19, 74-94.