Odd Prices at Retail Gasoline Stations: Focal Point Pricing and Tacit Collusion

Matthew S. Lewis*

John E. Walker Department of Economics
Clemson University
228 Sirrine Hall
Box 341309
Clemson, SC 29634-1309
mslewis@clemson.edu

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Abstract

This study empirically investigates the theory that odd numbered pricing points can be used as focal points to facilitate tacit collusion. Odd ending prices are heavily used in many retail markets. While the demand effects of odd pricing points are commonly studied, their potential role in the coordination of prices is rarely discussed. I show that gasoline stations in the U.S. disproportionately sell at prices ending in odd digits. Station prices tend to be higher and change less frequently in locations where more odd prices (particularly those ending in 5 or 9) are observed. These price differences remain even after controlling for other observable market characteristics commonly associated with higher retail gasoline prices. The results suggest that the use of pricing points may be an effective mechanism for tacitly coordinating prices, and that this motivation may help explain the widespread use of odd prices in retail markets.

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I. Introduction

Economists and marketing scholars have long discussed the widespread use of odd-numbered "pricing points" and the preponderance of prices just below round numbers in many retail markets (Bader and Weinland, 1932; Schindler and Wiman, 1989). Despite its long history, the cause for and effect of these "customary prices" is still widely debated. While many chalk the convention up to tradition others suggest that these prices have a psychological advantage leading consumers to purchase distinctly more than they would at the slightly higher round-number price.[1] A number of studies, including recent work by Kashyap (1995) and Levy et al. (2011), show that more frequent use of such pricing points by firms leads to increased price rigidity. However, there has been essentially no investigation of how the use of pricing points relates to the degree of competition or the resulting price level in the market.

There are a number of reasons why prices might be higher in markets that rely more heavily on pricing points. One possibility is that, for whatever reason, consumers are attracted to buy at certain pricing points, but firms are only able to keep prices at these customary levels when they have a sufficient level of market power. The incentives to undercut a rival may simply be too strong in highly competitive markets (even if one is undercutting an attractive pricing point). In other words, market power may lead to an increased use of pricing points.

An alternative possibility is that the use of pricing points can actually help firms keep prices higher by providing focal points for competitors to coordinate pricing decisions. Scherer (1967) provides a nice illustration of the potential for coordination:

> By setting its product price at some such focal point, a firm tacitly encourages its rivals to follow suit without undercutting. Conversely, if one firm announces a price which has no such compulsion, a rival is tempted to set its own price just a cent or two below. This leads to a further small retaliatory cut, precipitating a downward

[1] See Gedenk and Sattler (1999) for a survey of empirical studies attempting to identify the demand effects of 9-ending prices.

> spiral which, in the absence of focal points, has no clear cut stopping point. In setting one's price at the focal point, one in effect asks rhetorically, "If not here, where?" implicitly warning rivals of the danger of downward spiraling.[2]

In this case, the presence of customary pricing points serves as a type of facilitating device that firms with market power may use to more effectively keep prices high.

This study empirically examines the extent to which the prevalence of customary prices is associated with higher price levels using data on retail gasoline prices from gas stations throughout the United States during 2009 and 2010. Retail gas stations overwhelmingly charge prices for gasoline that end in odd numbers, particularly 5 and 9. After truncating off the ubiquitous nine-tenths of a cent per gallon that is added to the posted gasoline prices at all stations, 49% end in either a five or a nine and over 76% of prices end in an odd number. While the use of these pricing points may have evolved from tradition or may be a response to consumer perception, they may also have become an integral part of how firms exercise their market power.

There are certainly many other product markets where pricing points, such as round number prices or 9-ending prices, are used much more extensively than in retail gasoline. However, it becomes difficult to uncover the competitive effects of pricing points if they are always in use. Local retail gasoline markets, on the other hand, exhibit significant variation in the use of odd prices, across cities, across neighborhoods within a city, and even across stations within a neighborhood. This makes it possible to compare stations' pricing behavior within an area while controlling for unobserved factors, such as costs or consumer tastes, that affect all stations.

My empirical results consistently show a relationship between high price levels, price rigidity, and the use of pricing points. I find that areas or individual stations that exhibit a higher share of odd prices and prices ending in 5 or 9 change their prices significantly less often than other nearby stations. For example, when comparing zip codes within a city, zip codes that are one standard deviation below the mean with respect to the share of odd prices and

[2] Scherer (1967), pp. 497-498.

the share of odd prices that end in 5 or 9 change prices about 50% more often than zip codes that are one standard deviation above the mean. More importantly, these areas or stations also have significantly higher prices. Zip codes in which the share of odd prices that end in 5 or 9 is one standard deviation above the mean have prices that are 2.5 cents per gallon higher on average than zip codes one standard deviation below the mean. This represents a significant price difference for an industry in which net retail margins are only a few cents per gallon on average.[3] I find very similar differences in price level and the degree of price rigidity when comparing stations within the same zip code that differ in their use of odd pricing points. Additional analysis confirms that these relative price differences across zip codes remain even when controlling for zip code characteristics such as income, population, and station density that have been shown to impact local retail gasoline prices. Finally, odd pricing appears to have an "umbrella effect"—stations are able to charge higher price levels when their neighboring stations use odd pricing points more frequently. These results provide the first direct empirical evidence that retailers more frequently utilizing pricing points have consistently higher prices.

In the next section I discuss the role of focal points in facilitating tacit collusion and also describe why the standard demand-side or psychological theories used to explain the prevalence of 5 and 9 price endings seem inconsistent with the institutions and observed behavior in the gasoline market. These facts and the empirical evidence provided in the remainder of the paper suggest that customary price endings in the gasoline market seem to be more valuable to firms as a coordinating device than they are to consumers psychologically. In fact, in the few cities where the modal gasoline price endings deviate from the typical 5 and 9 it is these other price endings that are more strongly associated with higher and more rigid prices. While this coordination effect is often overlooked it provides an additional explanation for the widespread use of pricing points and expands our understanding of the overall role of pricing points in retail markets.

[3] According to the National Association of Convenience Stores gross retail gasoline margins average about 14 cents per gallon, but expenses such as credit card fees, labor, rent and utilities make up 12 to 13 cents per gallon.

II. Odd Pricing, Focal Points and Tacit Collusion

II. a. Odd Pricing

Retailers' use of odd prices or customary prices has been well documented in the marketing literature. Studies consistently find that odd price endings are much more common than even price endings, with 9 being the most popular and 5 being the second most popular ending digit, followed by 3 and 7 (Rudolph, 1954; Twedt, 1965; Friedman, 1967; Gendall et al., 1997).[4] Also referred to as "psychological pricing", some believe that consumers' demand is distinctly higher at these prices.

Two main psychological mechanisms have been proposed to explain these patterns. The first theory is based on the concept that consumers process prices starting with the leftmost digit and often ignore the rightmost digit (Lambert, 1975; Basu, 1997), making 9-ending prices particularly attractive for firms. A handful of studies have provided experimental evidence supporting this theory, including Schindler and Kibarian (1996), Anderson and Simester (2003), and Bizer and Schindler (2005), though many others have found no significant effects. The other main mechanism proposes that consumers have come to associate certain price endings with sales or discounts. This is partially based on the observation that some retailers frequently use odd price endings for sale items and round numbered prices for regular price items (Anderson and Simester, 2003). However, the information associated with a given price ending is likely to be very context specific, which may help explain the often contradictory results found in experimental studies.

Like other retailers, gas stations show a strong preference for charging odd prices, especially fives and nines. However, in this market the psychological motivations for the use of these pricing points are much less compelling. The idea that consumers don't process the rightmost digit of the price could help justify why 9-ending prices are more common, but it doesn't explain the heavy use of prices ending in 5 or the fact that prices ending in a 7 and 8 are not

[4] In some settings and in some price ranges it is also common to see prices ending in zero (Rudolph, 1954; Schindler and Kirby, 1997), but in many studies (often examining lower price ranges) zero price endings are rare.

more common than those ending in a 1, 2, or 3. Moreover, there is little reason for consumers in this market to have associated these odd price endings with “sales” or reduced prices. To the contrary, my findings suggest that stations charging these price endings tend to have higher prices than their competitors on average. Five-ending prices are sometimes said to be favored because they are round numbers (in the sense of making change without pennies), but this usually applies to situations where people are paying in cash for a discrete number of units (unlike gasoline) and is often accompanied by a high frequency of zero-ending prices which we do not see.

In contrast to these demand-side explanations for the concentration of price endings, Scherer (1967) suggests that firms may benefit from coordinating prices at certain pricing points as a method of discouraging undercutting and aggressive competition. Here he alludes to the broader theory that these customary price levels may act as focal points that help facilitate tacit collusion amongst retailers repeatedly interacting in the marketplace.

II. b. Tacit Collusion at a Focal Point

Oligopoly models of repeated interaction show that firms can often sustain prices above the static competitive level by using the threat of future punishment to deter cheating. Unfortunately, according to the Folk Theorem any price between the competitive level and some maximum sustainable price will be an equilibrium in this repeated game. The abundance of possible equilibrium outcomes often makes it difficult for economists to construct direct empirical tests of collusive behavior. Firms themselves may also find it difficult to identify and settle into a collusive equilibrium without directly communicating to coordinate a price level.

Focal points provide a mechanism for coordinating behavior in such non-cooperative situations. Schelling (1960) explores the use of focal points as a coordination device, and many studies of tacit collusion allude to this concept. Knittel and Stango (2003) argue that credit card issuers used interest rate ceilings as a focal point at which to set collusively high rates. Busse (2000) suggests that cellular telecommunications firms competing in multiple geographic markets used price schedules from other markets as a focal point to maintain higher than competitive price levels. Many other studies make the assumption that collusion will occur at the hypothetical monopoly price level because it is a focal equilibrium in the sense that it provides symmetric firms the highest possible collusive profit.[5] Overall, however, the empirical literature on tacit collusion is relatively limited, largely because of the difficulty of identifying candidate collusive mechanisms *a priori.*

Gasoline retailing possesses a number of characteristics that often facilitate competition. The product is nearly homogeneous and publicly posted prices help consumers to find and switch to low price sellers. But some of these same characteristics can also contribute to tacit coordination through the use of focal points. Posted prices make it easier for stations to monitor their rivals, and rivals can usually respond quickly to price cuts—reducing the attraction of undercutting. In other words, within the context of a repeated game, these firms make pricing decisions on a nearly continuous basis, lowering the relative payoff of cheating from a cooperative equilibrium. Focal pricing points can provide stations a convenient way to reach such an equilibrium in the absence of explicit communication.

Despite the frequent use of pricing points and the importance of repeated interaction between sellers in many retail product markets there has been no empirical work investigating pricing points as a coordination device. A few studies have have tried to link the use of pricing points with increased price rigidity. Kashyap (1995) examines sticky pricing using semiannual catalog prices and finds some clustering of prices just under round dollar amounts. He presents weak evidence suggesting that the use of pricing points inhibits price changes, but ultimately concludes that his data is not well suited to establish how pricing points influence price adjustment. Levy et al. (2011) study the importance of pricing points using weekly price observations for supermarket products and daily price observations for electronics from internet retailers. They confirm that prices are highly concentrated around pricing points (particularly prices ending in 9 or 99), and they provide much more compelling evidence that prices at these pricing

[5]See for example Porter (1983), Ellison (1994), Genesove and Mullin (1998), Fabra and Toro (2005)

points change less frequently. However, neither of these studies discuss coordination or empirically investigate how the use of odd pricing points relates to the level of prices or competitiveness in the market.

II. c. Coordination on Odd Prices and Testable Predictions

Unlike examples in which firms use a single higher-than-competitive focal price (such as a price cap) at which to tacitly collude, the idea of firms coordinating on the use of odd pricing points essentially amounts to a tacit restriction or coarsening of the pricing grid. It is straightforward to show that firms in a simple homogeneous-product Bertrand pricing model can earn positive profit if retail prices are restricted to a discrete pricing grid, and that the average profit margin earned will increase as the pricing grid becomes more coarse. The equilibrium price will always be the closest price on the grid that lies above the unrestricted continuous price equilibrium. The same result is also possible in differentiated product competition settings, such as in a Hotelling spatial competition model, though multiple equilibria arise. As illustrated in Appendix 1, equilibrium in the Hotelling model with a discrete price grid can occur either at the price directly above or directly below the continuous price equilibrium. If firms are able to coordinate more often on the higher profit equilibrium then, on average, profits will be higher than in the continuous price setting, and the profit difference will grow with the grid size. Consequently, cities in which firms largely restrict themselves to prices ending in 5 and 9 could be expected to have higher prices than those using all odd ending prices, and those where firms predominantly use only 9-ending prices should have higher prices still.[6]

In these simple models, the degree of price rigidity also increases with the coarseness of the pricing grid. Any cost change that occurs within a particular grid increment will no longer result in a change in equilibrium price. The larger the grid increment, the more likely it is that

[6]More specifically, if different wholesale cost levels occur with relatively similar frequencies within a relevant range, then over time the equilibrium price in the homogeneous product Bertrand model (and the highest profit equilibrium in the Hotelling model) will be .5 cents higher, on average, for markets in which firms use only odd prices, 2.5 cents higher for markets that use only 5 and 9 ending prices, and 5 cents higher for markets that only use 9 ending prices.

prices will remain unchanged when they would otherwise have been adjusted in a continuous price setting. As a result, the main focus of my analysis is to empirically investigate how the more frequent use of odd or five- and nine-ending prices within a given market relates to both the degree of observed price rigidity and the level of prices in that market.

The Bertrand models help to illustrate that coordinating on a more coarse pricing grid alone is enough to generate higher prices even if firms continue to compete (i.e., charge prices that unilaterally maximize individual profits) within the confines of the pricing grid. However, if firms in certain areas are able to more successfully coordinate on a restricted pricing grid, they may also be more successful at coordinating and maintaining prices above within-grid competitive levels. In this sense we might expect the price premium observed in areas using mostly odd or 5 and 9 prices to be even higher than would be predicted in the Bertrand model.

It is also important to highlight that, although prices are predicted to be higher on average when firms are restricted to a coarse price pricing grid, the price on any given day may not be significantly higher than if firm's prices were unrestricted. Moreover, the data reveal no evidence of stations in particular cities or local areas oscillating between periods of using only (or predominantly) odd or five-and-nine prices and periods in which price endings are unrestricted. As a result, examining how changes in the degree of odd pricing over time relate to changes in price levels or profit margins is not likely to be particularly informative. Even-ending prices may also be used by firms for reasons other than to undercut a competitor. For example, deviating from odd prices could be used as a signaling device, allowing a station to communicate an interest in increasing prices while still keeping its price relatively close to its competitors'. In fact, one cent price increases resulting in an even-ending price occur nearly as frequently as one cent decreases to even prices despite the fact that one cent decreases to odd-ending prices outnumber increases by ratio of nearly 5 to 1.

In this market it is also plausible to suspect that coordination on a restricted pricing grid could remain relatively stable even if some firms in the local market consistently deviate from this grid. It is not uncommon for some stations with less recognizable brands or fewer station amenities to maintain a fixed price discount relative to other local competitors. Others may try to maintain a small price premium. If most stations in an area are coordinating on odd prices, a station offering, for example, a 1 cent discount relative to the competition may predominantly charge even prices without destabilizing coordination.

In light of these subtleties and variants in station behavior and a lack of detailed data on wholesale costs, I do not attempt to specify and estimate any particular model of coordination on price endings. Instead, my empirical strategy is to identify a number of stylized facts describing how the use of pricing points relates to price levels and price rigidity, and discuss whether the estimated relationships are consistent with tacit coordination or other possible explanations.

III. Data

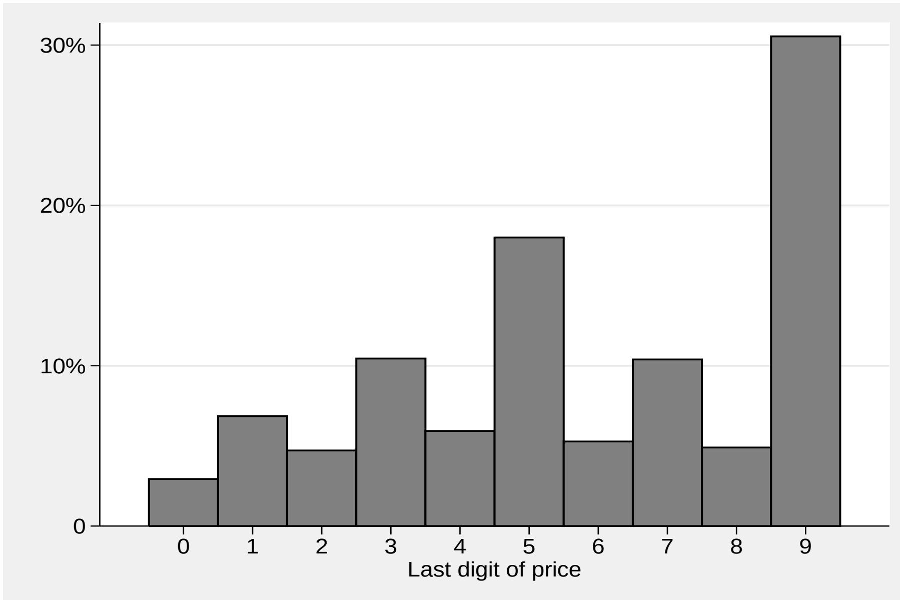
The analysis utilizes station level retail gasoline price data from 165 metropolitan areas in 33 different states across the U.S. during the years 2009 and 2010.[7] For each city the approximate coverage area in the sample corresponds to the Urban Area as defined by the U.S. Census Bureau. Prices are collected daily by Oil Price Information Service (OPIS) using fleet credit card transactions and direct feeds from stations.[8] Prices are not observed for every station on every day, but the sample includes over 20,658 stations and over 10.4 million price observations.[9] If more than one price is reported for a station in a particular day, my data will only include the last price observed. For the median station in the sample, prices are observed on nearly 87% of all days. The cities range in size from large cities (such as Los Angeles and Detroit) to smaller towns (such as Bellingham, WA and Dover, DE). The brand and location of each station are also observed.

[7]States with cities in the sample include: AL, AR, AZ, CA, CO, CT, DE, FL, IA, ID, IL, IN, KS, KY, ME, MO, NC, NE, NH, OH, OK, PA, SC, TN, TX, UT, VT, WA, WI, WV, and WY.

[8]A full description of OPIS's methodology for collecting retail prices can be found at: http://www.opisretail.com/methodology.html.

[9]Stations with fewer than 200 observed prices over the 2 year period are excluded from the sample. This was done to ensure that station level averages are not misleading due to small sample size.

Figure 1: Histogram of Prices at U.S. Retail Gasoline Stations by their Last Digit.[a]

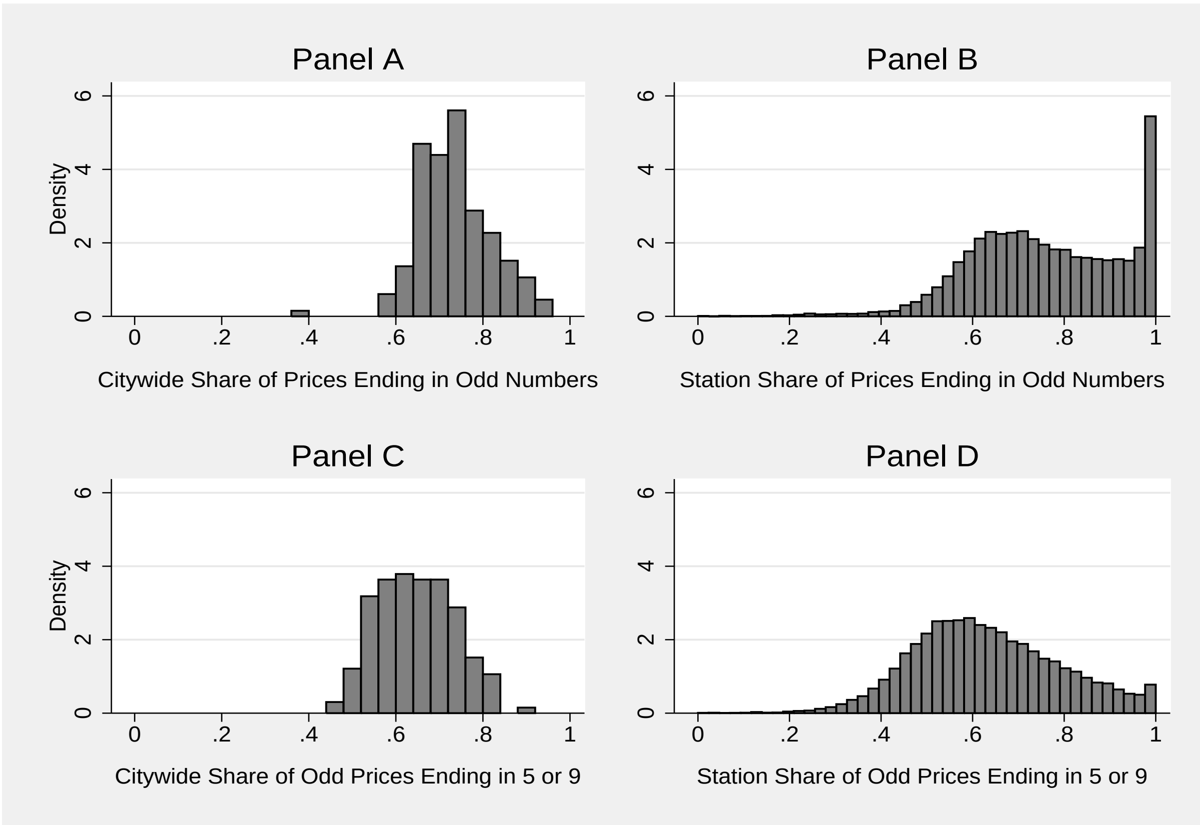


[a]The last digit of the price is the cent/gallon digit. The nine-tenths of a cent has been dropped from all prices.

Part of my analysis examines price changes. I define the change in price for a station on a given day as the difference between the price observed that day and the price on the previous day, meaning that price changes are only observed when there are two consecutive days of price observations for the station. As a result, both prices and price changes are observed from a slightly selected sample. Since most prices are recorded from credit card transactions, this selection may in fact be somewhat favorable as it gives us something closer to a quantity weighted average price measure. In any case, the selection appears to be fairly random. As a robustness check, I performed all of the empirical analysis using only the half of the sample for which prices are observed at least 87% of the time, and the results were very similar to those reported here.

Figure 1 reports a histogram of the entire sample of prices by their last digit (after truncating the nine-tenths of a cent). Not surprisingly, prices ending in a nine are the most common,

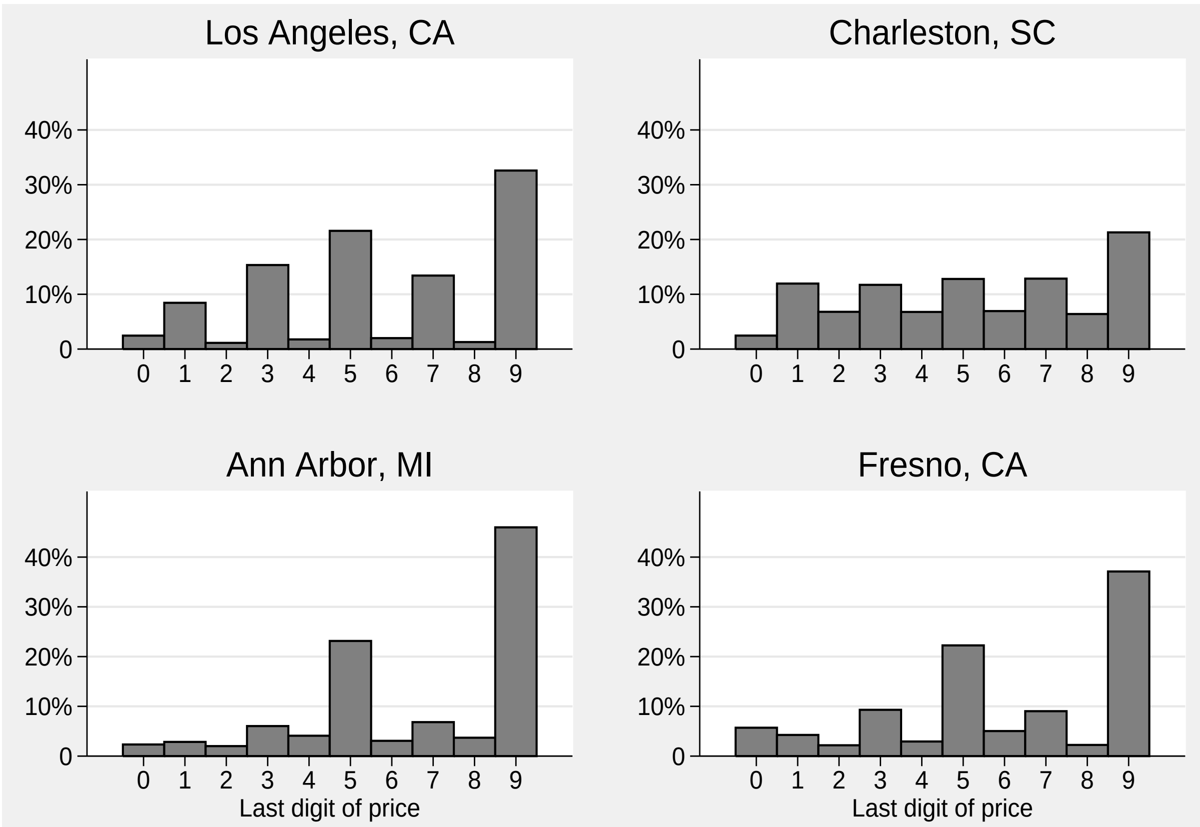
Figure 2: Frequencies of Odd Prices and Prices Ending in 5 or 9.



making up over 30% of the sample. However prices are also more likely to end in the other odd numbers than in an even number. The pattern is nearly universal, with 164 of 165 cities having more odd prices than even prices. Figure 2 Panel A shows the histogram of the share of prices in each city that are odd. The distribution reveals that even numbered prices are extremely rare in some cities, such as Los Angeles, Lancaster (PA), and Boise (ID), where over 90% of prices are odd. Panel B of Figure 2 shows the histogram of the share of odd prices charged at each station. There is a distinct mass of stations at 1 revealing that around 5.5% of observed stations exclusively charge odd prices.

In addition to variation in the overall share prices that are odd, the relative frequencies of different price endings also vary significantly across markets. Figure 3 reports histograms of

Figure 3: Histograms of Prices by their Last Digit for Selected Cities.



price endings for 4 cities: Los Angeles, Charleston (SC), Ann Arbor (MI), and Fresno (CA). In Los Angeles, while nearly all prices are odd, the relative frequencies for each odd price ending are roughly in proportion with those in the country as a whole. In contrast, each odd price ending occurs with almost equal likelihood in Charleston, SC, except for nines which are slightly more common.

In some locations stations rely particularly heavily on prices ending in 5 or 9. These two price endings account for over 70% of all observed prices in cities such as Harrisburg, PA, Charleston, WV, and Ann Arbor, MI. Such pricing patterns are illustrated in the histograms for Ann Arbor and Fresno in Figure 3, where 5 and 9 are by far the most common price endings.

A disproportionately high usage of 5 and 9 can be thought of as a further restriction of the price grid from odd prices to a subset of odd prices. Figure 2, Panel C reports the histogram of the share of odd prices in each city that end in 5 or 9, and Panel D reports the shares of each station's odd prices that end in 5 or 9. As with the use of odd prices, there is substantial variation across cities and across stations in the share of these odd prices that end in 5 and 9. The empirical investigation in the next section focuses mainly on the use of these two sets of pricing points: odd prices and the more restrictive set of only 5- and 9-ending prices.

IV. Empirical Analysis

There are many unobserved factors and market characteristics that may influence pricing behavior and the use of pricing points. My analysis relies on geographic region fixed effects to control for variation in unobserved factors across regions while examining variation in pricing behavior within the specified region. Using smaller control regions increases the ability of the fixed effect to capture unobserved characteristics but it also increases the extent to which variation in pricing behavior or use of pricing points will also be absorbed by the fixed effect. As a result, I estimate each regression using several different levels of geographic aggregation.

IV. a. Price Rigidity

Retail gasoline prices exhibit significant price stickiness. While local wholesale gasoline prices change almost every day, stations frequently leave retail prices unchanged for days or sometimes weeks at a time. Not surprisingly there is significant variation in price stickiness across stations and across regions. Almost 22% of observed stations average 5 days or longer between price changes, while another 23% of stations average a price change at least every other day. In this section I examine the extent to which price stickiness is related to the use of pricing points.

It is clear that stations charing a higher share of odd prices (particularly those using mostly 5- and 9-ending prices) would find it more difficult to frequently adjust prices to small changes in cost. However, if prices tend to adjust infrequently in gasoline markets for other reasons, the use of pricing points in a particular area may not significantly constrain the size or frequency of price movements. As a result, differences in price stickiness between markets that frequently use pricing points and those that do not are not a mechanical certainty. Identifying such a relationship empirically would suggest that these pricing points may, in fact, have an important role in generating price rigidity.

Since prices are observed daily, a price change for station i on date t is defined as $\Delta p_{it} = p_{it} - p_{i,t-1}$.[10] I first investigate the frequency of price changes by regressing the share of price changes that are non-zero on the share of prices that are odd and the share of odd prices that end in 5 or 9. I estimate this regression at the city level as well as at the zip code and station level. The city average regression includes state fixed effects, the zip code regression includes city fixed effects, and the station average regression includes zip code fixed effects.

The results from each specification (reported in Columns 1 through 3 of Table 1) confirm that areas and stations that more frequently charge odd prices change their prices significantly less often. Prices change even less frequently when more of these odd prices end in 5 and 9. The magnitudes of these coefficient estimates are fairly consistent across specifications. This is particularly striking given that the variation in pricing behavior used to identify the coefficients in each specification is completely independent of that used in the other specifications. For example, the station level regression is identified entirely off of within zip code variation while the zip code regression is identified off of between zip code variation.

As an illustration of the economic significance of these coefficients, consider comparing a hypothetical zip code in which the fraction of prices that are odd and the fraction of odd prices ending in 5 and 9 are both one standard deviation above the mean to another hypothetical zip code for which these shares are both one standard deviation below the mean. The coefficient estimates imply that an average station in the first zip code would change its price on a given day with a probability of .270, while a station in the second zip code changes with probability

[10] Prices are not observed for every station on every day, so the relevant sample for any analysis of price changes is simply the set of all price observations for which we also observe a price on the previous day for that station. This sample should be representative of the true population of prices as long as the likelihood of OPIS observing a price is not related to the fact that the price has changed.

Table 1: Price Rigidity and the Use of Odd-Ending Prices

Dependent Variable:	Fraction of Days on which Prices Change			Mean Absolute Size of Price Changes (in cents)		
	(1)	(2)	(3)	(4)	(5)	(6)
Level of Observation:	City	Zip Code	Station	City	Zip Code	Station
Fraction of Prices that are Odd	$-.424^{**}$	$-.416^{**}$	$-.516^{**}$	0.02	3.04^{**}	2.94^{**}
	(.110)	(.040)	(.036)	(1.22)	(0.32)	(0.23)
Fraction of Odd Prices Ending in 5 or 9	$-.356^{**}$	$-.317^{**}$	$-.160^{**}$	5.57^{**}	1.93^{**}	2.86^{**}
	(.085)	(.037)	(.026)	(1.03)	(0.34)	(0.23)
Fixed Effects Included:	State	City	Zip Code	State	City	Zip Code
# of observations	165	3715	20655	165	3715	20655

** and * denote significance at the 1% and 5% levels respectively.

Mean absolute price change is an average over all non-zero price changes.

In specifications 2, 3, 5, and 6 robust standard errors are clustered at the city level.

.413.[11] According to these probabilities, the durations between price changes would average 3.7 days in the first zip code and 2.4 days in the second, suggesting that prices remain unchanged 50% longer in the zip codes where pricing points are used more frequently.[12]

Given observed differences in price stickiness, it is not surprising that I also find that price changes (when they occur) tend to be larger in areas and at stations that use more odd-ending prices or more prices ending in 5 and 9. In Columns 4 through 6 of Table 1 I regress the average absolute magnitude of non-zero price changes on the share of odd prices and the share of odd prices ending in 5 or 9. Coefficients on both variables are positive and strongly significant in the zip code level and station level regressions. In the city level regression the coefficient on 5

[11]Since the zip code regression includes city fixed effects, the standard deviations used for these calculations are within-city standard deviations of zip code averages. The zip code share of odd prices has a mean of .769 and a within-city standard deviation of .092. The zip code share of odd prices that end in 5 or 9 has a mean of .645 and a within-city standard deviation of .100.

[12]Some cities in my sample exhibit Edgeworth price cycles (see Lewis (2009) or Noel (2007)) in which retail prices are more volatile and fluctuate along a regular cyclical pattern. Not surprisingly, prices in these cities change much more frequently. The average duration between price changes in cycling cities is around 2 days compared to 3.4 days in other markets. However, the use of pricing points appears to have similar effects in cycling and non-cycling markets. When regressions are estimated separately for each type, both sets of coefficients imply that a zip code in which the fraction of prices that are odd and the fraction of odd prices ending in 5 and 9 are one standard deviation below the mean will change prices 40-50% more often than a zip code one standard deviation above the mean. The results reported in the remaining sections of the paper are also fairly similar when estimated separately for cycling and non-cycling markets. It is interesting to note however that when price restorations occur in cycling markets the mode price to which stations jump is typically odd and often ends in either a 5 or a 9.

and 9 prices is large and positive while the coefficient on odd pricing is small and insignificant.[13] The magnitudes of these coefficients are roughly consistent with the frequency of price change results. Stations in zip codes in which the fraction of prices that are odd and the fraction of odd prices ending in 5 and 9 are both one standard deviation above the mean will have price changes that are 0.95 cents larger on average than stations in a zip code one standard deviation below the mean.

These findings are very similar to those of Levy et al. (2011) who document increased price rigidities for supermarket products and electronics for which retailers concentrate more on 9-ending price points. The use of pricing points acts to restrict the pricing grid, apparently resulting in fewer (and larger) price changes.

IV. b. Margins

Using the same empirical approach I now examine whether areas or stations that rely more heavily on odd prices or those ending in 5 and 9 also tend to also have higher margins. Since I do not have data on city-specific wholesale gasoline prices, I create a measure of relative prices by calculating the difference between each observed price and the mean price in the corresponding city for that day. Zip code level and station level averages of these daily price differences are then regressed on the frequency of odd prices and 5 and 9 prices just as in the price rigidity analysis.[14] More formally, let $\mathcal{Z}$ represent the set of stations in zip code z, and $\mathcal{R}$ represent the set of stations in city r. Then the relative price for station i on date t is calculated as:

$$\tilde{p}_{it} = p_{it} - \frac{1}{N_{rt}} \sum_{i \in \mathcal{R}} p_{it}$$

where N_{rt} represents the number of prices observed on date t in city r. Then station and zip code level average adjusted prices are calculated as follows:

$$\text{Station Level:} \qquad \bar{p}_i = \frac{1}{T_i} \sum_{t=1}^{T_i} \tilde{p}_{it}$$

[13]It is possible that state level fixed effect are unable to fully control for all of the other differences in market characteristics that may be associated the size of price changes.

[14]A city level regression is not reported because state fixed effects are unlikely to be able to sufficiently control for differences in wholesale costs. However, coefficients on the share of odd prices and the share of odd prices ending in 5 or 9 from the state level regression are both positive and statistically significant.

Table 2: Relationship Between Price Levels and the Use of Odd Prices

Dependent Variable: (cents per gallon)	Average Price Deviation from the State Mean		Average Price Deviation from the City Mean			
	(1)	(2)	(3)	(4)	(5)	(6)
Level of Observation:	City		Zip Code		Station	
Fraction of Prices that are Odd	5.01 (6.18)	14.71** (6.89)	−2.08 (1.47)	2.25 (1.65)	−1.81* (0.69)	2.08* (0.96)
Fraction of Odd Prices Ending in 5 or 9	20.25** (5.20)	15.85** (5.29)	14.65** (1.11)	12.57** (1.21)	12.15** (0.80)	10.69** (0.82)
Fraction of Prices Ending in Zero		83.41** (28.94)		23.91** (3.96)		15.94** (2.17)
Fixed Effects Included:	State	State	City	City	Zip Code	Zip Code
# of observations	165	165	3715	3715	20655	20655

** and * denote significance at the 1% and 5% levels respectively.
Robust standard errors are clustered at the city level in all specifications.

$$\text{Zip Code Level:} \qquad \bar{p}_z = \frac{1}{T_z}\sum_{t=1}^{T_z}\left(\frac{1}{N_{zt}}\sum_{i\in\mathcal{Z}}\tilde{p}_{it}\right)$$

where N_{zt} represents the number of stations in zip code z on day t, and T_i and T_z represent the total number of days for which station i's price or zip code z's average price are observed in the sample.

To construct a city level relative price measure it is necessary to use prices in other cities as a comparison group. Since prices vary from state to state due to tax differences and differences in wholesale cost, I have chosen to define the relative price of each city as the difference between the city average price and the mean price across observed cities within the state for that day. For the set $\mathcal{S}$ of stations within state s, the average adjusted price for the city is:

$$\text{City Level:} \qquad \bar{p}_r = \frac{1}{T}\sum_{t=1}^{T}\left(\frac{1}{N_{rt}}\sum_{i\in\mathcal{R}}\tilde{\tilde{p}}_{it}\right) \qquad \text{where} \qquad \tilde{\tilde{p}}_{it} = p_{it} - \frac{1}{N_{st}}\sum_{i\in\mathcal{S}}p_{it}.$$

The choice to normalize relative to the mean price in the area is somewhat arbitrary. I have also tried normalizing prices relative to the minimum price observed in the area each day, and found this approach to have only a negligible impact on the remaining analysis.

Columns 1, 3, & 5 of Table 2 report the baseline results of the city-level, zip-code-level, and station-level price regression. In all regressions the fraction of odd prices ending in 5 or 9 has a large positive coefficient suggesting that prices are significantly higher in areas and at stations that concentrate on these price endings. The coefficients on the share of prices that are odd are smaller in magnitude and are actually negative in the zip code and station level models.

It turns out that these negative coefficients on odd pricing are largely a result of stations that charge prices ending in zero. While zero ending prices are quite rare, they appear to be closely related to the use of 9-ending prices. Stations in the data are much more likely to charge a zero ending price when others in the zip code are charging 9-ending prices.[15] In addition, more than half of all zero ending prices result from a station increasing price by one from a 9-ending price, and more than 60% of all zero prices are eliminated by a one cent decrease to a 9-ending price.

Given that zero ending prices overwhelmingly occur during times when 9-ending prices are being used, it would not be surprising if margins were also higher for stations charging zero prices. To account for this I estimate an alternative specification of the price level regression that also includes the share of prices ending in zero. The results from these regressions are reported in Columns 2, 4, & 6. After controlling for zero pricing, the coefficients on the share of odd prices become positive (though still statistically insignificant in the zip code level regression). Estimated coefficients in the city level regression are noticeably larger, particularly on the share of odd prices, suggesting that there may be some unobserved differences in costs or competition across cities that are correlated with the use of odd prices but not well controlled for by the state fixed effects. The city level or zip code level controls used in the other specifications substantially mitigate these concerns. Generally, coefficients on the share of odd prices ending in 5 or 9 remain highly significant and of similar magnitude across specifications. The coefficients on the share of zero prices are also quite large, but the shares themselves are small. The mean zip code share of prices ending in zero is .03 with a standard deviation of .02.

Though areas and stations that charge more odd prices do not appear to have systematically higher prices, those that charge more prices ending in 5 and 9 earn a significant premium. The estimate from Column 4 implies that a zip code with a share of odd prices ending in 5 or 9

[15]For example, a station is nearly 50% more likely to charge a zero price on days when 75% of its competitors in the zip code are charging 9-ending prices than on days when only 25% of competitors are charging 9-ending prices.

Table 3: Summary Statistics for Market Characteristics

Statistic:	Mean	Standard Deviation	5th Percentile	95th Percentile
Zip Code Characteristics:				
Population (1,000s)	29.3	14.8	7.3	55.3
Population Per Sq. Mile (1,000s)	2.81	3.20	0.18	8.39
Median Income (1,000s)	44.6	14.9	24.9	72.3
Median Travel Time to Work	15.7	3.9	15	37
Number of Stations in Zip Code	8.95	5.34	2	19
Stations Per Square Mile	0.74	0.70	0.05	2.02
Share of stations with C-stores	0.87	0.15	0.57	1
Refinery-brand Station Share	0.62	0.25	0.20	1
Station Characteristic:				
# of Stations Within 1.5 Miles	8.55	4.71	2	17

that is one standard deviation above the city mean will have an average price that is 2.55 cents higher than a zip code in the same city that is one standard deviation below the mean. Similarly, according to the estimate in Column 6 stations whose share of odd prices ending in 5 or 9 is one standard deviation above the zip code mean will have an average price that is 2.44 cents higher than stations in the same zip code that are one standard deviation below the mean.[16] Much like the price rigidity results, the estimate of the price premium earned by stations charging more 5 and 9 prices in the station level regression is similar to that of the zip code level regression despite being being identified off of entirely different sources of variation.

Together the findings indicate that prices are substantially higher and more sticky in areas with more 5 and 9 pricing, consistent with the idea that these pricing points act as a coordinating mechanism and result in a softening of competition. However, it is also possible that these areas and stations have higher price levels for other reasons and just happen to also be more likely to set prices ending in 5 and 9. One way to test this is to include other explanatory variables in the price regression and see if their presence reduces the coefficient estimate on the share of prices ending in 5 and 9.

[16]As before, the standard deviations used for these calculations are within-city standard deviations of zip code averages and within-zip code standard deviations of station averages respectively. The zip code share of odd prices that end in 5 or 9 has a mean of .645 and a within-city standard deviation of .100. The station share of odd prices that end in 5 or 9 has a mean of .628 and a within-zip code standard deviation of .114.

Previous studies have found demographic characteristics and the degree of local competition to be important predictors of retail gasoline prices (Hosken et al., 2008; Barron et al., 2004). Using the 2000 U.S. Census I collect zip code level data on: total population, population density, median income, and median travel time to work (by motor vehicle). Stations that operate convenience stores also may be slightly more competitive in pricing in order to attract customers that also purchase other products. I am not able to observe whether individual stations have convenience stores, but based on information from the 2007 Economic Census establishments data I construct a measure of the fraction of gas stations in each zip code that also operate a convenience store. Using the OPIS data I also calculate zip code level measures of the total number of stations and the density of stations per square mile, and I construct zip code market shares for each of the major refinery brands or retail chains that operate over 2.5% of the stations in that region of the country (as defined by petroleum administration defense districts (PADDs)).[17] Summary statistics for the market characteristics are reported in Table 3.

Table 4 Column 1 contains the results of the zip code level price regression with these market characteristics. While not reported in the table, the regression includes a set of zip code market shares for each major refiner or retail chain, and the coefficient on each of these market share variables is allowed to differ across PADDs to reflect the fact that some brands may be perceived as a premium brand in certain regions but not in others. Many of the included characteristics appear to be strong predictors of zip code price levels, but the coefficients on odd pricing and 5 and 9 pricing remain roughly equivalent to those in Table 2. Differences in price associated with the use of pricing points appear to be largely independent of the price differences explained by other market characteristics.

The station level regressions in Table 2 include zip code fixed effects which absorb all variation in local market characteristics, but it is possible to include additional station level characteristics to further control for heterogeneity. Since the brand of station is observed, I include brand fixed effects and allow the effect for each brand to be different in each PADD. In addition, I use the location information from the OPIS data to construct a station-specific count of the number of competitors within a 1.5 mile radius of the station. When these brand fixed effects

[17] Including the 3 subdivisions of PADD 1 there are 7 PADD regions in total. There are a total of 77 brand-PADD combinations that have a PADD-level market share of over 2.5%. Appendix 1, Table A identifies each of these brand-PADD combinations and lists the PADD-level market share.

Table 4: Price Levels and Market Characteristics

Dependent Variable:	Average Price Deviation from the City Mean (in cents)		
	(1)	(2)	(3)
Level of Observation:	Zip Code	Station	Station
Fraction of Zip Code Prices:			
Odd Prices	2.28** (0.77)		0.056 (1.16)
Odd Prices Ending in 5 or 9	12.09** (0.64)		3.40** (0.81)
Prices Ending in Zero	25.65** (2.49)		8.73* (3.77)
Population (1,000s)	−0.023** (0.004)		−0.024** (0.008)
Population Per Sq. Mile (1,000s)	0.052* (0.026)		0.058 (0.039)
Median Income (1,000s)	0.034** (0.004)		0.027** (0.006)
Median Travel Time to Work	−0.036** (0.011)		−0.039* (0.016)
Number of Stations in Zip Code	−0.016 (0.013)		−0.025 (0.017)
Stations Per Square Mile	0.092 (0.101)		0.211† (0.113)
Share of stations with C-stores	−1.20** (0.33)		−1.19** (0.37)
Fraction of Station Prices:			
Odd Prices		1.57* (0.72)	1.51* (0.66)
Odd Prices Ending in 5 or 9		8.45** (0.77)	9.44** (0.74)
Prices Ending in Zero		12.48** (2.25)	12.75** (1.92)
# of Stations Within 1.5 Miles		−0.09** (0.01)	−0.07** (0.02)
Zip code market shares for each major retail chain	Yes		Yes
Brand fixed effect for each major retail chain		Yes	Yes
Fixed Effects Included:	City	Zip Code	City
# of observations	3547	20317	20317

**, * and † denote significance at the 1%, 5% and 10% levels respectively.
Robust standard errors are clustered at the city level in all specifications.

and the local number of competitors are included in the regression they are strongly statistically significant (Column 2, Table 4), but once again the coefficients on the use of pricing points are largely unaffected.

If the relationship between higher price levels and greater use of pricing points is, in fact, a result of firms tacitly coordinating on 5- and 9-ending prices, then one might also expect that nearby stations experience an umbrella effect allowing them to charge somewhat higher prices even if they do not use the pricing points as frequently. In this case, the average price level at a station might be correlated with both its use of pricing points and the use of pricing points by other stations in the zip code. To test this I remove zip code fixed effects from the station level price regression so that both station level variables and zip code level market characteristics can be included. Results of this specification are reported in Column 3 of Table 4. Prices are found to be significantly higher at stations whose competitors in the same zip code charge a higher fraction of 5- and 9-ending prices, though not surprisingly the effect is much smaller than that of the station's own share of 5- and 9-ending prices.

IV. c. Daily Analysis of Price Rigidity

In the analysis above stations (and zip codes) that more frequently use 5 and 9 pricing points consistently have higher prices and change price less often, even when fixed effects are used to control for unobserved local market characteristics. Given that daily prices are observed, the next logical step might be to examine how the use of pricing points varies over time for a given station and whether it is related to changes in the price level or the frequency of price changes. Unfortunately, the hypothesized behavior of firms coordinating on a restricted set of price endings does not necessarily predict that a station's prices will be higher on days when these endings are used.[18] The coordination theory simply predicts that over time stations and local markets that more effectively restrict prices to these price endings will have higher average profit margins.

If coordination is successful, however, a station's price should be less likely to change when one of these price endings is in use. Stations that typically use odd prices may occasionally set an even-ending price (as a signal to competitors, for example) but it will be changed more quickly. In contrast, this relationship between price endings and price rigidity should not occur, or should be much weaker, in areas where stations do not exhibit coordination on price endings. To examine this I separate markets that exhibit a heavy use of odd price endings from those that do not, and then test, for each group, whether stations are less likely to change price on days when an odd price ending is being used.

I classify areas that appear to be coordinating on a restricted price grid as those zip codes in which the share of prices that are odd and the share of prices that end in 5 or 9 are both higher

[18] See Section II. c. for a discussion of testable predictions resulting from coordination on a restricted pricing grid.

Table 5: Within-Day Differences in the Probability of a Price Change

Dependent Variable:	Station-Level Daily Price Change Indicator	
Sample:	Zip Codes Using Price Points More Frequently	Zip Codes Using Price Points Less Frequently
	(1)	(2)
Odd Price	-0.066^{**}	-0.009^{**}
	(0.012)	(0.003)
Price Ending in 5 or 9	-0.051^{**}	-0.034^{**}
	(0.003)	(0.002)
Price Ending in Zero	0.101^{**}	0.075^{**}
	(0.013)	(0.005)
# of observations	1,813,673	2,039,745

Notes: ** denotes significance at the 1% level. Robust standard errors are clustered at the city level in all specifications. All specifications include station fixed effects and city-specific day-of-sample fixed effects.

than the 66th percentile in the data. Similarly, I select areas that do not appear to be coordinating significantly as those for which these shares are both below the 33rd percentile. Then, using a linear probability model separately for each group, I regress an indicator for whether a station changes its price in a given day on indicators for whether the price had been odd, whether the price had ended in 5 or 9, and whether the price had ended in zero prior to the change. Within-day variation in the probability of a price change is isolated by including city-specific day-of-sample fixed effects, and station fixed effects are included to control for the average pricing behavior of the station. The results are reported in Table 5. Column 1 contains estimates for stations in zip codes that more frequently use pricing points, while Column 2 contains estimates for zip codes that use pricing points less often.

The findings indicate that stations in areas that more frequently use pricing points are 7 percentage points less likely change price on days when they are charging an odd price and 12 percentage points less likely to change price on days when their prices end in a 5 or a 9. According to these probabilities, even prices (not ending in zero) are maintained for an average of 2.5 days while prices ending in 5 or 9 are maintained for an average of 3.6 days and other odd prices are maintained for 3.0 days.

In contrast, stations in areas that do not use pricing points as heavily are nearly as likely to change price days when they are charging odd-ending prices as when they are charging even-ending prices. Prices ending in five or nine are maintained for slightly longer, though not nearly to the extent observed in markets that more heavily rely on these price points. On average in these markets, prices ending in 5 or 9 are maintained for less than 2.4 days while both even prices and other odd prices are maintained for around 2.2 days. The findings confirm that these pricing points are in fact used differently in markets where they are observed more often, and that their use is associated with firms making fewer price adjustments.

IV. d. Where are Odd Prices Used?

Much of the empirical analysis in this study relies on variation in the use of odd pricing points across stations to link odd pricing with greater price rigidity and higher price levels. *So, why are stations in some areas able to successfully collude using odd prices while other are not?* If it were possible to identify exogenous variables that predict stations' ability to collude, these could be used as instruments for the use of pricing points in the price level regression to more effectively isolate a causal relationship. For example, tacit collusion between gas stations may be easier to sustain if there are fewer stations in the local market or if consumers have lower cross-elasticity of demand between stations (lowering the incentive for a station to undercut its rival).[19] Unfortunately, these types of facilitating factors are also likely to be associated with higher non-cooperative oligopoly price levels, violating the necessary exclusion restriction.

Though these market characteristics cannot be used as instruments, it is still valuable to investigate how these characteristics are associated with the use of pricing points. Table 6 reports the results of zip code level regressions of the share of prices that are odd and the share of odd prices ending in 5 or 9 on observed zip code characteristics. In both regressions, zip codes with a larger share of branded stations, lower median incomes, and (perhaps) a smaller number of stations exhibit more frequent use of pricing points. Zip codes with smaller populations also appear to rely more heavily on prices ending in 5 and 9. These relationships are consistent with

[19] Using two popular models of competition with differentiated products, Ross (1992) illustrates that higher degrees of differentiation can make it easier for firms to maintain a collusive equilibrium.

Table 6: Market Characteristics and the Use of Pricing Points

Dependent Variable:	Fraction of Prices that are Odd (×100)		Fraction of Odd Prices Ending in 5 or 9 (×100)	
	(1)		(2)	
Level of Observation:	Zip Code		Zip Code	
Population (1,000s)	−0.002	(0.016)	−0.034*	(0.015)
Population Per Square Mile (1,000s)	0.015	(0.075)	−0.143	(0.142)
Median Income (1,000s)	−0.033**	(0.013)	−0.048**	(0.013)
Median Travel Time to Work	−0.031	(0.035)	−0.003	(0.039)
Number of Stations in Zip Code	−0.072	(0.046)	−0.070	(0.046)
Stations Per Square Mile	−0.334	(0.277)	−0.025	(0.436)
Branded Station Share	4.654**	(0.986)	9.17**	(0.860)
Share of stations with C-stores	−0.830	(1.212)	−0.727	(1.116)
Fixed Effects Included:	City		City	
# of observations	3620		3620	

**, * and † denote significance at the 1%, 5% and 10% levels respectively.
Robust standard errors are clustered at the city level in all specifications.

the idea that certain market factors facilitate collusion. Stations in areas with fewer competitors, a smaller population, and a higher share of branded stations (whose consumers often exhibit brand loyalty) are likely to have lower incentives to undercut rivals. The negative coefficient on median income in both regressions is harder to interpret since lower income areas may have more price sensitive consumers, but may also have consumers with different driving patterns or stations with different characteristics. While not reported, the estimated coefficients from both specifications remain very similar to those in Table 6 when zip code market shares for each of the major brands are included as additional controls (as in Table 4).

Overall, these findings confirm that some of the same market factors that influence local price levels are also associated with the use of pricing points. Nevertheless, as the results in Table 4 reveal, prices levels are still strongly correlated with the use of pricing points even after controlling for these market characteristics, suggesting that odd pricing reveals something about the competitiveness of the market that other observable characteristics cannot.

V. Conclusions

Comparing retail gasoline prices across cities, across zip codes, and across individual stations reveals a highly consistent result that prices are higher and change less frequently when odd prices or prices ending in 5 and 9 are used more often. The price premium associated with 5 and 9 pricing cannot be explained by any of the other local market characteristics that commonly predict higher prices in retail gasoline markets. These findings are consistent with the theory that odd pricing points, particularly prices ending in 5 and 9, provide stations with focal points at which to coordinate prices and avoid aggressive undercutting. Though the use of pricing points as a mechanism for tacitly coordinating prices has not been a traditional focus of analysis, the evidence here suggests that this could provide a significant motivation for firms and may help explain the widespread use of odd pricing points in retail markets.

Perhaps the most likely alternative explanation for the use of these odd pricing points centers around the idea that consumers process prices from left to right and put less weight on the last digit. While this could explain the use of 9-ending prices it is hard to justify the disproportionate use of prices ending in 5 (or other odd numbers). Regardless of the true motivation for the use of these pricing points, this study provides evidence that price levels are in fact higher in areas where retailers rely more heavily on these "customary prices". Given the ubiquitous nature of price points, and particularly 9-ending prices, this result suggests that the prices of many products might be higher than our continuous pricing models would imply.

Although the evidence from the gasoline market indicates that certain market characteristics are associated with a greater use of odd prices, further investigation is necessary to determine why stations in some areas appear to be better able to "collude" around these pricing points. It may be that the use of focal pricing points is simply the most convenient tacit coordination mechanism available to firms that are already in an environment favorable to collusion. In light of this, a concentration of prices at pricing points is not likely to be something that antitrust authorities should be interested in addressing directly, but it may serve as a valuable indicator of tacitly collusive activity in a market.

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Appendix 1: Equilibrium in Hotelling Spatial Competition Model with Discrete Pricing Grid

This section considers how equilibrium prices change in a simple two firm spatial competition model when both firms are restricted to choose prices from a discrete grid rather than from a continuous set. Consider the standard Hotelling linear city model in which consumers are distributed uniformly along an interval of length 1 with one firm located on each endpoint of the city (firm 1 at $x = 0$ and firm 2 at $x = 1$). The unit cost for each firm is c. Consumers incur a transportation cost t to travel the length of the interval, and their reservation price for the good is sufficiently high so that all consumers will purchase the product. Firms are assumed to choose prices simultaneously. In this setting, firm i's demand can be characterized by the following function which also depends on its price and the price of its competitor, firm j:

$$D_i(p_i, p_j) = \frac{p_j - p_i + t}{2t}.$$

Given this demand curve for each firm, the profits earned by firm i will be:

$$\Pi^i(p_i, p_j) = \frac{(p_i - c)(p_j - p_i + t)}{2t}.$$

When firms are free to choose prices from a continuous set, it is straightforward to show that firms, in equilibrium, will charge:

$$p_1^c = p_2^c = t + c.$$

Now in order to consider the case in which firms are restricted to some discrete set of prices it is helpful to highlight two key results. Consider an arbitrary pair of prices such that $p^h > p^l$.

Lemma 1 *If firm j sets a price of p^h, firm i will earn higher profit from charging p^h rather than p^l when $p^l < t + c$.*

Proof: Using the profit function above, if firm j sets a price of p^h, firm i will earn higher profit from charging p^h rather than p^l when the following condition is satisfied:

$$\frac{(p^l - c)(p^h - p^l + t)}{2t} < \frac{(p^h - c)(t)}{2t}$$

$$(p^l - c)(p^h - p^l) < t(p^h - p^l)$$

$$p^l < t + c.$$

Lemma 2 *If firm j sets a price of p^l, firm i will earn higher profit from charging p^l rather than p^h when either $p^h - p^l \geq t$ or $p^h > t + c$.*

Proof: If firm j sets a price of p^l and $p^h - p^l \geq t$ then $\Pi(p^h) = 0 < \Pi(p^l)$. If $p_h - p_l < t$ then firm i will earn higher profit from charging p^l rather than p^h when:

$$\frac{(p^h - c)(p^l - p^h + t)}{2t} < \frac{(p^l - c)(t)}{2t}$$

$$(p^h - c)(p^l - p^h) < t(p^l - p^h)$$

$$p^h > t + c.$$

Using these results it is straightforward to show that, when firms are restricted to a discrete pricing grid. exactly two equilibria exist—one in which both firms charge the lowest price from the discrete set that is greater than the equilibrium price in the continuous case ($t + c$) and one in which both firms charge the highest price from the discrete price that is less than $t + c$.

Proposition 1 *If firms are restricted to a discrete pricing grid of grid size Δ and $p^c = t + c$ is not a member this discrete grid, then there will exist exactly two equilibria (p^* & p^{**}) both lying within the range $[t + c - \Delta, t + c + \Delta]$ with $p^* < t + c$ and $p^{**} > t + c$.*

Proof: If $p_1 = p_2 = p^* < t + c$, then Lemma 1 implies that it is unprofitable for either firm to deviate to a lower price since this lower price will be below $t + c$, and Lemma 2 implies that it will be unprofitable for either firm to deviate to a higher price since this higher price will be above $t + c$. Hence p^* is an equilibrium. Similarly, $p_1 = p_2 = p^{**} > t + c$ will be an equilibrium because Lemma 1 implies deviating to a lower price will be unprofitable and Lemma 2 implies deviating to a higher price is unprofitable. These will be the only two equilibria because for any price $\tilde{p} < p^*$ there will be a $\tilde{p} + \Delta < t + c$ which will represent a profitable deviation from $\tilde{p}$ according to Lemma 2, and for any price $\tilde{p} > p^{**}$ there will be a $\tilde{p} - \Delta > t + c$ which will represent a profitable deviation from $\tilde{p}$ according to Lemma 1.

Appendix 2: Extra Tables

Table A: Market Shares (within Sampled Cities) of Major Brands by PADD

Retailer	New England	Central Atlantic	Lower Atlantic	Midwest	Gulf Coast	Rocky Mountain	West Coast
7-Eleven	3.3		5.9			15.7	3.5
76							17.1
BP		6.4	14.9	16.3	10.2		
Chevron			7.7		14.0	7.0	23.3
Circle K	3.4		6.7		2.5	4.0	9.7
Citgo	15.7	2.6	8.1	2.7	5.9		
Conoco					2.7	16.9	
Cumberland	6.7						
E Z Mart					2.8		
Exxon	4.3				3.3		
Getty	8.0	3.1					
Giant / Martins		3.1					
Gulf	6.5	4.0					
Hess	3.0	7.1	4.0				
Irving	2.7						
Kangaroo			7.1				
Marathon Ashland				10.3			
Maverik						4.4	
Mobil	2.6						
Murphy USA					3.1		
Phillips 66				7.1	6.4	9.6	
Quik Trip				3.4			
Sheetz		4.5					
Shell	13.1	6.6	11.3	9.3	19.5		20.2
Sinclair						11.4	
Speedway				10.8			
Sunoco	13.5	4.3	4.4	3.3			
Tesoro						3.0	
Texaco			3.2		4.2		
Turkey Hill		18.5					
Valero	3.0	4.3			5.2	8.5	9.4
Wawa		6.4					

Table reports the PADD level market share (in percentages) for each brand that has over 2.5% market share in the corresponding PADD.