**Retail Gasoline Pricing: What Do We Know?**

Daniel S. Hosken[1]
Federal Trade Commission

Robert S. McMillan
Federal Trade Commission

Christopher T. Taylor
Federal Trade Commission

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Abstract

We examine retail gasoline pricing behavior using a three year panel of weekly prices for 272 stations in the Virginia suburbs of Washington, DC and report a number of empirical findings. First, we find that the relationship between retail gasoline prices, concentration, and station characteristics is dynamic. Second, we find that the distribution of retail gasoline prices has relatively thick tails. Third, we find that while the median retail margin changes substantially over time (by more than 50%), the shape of the distribution remains relatively constant. Fourth, we find there is substantial heterogeneity in pricing behavior: stations charging very low or very high prices are much more likely to maintain their pricing position over time than stations charging prices near the mean, even after controlling for permanent differences in marginal costs. Finally, we find that stations frequently change their relative prices (measured in either dollars or price order relative to nearby stations).

[1] Corresponding author, Daniel Hosken, Bureau of Economics, Federal Trade Commission, 600 Pennsylvania Ave, NW, Washington, DC 20580, dhosken@ftc.gov, 202-326-3491. Views and opinions expressed in this paper are solely those of the authors and should not be interpreted as reflecting the views of the Federal Trade Commission, any of its individual Commissioners, or other members of the staff. Comments by David Meyer and Steven Tenn and excellent research assistance by Van Brantner are appreciated.

## I. Introduction

In response to the recent increases in the price of gasoline much attention has been directed at all levels of the gasoline supply chain, from refining to retail. Following Hurricane Katrina retail prices jumped more than 50 cents per gallon in some cities causing claims of 'gouging' by firms in the industry. In response to these price spikes Congress has considered legislation that would provide civil and criminal sanctions for price gouging.[1] In contrast, states have also expressed concern about new retail formats (including supermarkets and mass merchandisers) selling gasoline at too *low* of a price. In response to these concerns, some states have modified or increased enforcement of their "sales below cost" laws or *minimum* markups laws.[2]

With the increased concern about gasoline pricing, there is increased demand for understanding how retail gasoline prices are determined and how they change over time. Until quite recently, larger panel data sets of station specific gasoline prices were not available. However, we use credit card (fleet card) transaction data, which allows us to examine a larger number of gasoline stations' pricing behavior over an extended period of time.

The existing literature examining retail gasoline pricing can be grouped into three categories. The first and largest category estimates static pricing models using either data on a cross-section of gasoline stations for one period or with a short panel.[3] These papers find that retail price variation can be explained by brand affiliation, some measures of localized competition (typically a measure of localized station density and/or distance to the closest rival), and a handful of station attributes (e.g., if the station also performs repairs, has a convenience store, or offers full service gasoline).

The second line of research, often referred to as the "rockets and feathers" literature, uses pricing data at various levels of the industry (i.e., spot, rack and retail) usually aggregated over large geographic areas to examine how the price of gasoline at one level, e.g. retail,

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[1] Many states already have price gouging statutes. Following Hurricane Katrina more than 100 gasoline stations were investigated by states for price gouging. See: U.S. Federal Trade Commission "Investigation of Gasoline Price Manipulation and Post-Katrina Gasoline Price Increases," May, 2006.

[2] At least six states (Alabama, Kansas, New York, Michigan, Virginia, and Wisconsin) have considered legislation that would have introduced or modified minimum markup or sales below costs laws on gasoline. See FTC staff letter to The Honorable Gene DeRossett, Michigan House of Representatives, June 2004. http://www.ftc.gov/os/2004/06/040618staffcommentsmichiganpetrol.pdf

[3] For examples of papers examining retail gasoline pricing in a cross section or short panel see, Slade (1992), Shepard (1990, 1991, 1993), Barron et al. (2000, 2004), or Hastings (2004).

responds to a change in price at another level, e.g. wholesale. Some papers in this literature find that retail prices increase more quickly following increases to wholesale prices than decreases, (see, e.g., Borenstein et al (1997)), while others (e.g. Galeotti et al. (2003)) find the opposite result. The results of the rockets and feathers literature are mixed and seem to depend on the time aggregation of the data (daily, weekly, or monthly), the level of the industry examined (refining, distribution, or retail), and the estimation technique.

Our paper belongs to a third group of papers, which seek to use relatively long panels of weekly (or even daily) station-level pricing data to examine dynamic pricing behavior. Eckert and West (2004) verify that using aggregated weekly price data masks substantial meaningful variation across stations and within weeks. Lewis (2005b) attempts to correlate price dispersion with the level of competition by extending Barron et al (2004) to a panel setting. Lewis (2005a) verifies that the "rockets and feathers" pattern is present in station-level data while Noel (2005) examines apparent changes in city-level pricing equilibria.

We analyze a detailed panel data set of weekly gasoline prices for 272 gasoline stations located in the Northern Virginia suburbs of Washington, DC over three years, 1997 to 1999. We use this data to establish a number of empirical findings about gasoline pricing.

First, we find that static pricing equations have potentially serious shortcomings in explaining individual gasoline stations' pricing behavior over time. While we are able to generate empirical estimates similar to the cross-sectional literature using our data, these estimates are very sensitive to sample composition. The estimated relationship between prices and competition changes in economically (and statistically) significant ways, both over time and across brands.

Second, we find that the distribution of retail prices at a point in a city or within local areas has thick tails. Although roughly 70% of stations charge prices that are within 3.5 cents of the mean, some stations charge prices much different than the mean, with 3.5% of stations charging prices that are more than 10 cents different than the mean. This is somewhat contrary to economic intuition, which suggests that in a market where the product is fairly homogenous (gasoline) and search costs are relatively low (gasoline prices are prominently posted, and consumers are in their cars while searching) price dispersion should be low.

Our third finding is that the retail markup (defined as retail price less a measure of wholesale price and taxes) for gasoline shows sizeable changes over time. For instance, in our sample the weekly median margin is more than 17 cents a gallon for 26 consecutive weeks (the mean of the median is 19.4 cents) in 1997 and 1998 before falling to less than 14 cents a week (the mean of the median is 10.7 cents) for 12 weeks.

Fourth, we find that stations do not appear to use simple static pricing rules: stations do not charge a fixed mark-up over their wholesale costs, nor do they simply maintain their relative position in the pricing distribution over time. Instead, a particular gasoline station frequently changes its relative position in the pricing distribution, often dramatically. From one week to the next, stations are more likely than not to change their relative position measured in either dollars (above or below the mean in a given week) or rank (price relative to closest stations). We also find differences in the pricing strategies of gasoline stations. Stations that charge very high or very low prices in one period are much more likely to charge high or low prices in subsequent periods. Interestingly, there appears to be an asymmetry in this behavior. Stations charging low prices appear to remain low priced stations for much longer periods than high priced stations.

The paper is organized as follows. The next section provides some very brief institutional detail about gasoline retailing and describes our data. Section three presents our empirical findings. Section four presents our conclusions and presents possible avenues for further work.

## II. Background and Data

Gasoline stations are retailers. They receive gasoline from a distributor (sometimes vertically integrated) and resell it to consumers. Like other retailers, gasoline stations compete by offering low prices, quality (location, cleanliness, speed of pumps), and attractive bundles of services (having a nice convenience store, offering repair services). There are, however, a number of important characteristics of gasoline retailing that differentiate it from other retailing. First, the issue of consumers purchasing "bundles" of products is less important to gas stations than to other types of retailers, such as food or clothing. Virtually every consumer entering a gas station will be purchasing gasoline while only a small subset will purchase other goods (beer, cigarettes, or repair services). Because a low price on gasoline is attractive to *every* potential consumer, the price of gasoline takes on a much more strategic role than the pricing of other products sold by the gas station.[4] Second, relative to many other products, gasoline is fairly homogeneous which facilitates consumer search. Any brand of gasoline of a given octane[5] will run an automobile. Taken together, these factors suggest consumer search for gasoline is easier than many other retail goods.

One advantage of studying gasoline retailing is that some measures of marginal cost are observable. Wholesale or "rack" prices for branded and unbranded gasoline are observable.[6] The gas stations that purchase branded gas at the rack are owned and operated by individuals who, in essence, operate franchises. Other firms (sometimes the same firms selling branded gasoline, sometimes firms acting purely as distributors) will post unbranded prices for gasoline that will be sold at stations unaffiliated with a brand.

There are, however, two other factors of marginal cost that are unobserved. Stations that are owned and operated by a refiner (completely vertically integrated) "pay" an unobserved transfer price for gasoline. There are also a significant number of "lessee dealer" stations in Northern Virginia. These are stations are owned by the refiner but operated by separate entities.[7] These stations pay an unobserved wholesale price for gasoline that is determined by the refiner. In addition, the wholesale price paid by different lessee dealers operating in the same metropolitan area may vary.[8] Thus, at any time there may be a number of different marginal costs across stations within the same region. We follow the literature in viewing the posted rack prices as the opportunity cost of gasoline, since refiners and distributors choose to sell at this price.

The stations we examine are located in the Northern Virginia suburbs of Washington DC. This region likely contains the set of all important competitors in the retail sale of gasoline in Northern Virginia. While Northern Virginia is in the same metropolitan area as both Washington DC and Suburban Maryland, commuting patterns and the prevailing

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[4] Lal and Matutes (1994) develop a model describing how retailers selling bundles of products will charge low prices on a subset of products in the bundle to attract consumers. Hosken and Reiffen (2004) extend the Lal and Matutes model to show that the items likely to be offered at low prices will be those in most consumers bundles.

[5] 87 octane gasoline accounted for 69% of gasoline sold in the U.S. in 1999 (EIA).

[6] The wholesale distribution point in gasoline markets is typically refereed to as the "rack", referring to the distribution point where the trucks obtain the gasoline that is delivered to retail stations. The terms rack and terminal are often used synonymously. The terminal is the point where gasoline is stored before distribution to retail stations. The terminal contains a truck "rack."

[7] In Virginia refiners can not build new company owned and operated gasoline stations. However, at the time the law forcing vertical separation was passed (divorcement), refiners were allowed to continue to operate the stations they owned.

[8] See Fisher and Meyer (2004) for an extensive description of lessee dealer pricing.

relative prices of gasoline in the three areas likely negates the impact of pricing in Maryland and DC on stations in Virginia. The regions in Virginia beyond our sample area likely do not contain many important competitors because there are very few stations in the regions with very little population.

Our data come from three sources. First, we have a three year panel of prices for 272 stations in Northern Virginia. This data comes from the Oil Price Information Service ("OPIS"), and are generated from fleet card[9] transaction data. We also have data from OPIS on the wholesale prices of both branded and unbranded gasoline.

We also have a census of all the location and attributes of all of the roughly 600 stations in Northern Virginia for each of the years, 1997, 1998, and 1999. This data comes from New Image Marketing, and consists of annual surveys of stations' addresses, locations attributes (such as the whether the station has service bays, a convenience store, and the number of pumps, etc.), and a description of the station's vertical relationship with its supplier. While we do not observe the pricing of all stations, we are able to construct variables measuring the competitive environment each of the stations in our sample faces. Specifically, we calculate measures of station density (the number of stations located within different mileage bands of our sampled station) and the distance to the closest station.

Finally, we obtained information on neighborhood characteristics (measured at the zip-code level) from the U.S. Census. These variables, which include household median income, population, and population density, are from the 2000 census and correspond to conditions in 1999.

In the paper we examine three different gasoline prices. The retail price of gasoline is the price recorded at the pump (including taxes) for the most commonly sold variation of gasoline (87 octane). We use the average "branded rack" as our measure of wholesale price. This is defined as the average price of all of the "branded" gasolines offered at the rack in a week. We have chosen the branded rack as our benchmark measure of wholesale price because the majority of stations sell a branded product. Our results, however, are robust to the choice of rack price.[10] Finally, we define a station's mark-up (margin) to be the retail

[9] Fleet cards are often used by firms whose employees drive a lot for business purposes, e.g., salesman or insurance claims adjusters. Fleet cards are often used to closely monitor what items employees charge to the firm, e.g., to ensure that an employee only bills fuel and not food when visiting a filling station.

[10] Branded rack prices are the wholesale prices sold under the name of the refiner providing the gasoline, (such as Texaco, Exxon, or Mobil). Unbranded rack prices are the prices charged by a distributor (often, but not

price less the branded rack price and taxes. Thus, a station's margin corresponds to its incremental profit.

Descriptive statistics for the data used in this study are presented in Table 1. The break down of station affiliations in our sample is presented in Table 2.

**III. Results**

In this section we describe the empirical regularities in retail gasoline pricing and establish the paper's key findings: First, we examine our data using the conventional approach in the literature. We find that the empirical estimates generated by specifications similar to those found in the literature, which assume a stable linear relationship between prices, localized competition, and station characteristics, are sensitive to minor changes in model specification. In particular, many of the coefficients relating to competition change significantly over time and are sensitive to sample composition. Second, we find that the distribution of retail gasoline prices has relatively thick tails. Third, we find that the distribution of retail margins within a region shifts dramatically over time. Fourth, we find that stations do not appear to follow simple pricing rules: both their margins and their prices *relative to each other* fluctuate over time.

**Finding 1: The Relationship Between Prices and Station Attributes is Dynamic**

Most studies which examine localized gasoline pricing use data which is limited to either a cross-section or a short panel.[11] These data limitations have forced researchers to assume that the relationship between stations' prices and their measurable characteristics are relatively constant over time.[12] Most of these studies estimate a linear specification which relates each station's price to some combination of the localized competitive environment (e.g., distance to the closest rival station, number of nearby stations), the station's brand affiliation, the vertical relationship between the station and the refiner supplying gasoline, the characteristics of the station (e.g., its age, whether it provides car repair services), and the

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always a refiner) but sold under the name of an independent gasoline retailer (Bob's Gasoline). During our sample period branded gasoline is typically a few cents a gallon more than unbranded gasoline.

[11] Eckert and West (2004) (who look at pricing dynamics in Canada over a 5 month period) and Lewis (2005a and 2005b) are notable exceptions.

[12] The goal of most of these studies is not to accurately measure the returns to different station characteristics or the coefficients on brand affiliation. In most cases, the authors are trying to control for other factors that affect gasoline prices and include these characteristics as control variables. In some of the short panel studies, (such as, Hastings (2004)), authors use station level fixed-effects as controls.

demographics of the station's neighborhood (e.g., median household income, population). These studies typically find that more competition (measured by station density and/or distance to the closest rival) is correlated with lower prices. In addition, in a given market, the brand of gasoline being sold is an important predictor of price. This finding, however, is difficult to generalize since not all brands are distributed nationally and the perceived quality of a given brand differs throughout the U.S. Finally, some of these studies find that some station characteristics, selling full service gasoline, providing repair services, having a convenience store have modest affects on prices (on the order of 1-3 cents).

Our first goal is to test the stability of the relationship between price and observable characteristics. Because our dataset differs from those typically used in the literature, our first exercise is to see if we can replicate findings similar to the literature using our data.

We begin by estimating a specification including the key control variables from the literature. Specifically we estimate a station's retail margin in each week (markup over the wholesale price of branded gas) as a function of station attributes, demographics corresponding to the zip code the station is located in,[13] indicators for the brand of gasoline sold, localized competition, and the vertical relationship between the station and its gasoline supplier as in equation (1) below where *i* is the store index and *t* refers to a given week.[14]

$$
\begin{aligned}
\text{(1)}\quad \text{Margin}_{\text{i,t}} &= \alpha_0 + \sum_k \beta_k (\text{Station Characteristics}_{\text{i,t}}) + \sum_k \gamma_k (\text{Localized Competition}_{\text{i,t}}) \\
&+ \sum_k \delta_{ki} (\text{Demographics}_{\text{i,t}}) + \sum_k \theta_k (\text{Brand Indicator}_{\text{i,t}}) + \sum_k \pi_k (\text{Vertical Relationship}) \\
&+ \sum_t \lambda_t (\text{Year}_{\text{t}}) + \text{e}_{\text{it}}
\end{aligned}
$$

The results from this equation are shown in the first column of Table 3. Consistent with the literature we find that brand effects are very important predictors of retail margins. Interestingly, we find that although the station's demographic environment (median household income, population, and population density) are important predictors of margins, none of the stations' physical attributes (e.g., having a convenience store) appear to be important predictors. The estimated coefficients on the stations' physical attributes are both statistically and economically (all less than a penny) insignificant.

[13] Because gasoline stations likely draw customers from a region larger than a census block, we use zip code level measures of the demographic variables.
[14] Because individual stations appear many times in the data set, we estimate clustered standard errors (where the clustering is at the station level).

The remaining columns of Table 3 report the estimates when we allow the coefficients to vary across years. A few findings are worth noting. First, the estimated coefficients on the demographic variables change significantly when comparing 1997 and 1998 or 1999. Whether this is the result of measurement error (these variable come from the 2000 census and correspond to conditions in 1999), or a change in the pricing function is unclear. Second, the estimated brand coefficients for those stations which make up a large share of our sample, Mobil, Crown, Shell and Texaco, vary from year to year. Third, in none of the years does there appear to be a consistent relationship between price and either station characteristics or localized competition. This finding is unlikely an artifact of the specific functional form used to measure competition or station characteristics. We have examined many specifications of localized competition, including the number of stores within 1/2 mile, 1 mile, 3 miles, and interactions of these measures, and found similar results. Similarly, we have examined many other station attributes (including measures of nearby traffic conditions) and found no effect using this sample of gas stations.

In examining the underlying pricing data, it became clear that the during this time period Crown stations played a very different pricing strategy than other station in Northern Virginia (this will be discussed in more detail below). In particular, Crown stations tended to charge relatively low prices independent of the localized competitive environment. For this reason, we fully interacted a Crown indicator variable with all of the other variables in the pricing equation – effectively dropping the Crown stations from the sample. The results for the non-Crown coefficients appear in Table 4.

The key difference we see in estimating the model for the non-Crown stations is the importance of the competition variables. The distance to the closest station is now both economically and statistically significant. For example, a station having a rival located next door is estimated to charge a price 1.4 cents lower than a station whose nearest rival is a mile away. While this finding causes our results to look more similar to the literature, it also suggests that the pricing function implied by equation (1) is not uniform across stations.

The other competition variable, the number of stations located within 1.5 miles of a station, is of the expected sign and economically (and marginally statistically, t=1.95) significant in 1997, but is not significant in the pooled sample in 1998 or 1999. To further examine this point we estimated the pricing relationship week by week and plotted the estimated coefficient and the 95% confidence interval around it (see Figure 1). While the coefficient is not estimated very precisely, the pattern is clear. In 1997 the estimated coefficient appears to be negative with a mean of -0.039. In 1998 and 1999 the coefficient has a mean centered at 0.017. Of note, the estimated value of the coefficient during some periods in 1998 falls outside of the very large confidence interval for the coefficient in 1997. We take this as fairly strong evidence that the relationship between prices and localized competition (as measured by localized station density) implied by equation (1) is not robust.

**Finding 2: The distribution of retail gasoline prices has relatively thick tails.**

Relative to many other consumer products, we expect that the search costs associated with purchasing gasoline are low. Although retailers are differentiated by physical location (proximity to an interstate or relative isolation) and station attributes (having a large convenience store), gasoline is fairly homogenous: any brand of gasoline (of a given octane) will work in an automobile. Indeed, the only technical differentiation across brands are the chemicals (typically detergents) added to the gasoline before it is delivered to the station. Further facilitating search, consumers are in their cars while shopping for gas and gasoline prices are prominently posted outside stations. Taken together, these factors suggest that there should be relatively little dispersion in gasoline prices across a region at a point in time.

The wholesale price of gasoline is very volatile. At the beginning of our sample the wholesale price of gasoline is approximately 75 cents per gallon. In early 1999 it fell to 35 cents before rising back to 75 cents per gallon in late 1999. To control for changes in costs, we define retail price variation as deviations about the mean price at a point in time. Specifically, we estimate price dispersion by examining the residuals from the following regression:

$$\text{(2)} \quad p_{i,t} = a_0 + \sum_t \gamma_t (\text{Week Indicators})_{i,t} + e_{i,t}$$

where $p_{i,t}$ is station *i*'s gasoline price in week t, and the $\gamma_t$ are the coefficients corresponding to weekly indicators. We estimate equation (2) using data for each station for each time period. The frequency distribution of the estimated error terms ($e_{it}$) is presented in Figure 2. We find that most prices are very close to the mean: 56% and 71% of prices are within 2.5 cents and 3.5 cents of the mean, respectively. However, the tails are quite thick, e.g., roughly 3.5% of prices are more than 10 cents from the mean. To facilitate interpretation of these findings, we also plot the frequency distribution of a normal with the same mean and standard deviation as the observed residuals (mean zero, standard deviation of 3.99 cents). If the residuals were normal, we would expect to see 47% and 62% of prices within 2.5 and 3.5 cents of the mean, and 1.2% of prices more than 10 cents from the mean.

The general pattern seen for the pooled data also holds when looking at the residuals separately by year.[15] While the shape of the distribution differs somewhat across years (prices appear less disperse in 1997 than either 1998 or 1999), most gasoline prices are very close to the mean, 75%, 69% and 66% within 3.5 cents of the mean in 1997, 1998 and 1999. Further, the tails are thick: roughly 2% of prices are more than a dime from the mean in 1997 and 4% of prices are more than a dime from the mean in 1998 and 1999. [16]

**Finding 3: Retail Margins Vary Substantially Over Time**

The static pricing models used in the past to examine retail price dispersion implicitly assume that retail margins are basically fixed (either in dollar or percentage terms) over time; that is, the markup a station charges is a function of localized competition, station amenities, demographics, and brand affiliation. Retail margins, however, vary dramatically over time. Figure 3 shows the branded rack price of gasoline and the plot of the 25th, 50th, and 75th percentiles of the distribution of gasoline stations' retail margins (retail price less wholesale prices and taxes) by week from 1997 through 1999. During this time period the average retail margin was 14.4 cents a gallon, as high as 20.9 cents a gallon (in 1999), and as low as 5.7 cents (also in 1999). The figure also shows that the entire pricing distribution tends to shift over time; i.e., the spread between the 25th and 75th percentile is fairly stable, roughly 4 cents per gallon in 1997, and 5 cents in 1998 and 1999.

The margins in our dataset vary over time while exhibiting a high degree of persistence. For example, the median margin is more than 17 cents per gallon for 26 consecutive weeks (averaging 19.4 cents) in 1997 and 1998 before falling to less than 14 cents per gallon (averaging 10.7 cents) for 12 weeks. Obviously, the change in retail profits associated with this change in margins is sizeable. While we do not observe output, it is

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[15] See Appendix Figures 1-3.

[16] Again, assuming residuals were normally distributed with standard deviations equal to the observed standard deviations of 3.55, 4.15, and 4.27 in 1997, 1998 and 1999, the expected proportion of prices within 3.5 cents of the mean would be: 68%, 60% and 59% in 1997, 1998 and 1999 and the proportion of prices more than 10 cents from the mean would be .5%, 1.6%, and 1.9% in 1997, 1998 and 1999.

reasonable to assume that changes in quantity are relatively small (gasoline demand is very inelastic), while margins fell by 50%.

**Finding 4: Stations Do Not Appear to Follow Simple Pricing Rules**

We have established that in each week, retail gasoline prices are fairly tightly distributed about the mean price, however, some stations charge very different prices than the mean price. Furthermore, we have shown that the markups that stations charge change substantially (by 50%) and stay at very different levels for relatively long periods of time. However, despite significant changes in retail margins and gasoline prices over time, the distribution of prices about the median margin at a point in time does not change very much – during our sample period the interquartile range is typically between 3 and 6 cents. This leads to a natural question: is the gasoline pricing distribution stable over time? That is, do individual stations pick a price relative to their rivals and maintain that price, or do stations change their relative position in the pricing distribution over time?

Unlike most other retailers, gasoline stations face sizeable and somewhat frequent shocks to their wholesale costs. These large cost shocks force gasoline retailers to change their price frequently. Thus, in contrast to other retailing environments,[17] costs are the cause of most changes in retail gasoline prices. However, while changing the price they charge, gasoline stations may also reevaluate how they wish to price *relative* to their rivals. Again, in contrast to other types of retailing, the cost to a gasoline station of determining its relative price is very low: its rivals post their prices on huge signs in front of their stores.

We find that gasoline stations appear to change their *relative* prices frequently. While some stations appear to charge systematically higher or lower prices, relative prices change fairly frequently. Further, some stations change their relative pricing position dramatically during our sample period.

In documenting and analyzing the relative prices we have used four related empirical approaches. First, we analyze how a given gasoline station's relative price changes between consecutive time periods (controlling for changes in the overall price level). Second, we

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[17] In food retailing, most changes in retail prices are the likely the result of a combination retail price competition rather than changes in wholesale costs (see, Chevalier et al (2003) and Hosken and Reiffen (2004)); that is, retailers (and manufacturers of branded consumer goods) play pricing games that cause retail prices to change over time independent of changes in wholesale prices. In clothing retailing, predictable fashion cycles also generate price variation independent of changes in wholesale costs (Pashigan (1988)).

analyze how a given gasoline station's relative price changes between consecutive time periods controlling for both changes in the overall price level and a station's systematic pricing behavior (such as permanent differences in marginal costs). Third, we measure how many stations dramatically change their pricing strategy, (such as going from being very high to low priced stores,) during our sample period. Finally, we analyze how the relative position (rank) of a gasoline station changes between weeks relative to its closest rivals.

We begin by analyzing how a firm's relative price changes over time. Specifically, we define a firm's relative price in week *t* to be the residual from equation (2); i.e., the difference between station *i*'s price in week *t* and the mean price in week *t*. We round the residual to the nearest cent and construct a Markov transition matrix where the elements of the matrix show the probability of being *y* cents above (below) the mean in period *t+1* conditional on being *x* cents above (below) the mean in period *t*. The matrix is presented in appendix table 1, however, a more intuitive understanding of the information in the matrix can be seen from plotting the data (see Figure 4). Figure 4 shows the frequency distribution of a station's price in period *t+1* conditional on its price in period t. For example, if a station's price in period *t* is less than 10 cents below the mean in period *t* there is an 80% probability that its price will be at least that low in period *t+1*.

There are two key findings from the figure. First, there is persistence in gasoline stations' relative prices. The modal choice of a station is to maintain its relative pricing position from week to week; i.e., if a station is 4 cents below the mean in period *t* it is most likely to be 4 cents below the mean in period *t+1*. Second, despite this persistence, for all but two of the frequency distributions, the mode is less than 50%.[18] Thus, more than 50% of the time a station's relative price will change by at least one cent each week. The shape of the frequency distributions of stations charging low prices in period *t* looks very different than stations charging high prices in period *t*. Stations charging relatively low prices in period *t* have higher modes and more probability mass very close to the mode than those stations charging relatively high prices. This suggests that stations charging high prices are converging to the mean more quickly than stations charging low prices. Thus, in contrast to food retailing where retailers periodically offer low prices and normally charge high prices,

[18] For these two cases, the empirical distribution of prices in *t+1* conditional on prices at time t being either 10 cents or more above the mean or 10 cents or less below the mean, are not directly comparable to the other cases. Obviously, in these two cases the set of prices we are conditioning on corresponds to a much broader range of prices.

the transition matrix shows that gas stations periodically charge high prices, but do not maintain abnormally high prices for very long. However, low prices appear to be more persistent; that is, a subset of stations appear to charge everyday low prices.

The findings from Figure 4 suggest there is systematic heterogeneity in pricing across stations over time. To examine the importance of this heterogeneity in explaining retail gasoline pricing we control for both time effects and time invariant station effects in regression (3) below,

$$(3) \quad p_{i,t} = \sum_{i} \theta_i (\text{Store Indicators})_{i,t} + \sum_{t} \gamma_t (\text{Week Indicators})_{i,t} + e_{i,t}$$

where the $\theta_i$ are gasoline station fixed-effects. This model corresponds to one where stations pursue a static pricing strategy where the relative price a station charges is a function of all of its observed and unobserved (to the econometrician) attributes (as measured by $\theta_i$). The interpretation of the residuals from equation (3) is very different than equation (2). For example, $e_{it}$ is now the deviation from station *i*'s pricing in period *t* after controlling for station *i*'s idiosyncratic pricing behavior. Thus, if we observe persistence in a station's residual, then the station is systematically charging higher or lower prices *than its typical price* for some period of time. Not surprisingly, equation (3) explains more of the variation in retail pricing than (2), e.g., the r-squared increases from 0.88 to 0.95 in moving from equation (2) to (3). Further, controlling for both time effects (changes in average margins and wholesale costs) and time-invariant station effects, explains most of the large deviations in station's relative price. For example, Figure 5 (which plots the residuals from regression 3) shows that 0.9% of residuals are more than 10 cents from the mean (compared to 3.4% from the regression in equation (2)).

Figure 6 presents the Markov transition matrix corresponding to the residuals from equation (3) (the analogue to Figure 4).[19] Not surprisingly, after controlling for (time-invariant) station-specific pricing, there are some significant changes in describing how prices change from week to week. The transition matrix suggests there is more convergence to the mean over time. While the matrix predicts that a station is most likely to charge the same relative price in the following week as the current week, this probability has decreased for the cells corresponding to prices far from a station's mean price (by construction, zero)

[19] Appendix Table 2 contains the matrix corresponding to Figure 6.

in all but one case.[20] Generally speaking, more of the probability mass in a given conditional frequency distribution is associated with prices closer to a station's mean price. However, there is still a significant probability that a station will charge prices systematically different than its mean. For example, stations do periodically charge prices very different than their "normal" relative price and that the return path to that normal price is typically not to return to that price in one step but to converge over time; e.g., a station changing a price 5 cents below its mean price in period *t* is not very likely to charge its mean price in period *t+1*.

The persistence in pricing we see in Figure 6, after controlling for both time and station fixed-effects, suggests that stations may change their pricing behavior over time; i.e., a station may *permanently* change the relative price it charges over time. To examine this we consider a slight modification of regression (3) where we allow the station effects to vary by calendar year (K=1997, 1998, 1999):

$$(4) \quad p_{it} = \sum_{t} \gamma_t \,(\text{Week Indicators})_{i,t} + \sum_{i,K} \theta_i^K \,(\text{Store Indicators, by Year})_{i,t} + e_{it}$$

First, we determine how much stations change their relative position in the pricing distribution for year to year. Specifically, we record the percentile corresponding to the estimated store effect in each year and calculate the difference in percentiles between years.[21] The results appear in table 5. The table shows that small changes in relative pricing are fairly common. For example, between 1997 and 1998 more than half of gasoline stations change their relative position in the pricing distribution by at least 10 percentage points. Further, while less frequent, some stations dramatically change their position in the pricing distribution, e.g., between 1997 and 1998 4% of gasoline stations estimated store-effects changed by more than 50 percentage points in the pricing distribution. Finally, the table shows that many of these differences are statistically significant. In comparing stores observed in 1997 and 1998, 1997 and 1999, and 1998 and 1999, we find that 33%, 45%, and 27% (respectively) of changes in estimated store effects are statistically significant with a (conditional) mean change in price between 3 and 4 cents.

The previous analysis has compared prices over a relatively large area. While this analysis is informative, it potentially misses some important aspects of localized competition.

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[20] For prices greater than 10 cents above the mean in the current week. However, the fraction of prices in this cell as decreased dramatically (by roughly 50%).

[21] In estimating equation 4 we require at least 10 observations per year. Thus, not all stations appear in all years. With this restriction we were limited to examining 170, 163, and 193 comparisons between 1997 and 1998, 1997 and 1999, and 1998 and 1999 respectively.

For example, in densely populated Northern Virginia, it is unlikely that a gas station considers the prices of stations 10 miles away  when setting its prices.  The set of relevant stations that factor in the price-setting process is likely relatively narrow, consisting of the set of stations "nearby".  It is easy to imagine that stations develop simple pricing rules within these regions, such as maintaining the second lowest price among the ten closest stations, or being 3 cents lower than a store with a prime location.

We examine localized pricing by determining the each station's price position relative to its 9 closest rivals each week (where a rank of 1 corresponds to having the lowest price and 10 corresponds to having the highest).[22]  To illustrate what a station's rank looks like over time, we begin by plotting the week to week price ranks of all Crown stations in our data set (see Figure 7).  The figure shows a clear pattern: Crown stations tend to charge very low relative prices.  Stations 6, 7, 8, and 14 are almost always charging the lowest prices of the ten closest stations.  While the relative ranking of other Crown stations is more variable (stations 2 and 5), on average Crown appears to charge among the lowest prices of its nearby competitors.

Because it is not feasible to examine the relative rank series for every station in our sample we create an aggregate measure analogous to that used to examine a station's relative price.  Specifically, we examine how a station's rank changes from week to week by constructing a Markov transition matrix and presenting it in a figure with the same interpretation as Figures 4 and 6.  The pattern that emerges in Figure 8 is very similar to what we see in examining week to week price changes using the sample of relative prices from all of Northern Virginia.  First, the modal strategy for a firm is to maintain its relative pricing position from week to week.  Firms that charge very low or very high prices, however, appear very different than those charging prices near the median of the distribution: stations that charge very high or very low prices in one week are very likely to charge very high or very low prices in the next week. Stations charging prices close to the median of the distribution (a rank of 4, 5, 6, or 7) are much more likely to change relative position from week to week.  We find the same pattern holds when viewing stations prices relative to a more narrow group of stations, comparing them to their four closest rivals (see

[22] Our price data corresponds to a sample of stations rather than the population.  Therefore we analyze the prices relative to a station and the 9 closest stations *in our sample*.  This set of stations potentially differs from the 9 closest in the population.

Figure 9). Stations charging low or high prices in one week (rank 1 or 5) are much more likely to be charge those prices in the subsequent week than stations charging prices near the median (ranks 2, 3, and 4).

## IV. Discussion and Conclusion

We have examined weekly pricing over a three year period in the late 1990s using a sample of 272 stations in Northern Virginia. Our main finding is that gasoline stations do not appear to follow simple static pricing rules. Gasoline stations do not appear to charge constant margins, nor do they appear to simply maintain a relative position in the pricing distribution from period to period. A number of pieces of evidence support this finding. First, the estimated coefficients from regressions of gasoline prices on station characteristics (including station attributes, such as the presence of service bays or convenience stores, and localized competition) are sensitive to sample composition and time period. Second, we find that from week-to-week gas stations are more likely than not to change their relative position in the pricing distribution (measured relative to a regional price or rank among nearby stations). There is also heterogeneity in stations' pricing behavior over time. Stations that charge very high prices or very low prices in one week are much more likely to charge high or low prices in subsequent weeks than stations charging prices near the mean.

There is also an interesting asymmetry in this behavior: low priced stations are much more likely to remain low priced than high priced stations are to remain high. While most week-to-week changes in pricing position are small, a significant number of stations make large changes in their pricing behavior over time. For example, 24% of stations change their relative position in the pricing distribution by more than 25 percentage points between 1998 and 1999.

Our second finding is that the distribution of retail gasoline prices has relatively thick tails. We did not have a strong prior for what the distribution of gasoline prices should look like. Some characteristics of retail gasoline markets suggest that prices should be very tightly distributed about the mean price at a point in time, e.g., gasoline is fairly homogeneous and search is facilitated by prices being prominently posted in front of gas stations and consumers being mobile (in cars) when shopping. Alternatively, the empirical literature suggested there were some aspects that differentiated gasoline stations, such as station attributes and localized competition. While the variance of prices changes somewhat from year to year, the pattern is the same: retail gasoline prices are characterized by a distribution with relatively thick tails.

We believe our most interesting finding is that retail margins change sizably over time. For example, for a six month period the implied retail mark-up (retail price less taxes and wholesale prices) is roughly 19 cents for 6 months and then falls to about 10 cents for 3 months. The evidence suggests that the entire distribution is shifting over time; i.e., not just the median or mean. In a market with little entry or exit, little non-geographic differentiation, where wholesale prices are easily observed (rack prices are essentially public information), and roughly common across firms (there is very little variation in rack prices at a point in time), and with inelastic demand, one would expect roughly constant retail margins. Instead we see large changes in retail margins over time. An alternative explanation of coordinated behavior, such as tacit collusion followed by periodic price wars, is also difficult to accept given the apparent low level of concentration at the retail level in Northern Virginia – there are roughly *25* different brands of retail gasoline in Northern Virginia.[23] This finding is worthy of further investigation.

Our findings suggest that gasoline retailers may be playing more complicated strategies, such as a mixed strategy in relative prices. The finding that static pricing equations are not stable does not imply that station characteristics do not affect pricing decisions. Instead, a retailer's pricing strategy may depend on station specific characteristics. Including station specific fixed-effects in a pricing regression explains some price variation, and high and low priced stations exhibit different levels of persistence. Further work could make use of more general pricing models, (à la Varian (1980)) to explain retail gasoline pricing.

[23] Because most of the individual branded stations are operated by firms other than the refiner, this likely understates the number of independent price-setting agents. Most stations in our data are operated either by a lessee dealer (an individual who leases the station from the refiner) or a jobber (a gas station owned by the dealer who operates as a franchisee). In these cases, the lessee dealer or jobber sets the retail price, not the refiner.

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# Table 1: Descriptive Statistics for OPIS Sample

| Variable | Station-Weeks | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| Price (cents) | 28443 | 111.47 | 11.33 | 72 | 146 |
| Number of gas stations within 1.5 miles | 28443 | 12.94 | 6.53 | 0 | 30 |
| Distance to Closest Gas Station (miles) | 28443 | 0.21 | 0.35 | 0 | 3.08 |
| Number of Pumps | 28443 | 7.63 | 2.77 | 0 | 16 |
| Indicator Variables: | | | | | |
| Convenience Store | 28443 | 0.05 | | | |
| Provides Repair Service | 28443 | 0.63 | | | |
| Outdated Format | 28443 | 0.25 | | | |
| Self Serve Only | 28443 | 0.84 | | | |
| Lessee Dealer | 28443 | 0.57 | | | |
| Jobber Owned | 28443 | 0.07 | | | |
| Population in Zip Code | 28443 | 30,388 | 12458 | 1377 | 62132 |
| Population Density in Zip Code | 28443 | 4,390 | 2787 | 63 | 12306 |
| Median Family Income in Zip Code | 28443 | 72,106 | 18083 | 37304 | 154817 |
| Percentage of Sample From: | | | | | |
| 1997 | | 36.25% | | | |
| 1998 | | 31.77% | | | |
| 1999 | | 31.98% | | | |

## Table 2: Comparison of Brand Distribution In New Image Marketing Census and OPIS Sample

| Brand | OPIS Sample Brand Percentages, Weighted By Observations in OPIS sample | OPIS Sample Station Counts |
|---|---|---|
| AMOCO | n/a | n/a |
| BLUE MAX | n/a | n/a |
| BP | 0.61% | 1.47% |
| CHEVRON | 0.65% | 2.21% |
| CITGO | 10.09% | 15.44% |
| COASTAL | 0.05% | 0.37% |
| CROWN | 7.54% | 5.88% |
| DIXIE | | |
| EAGLE | | |
| EXXON | 0.18% | 0.37% |
| GAS KING | | |
| GETTY | 0.69% | 0.74% |
| GLOBAL | | |
| HESS | 0.73% | 1.47% |
| JAC | | |
| MERIT | 0.24% | 0.37% |
| MOBIL | 27.75% | 24.26% |
| NO BRAND | | |
| QUARLES | | |
| RACETRAC | | |
| SHEETZ | 0.26% | 0.37% |
| SHELL | 23.35% | 21.32% |
| SUNOCO | 5.19% | 5.88% |
| TEXACO | 22.33% | 19.12% |
| WAWA | | |
| XTRA FUELS | 0.33% | 0.74% |

**Table 3: Regress Retail Margin**
**(Retail Price less Branded Rack) on Station Characteristics And Time Indicators**

| | **Pooled** | | **1997** | | **1998** | | **1999** | |
|---|---|---|---|---|---|---|---|---|
| Variable | **Beta** | Std Error | **Beta** | Std Error | **Beta** | Std Error | **Beta** | Std Error |
| Number of Stations with 1.5 miles | 0.000 | 0.027 | -0.036 | 0.020 | 0.018 | 0.038 | 0.026 | 0.037 |
| Distance to Closet Station (miles) | 0.357 | 0.657 | 0.996 | 0.463 | 0.020 | 0.848 | -0.005 | 0.766 |
| If Convenience Store | -0.798 | 0.689 | -0.169 | 0.678 | -0.234 | 0.821 | -0.709 | 0.912 |
| If Service Bays | 0.584 | 0.385 | 0.370 | 0.285 | 0.837 | 0.516 | 0.894 | 0.523 |
| If Outdated format | 0.595 | 0.319 | 0.126 | 0.415 | 0.700 | 0.410 | 0.946 | 0.412 |
| Number of Pumps | -0.035 | 0.074 | -0.048 | 0.050 | -0.070 | 0.102 | -0.018 | 0.108 |
| If Self Serve | 0.333 | 0.367 | 0.148 | 0.464 | 1.010 | 0.524 | 0.215 | 0.525 |
| If Lessee Dealer | -0.152 | 0.368 | -0.050 | 0.333 | -0.446 | 0.487 | 0.117 | 0.472 |
| If Jobber Owned | -0.351 | 0.603 | -1.097 | 0.712 | -0.719 | 0.758 | 1.027 | 0.859 |
| log of population in zip code | -1.880 | 0.451 | -0.740 | 0.270 | -2.400 | 0.569 | -2.557 | 0.616 |
| Log of population density in zip code | 0.985 | 0.224 | -0.042 | 0.171 | 1.368 | 0.336 | 2.042 | 0.378 |
| Log of median income in zip code | 2.497 | 0.580 | 0.537 | 0.536 | 3.173 | 0.837 | 4.480 | 0.881 |
| Station indicators (Citgo Ommited Station) | | | | | | | | |
| BP | 4.168 | 1.594 | 3.178 | 1.039 | 4.265 | 3.449 | 7.648 | 2.072 |
| Chevron | -2.717 | 1.019 | -2.770 | 1.067 | -5.604 | 0.870 | -0.447 | 1.005 |
| Coastal | -11.483 | 0.806 | -12.132 | 0.832 | n/a | | n/a | |
| Crown | -3.590 | 0.548 | -3.883 | 0.710 | -4.351 | 0.788 | -2.041 | 0.802 |
| Getty | 0.760 | 1.218 | 0.314 | 2.148 | 0.623 | 0.783 | 1.737 | 0.940 |
| Hess | -3.353 | 0.773 | -1.902 | 1.155 | -4.878 | 0.844 | -2.808 | 0.964 |
| Kenyon | -0.404 | 0.700 | n/a | | -1.691 | 0.856 | n/a | |
| Merit | -1.729 | 1.331 | n/a | | -4.308 | 0.921 | -1.063 | 1.541 |
| Mobil | 0.668 | 0.543 | 1.797 | 0.690 | -0.438 | 0.731 | 0.667 | 0.797 |
| Sheetz | -6.825 | 1.056 | n/a | | -7.005 | 1.345 | -6.581 | 1.382 |
| Shell | 1.178 | 0.527 | 1.536 | 0.709 | 0.245 | 0.710 | 1.800 | 0.809 |
| Sunoco | -2.352 | 0.675 | -1.522 | 0.754 | -3.356 | 0.891 | -2.432 | 1.059 |
| Texaco | 2.250 | 0.479 | 2.665 | 0.701 | 1.320 | 0.672 | 2.766 | 0.724 |
| Xtra Fuels | -1.725 | 0.736 | -0.858 | 0.707 | -0.671 | 0.847 | n/a | |
| Constant | 33.829 | 7.936 | 52.645 | 7.502 | 35.893 | 11.648 | 8.907 | 12.725 |
| Number of Observations | 28,156 | | 10,228 | | 8,932 | | 8,996 | |
| R-squared | 0.644 | | 0.670 | | 0.647 | | 0.597 | |

Notes: Omitted Brand is Citgo, Clustered Standard Errors

## Table 4: Regress Retail Margin (Retail Price less Branded Rack) on Station Characteristics Non-Crown Stations

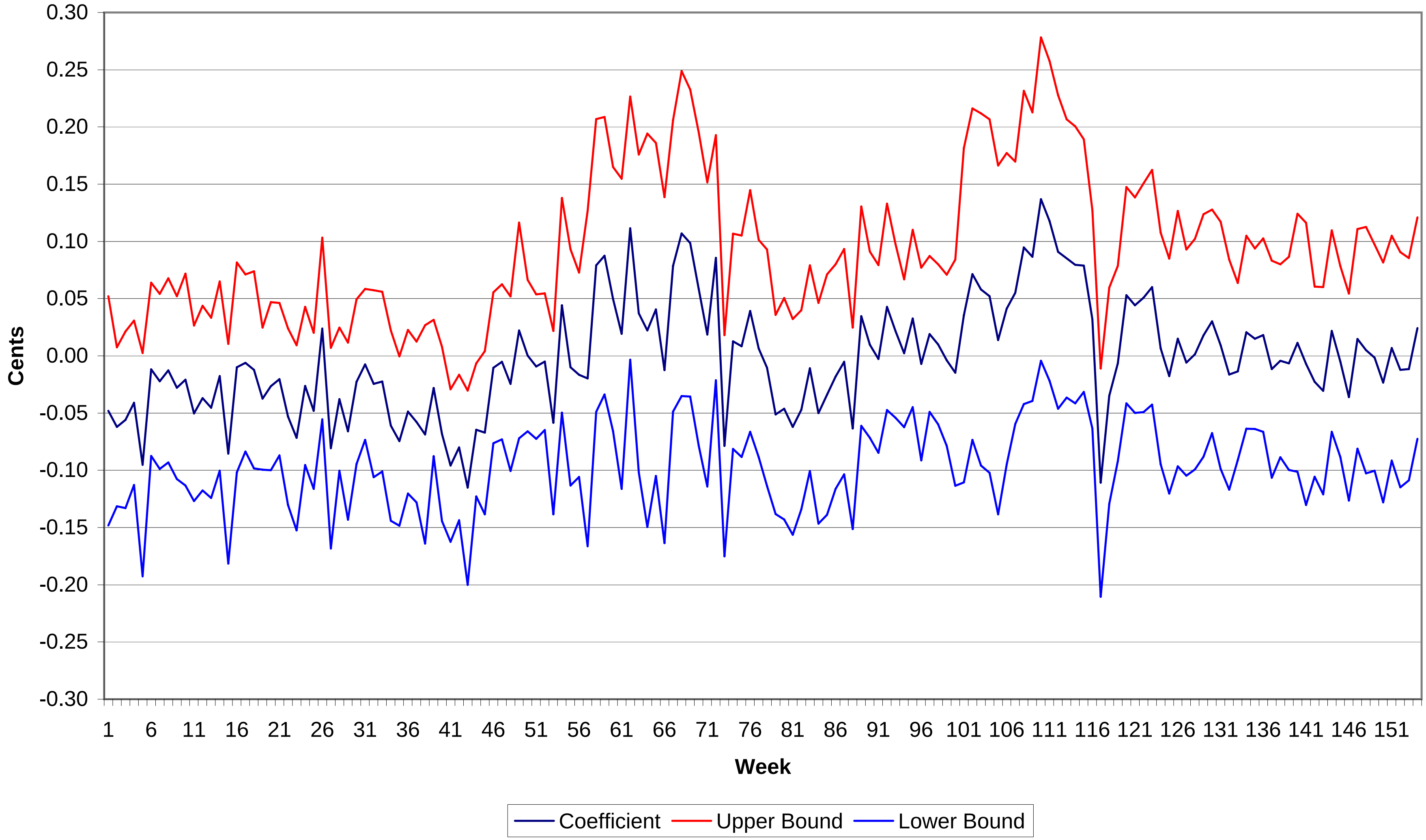
| | **Pooled** | se | **1997** | se | **1998** | se | **1999** | se |
|---|---|---|---|---|---|---|---|---|
| Number of Stations with 1.5 miles | -0.002 | 0.028 | -0.040 | 0.021 | 0.018 | 0.040 | 0.025 | 0.039 |
| Distance to Closet Station (miles) | 1.446 | 0.510 | 1.595 | 0.523 | 1.453 | 0.781 | 1.257 | 0.619 |
| If Convenience Store | -0.947 | 0.697 | -0.238 | 0.677 | -0.462 | 0.836 | -0.878 | 0.893 |
| If Service Bays | 0.575 | 0.385 | 0.367 | 0.287 | 0.821 | 0.516 | 0.882 | 0.526 |
| If Outdated format | 0.449 | 0.304 | 0.054 | 0.407 | 0.496 | 0.391 | 0.765 | 0.406 |
| Number of Pumps | -0.070 | 0.076 | -0.063 | 0.053 | -0.130 | 0.104 | -0.060 | 0.112 |
| If Self Serve | 0.447 | 0.365 | 0.187 | 0.473 | 1.233 | 0.529 | 0.343 | 0.518 |
| If Lessee Dealer | -0.119 | 0.375 | -0.002 | 0.347 | -0.442 | 0.496 | 0.151 | 0.485 |
| If Jobber Owned | -0.494 | 0.609 | -1.218 | 0.706 | -0.804 | 0.773 | 0.970 | 0.896 |
| log of population in zip code | -1.886 | 0.467 | -0.749 | 0.279 | -2.437 | 0.594 | -2.519 | 0.632 |
| Log of population density in zip code | 0.965 | 0.233 | -0.044 | 0.178 | 1.348 | 0.349 | 1.999 | 0.393 |
| Log of median income in zip code | 2.469 | 0.637 | 0.407 | 0.581 | 3.288 | 0.932 | 4.484 | 0.966 |
| Station indicators (Citgo Ommited Station) | | | | | | | | |
| BP | 4.112 | 1.600 | 3.062 | 1.087 | 4.443 | 3.426 | 7.846 | 2.089 |
| Chevron | -2.667 | 1.048 | -2.696 | 1.082 | -5.661 | 0.882 | -0.300 | 0.998 |
| Coastal | -11.608 | 0.824 | -12.158 | 0.842 | n/a | | n/a | |
| Crown | n/a | | n/a | | n/a | | n/a | |
| Getty | 0.903 | 1.236 | 0.447 | 2.150 | 0.818 | 0.785 | 1.940 | 0.987 |
| Hess | -3.217 | 0.778 | -1.813 | 1.185 | -4.665 | 0.842 | -2.631 | 0.964 |
| Kenyon | -0.278 | 0.711 | n/a | | -1.670 | 0.891 | n/a | |
| Merit | -1.538 | 1.340 | n/a | | -4.028 | 0.924 | -0.842 | 1.566 |
| Mobil | 0.643 | 0.552 | 1.766 | 0.693 | -0.381 | 0.723 | 0.673 | 0.835 |
| Sheetz | -6.380 | 1.080 | n/a | | -6.354 | 1.375 | -6.197 | 1.404 |
| Shell | 1.177 | 0.532 | 1.504 | 0.719 | 0.330 | 0.694 | 1.841 | 0.847 |
| Sunoco | -2.235 | 0.674 | -1.481 | 0.764 | -3.122 | 0.871 | -2.259 | 1.077 |
| Texaco | 2.214 | 0.483 | 2.616 | 0.705 | 1.358 | 0.659 | 2.768 | 0.755 |
| Xtra Fuels | -1.252 | 0.726 | -0.596 | 0.687 | 0.006 | 0.875 | n/a | |
| Constant | 34.459 | 8.421 | 54.260 | 7.990 | 26.804 | 12.455 | 8.945 | 13.437 |
| Number of Observations | 26,154 | | 9,453 | | 8,291 | | 8,410 | |
| R-squared | 0.630 | | 0.632 | | 0.634 | | 0.590 | |

Notes: Omitted Brand is Citgo, Clustered Standard Errors

# Table 5: Change In Relative Position of Gas Station Fixed Effects By Year

| Change In Relative Position of at least: | Between 1997 and 1998 | Between 1997 and 1999 | Between 1998 and 1999 |
|---|---|---|---|
| **10 Percentage Points** | 51.76% | 66.87% | 35.23% |
| **15 Percentage Points** | 37.06% | 51.53% | 20.73% |
| **20 Percentage Points** | 24.71% | 40.49% | 13.47% |
| **25 Percentage Points** | 16.47% | 26.99% | 9.84% |
| **50 Percentage Points** | 4.12% | 6.13% | 2.07% |
| **75 Percentage Points** | 0.59% | 0.61% | 0.52% |
| **Changes that are Statistically Significant (T>2)** | 32.94% | 44.79% | 27.46% |
| **(Conditional on being significant, in cents)** | 3.82 | 3.84 | 2.76 |
| **Number of Comparisions** | 170 | 163 | 193 |

**Figure 1: Estimated Coefficient on Number of Stations within 1.5 miles and 95% confidence Bound: Weekly Regression of Margin on Station Characteristics Non-Crown Stations**



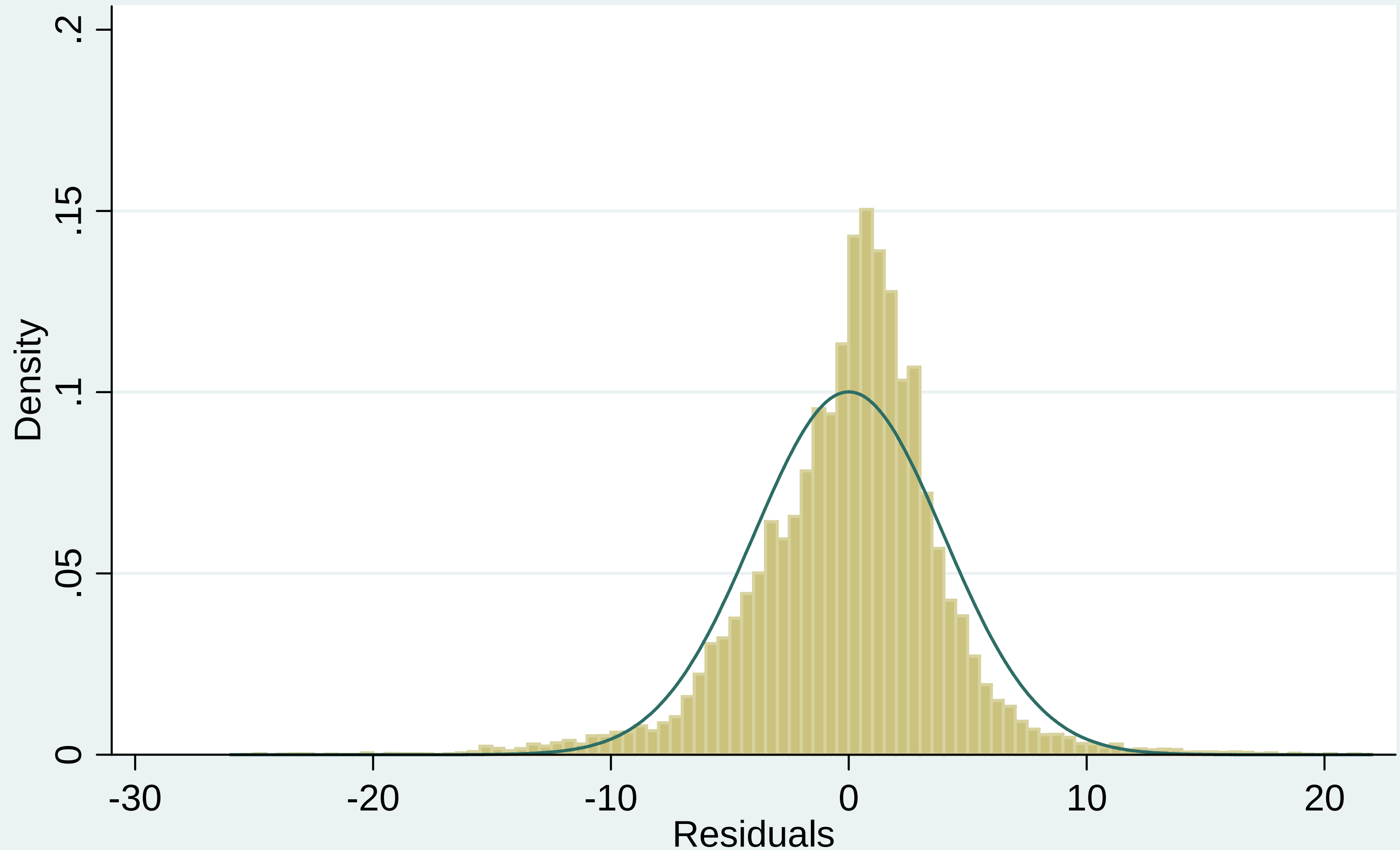



Figure 2: Frequency Distribution of Residuals
from Regression of Weekly Station Prices on Weekly Indicators
1997-1999

Figure 3: Weekly Retail Gasoline Margins and Branded Rack Prices
1997-1999

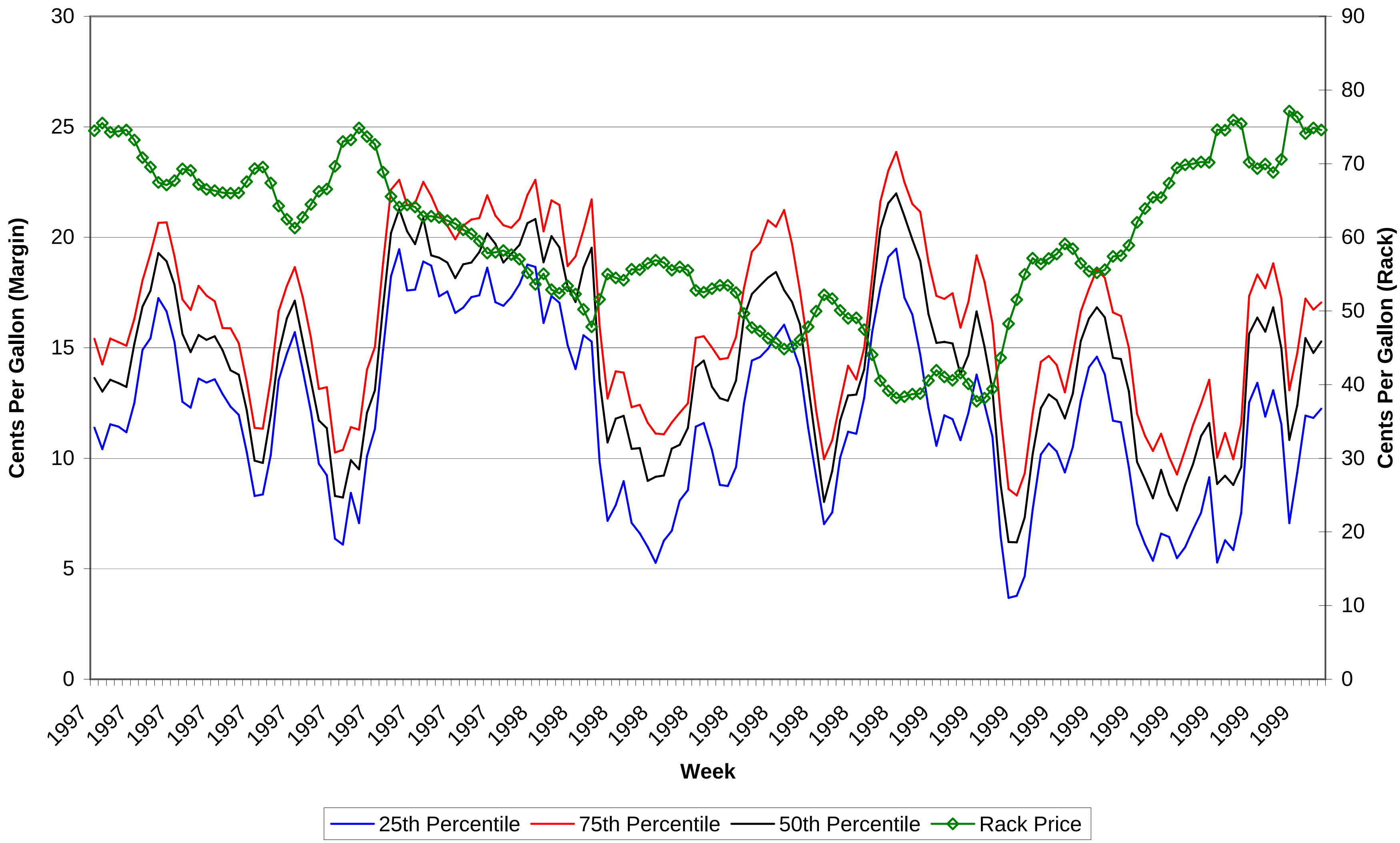


**Figure 4: Single-Period Empirical Markov Transition Matrix (Residuals from Regression of Price on Week Indicators)**

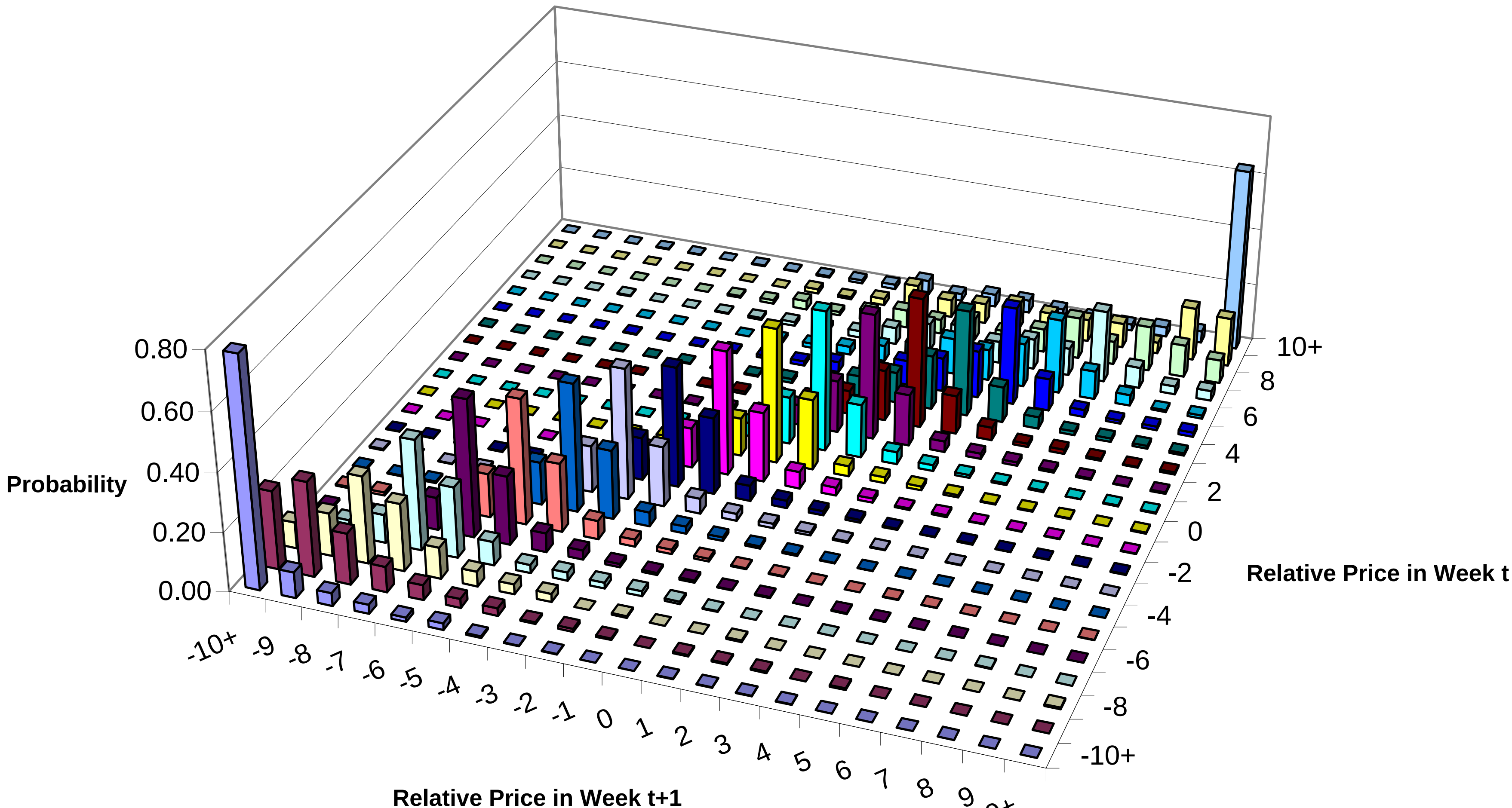


Figure 5: Frequency Distribution of Residuals
from Regression of Weekly Station Prices on Store and Weekly Indicators
1997-1999

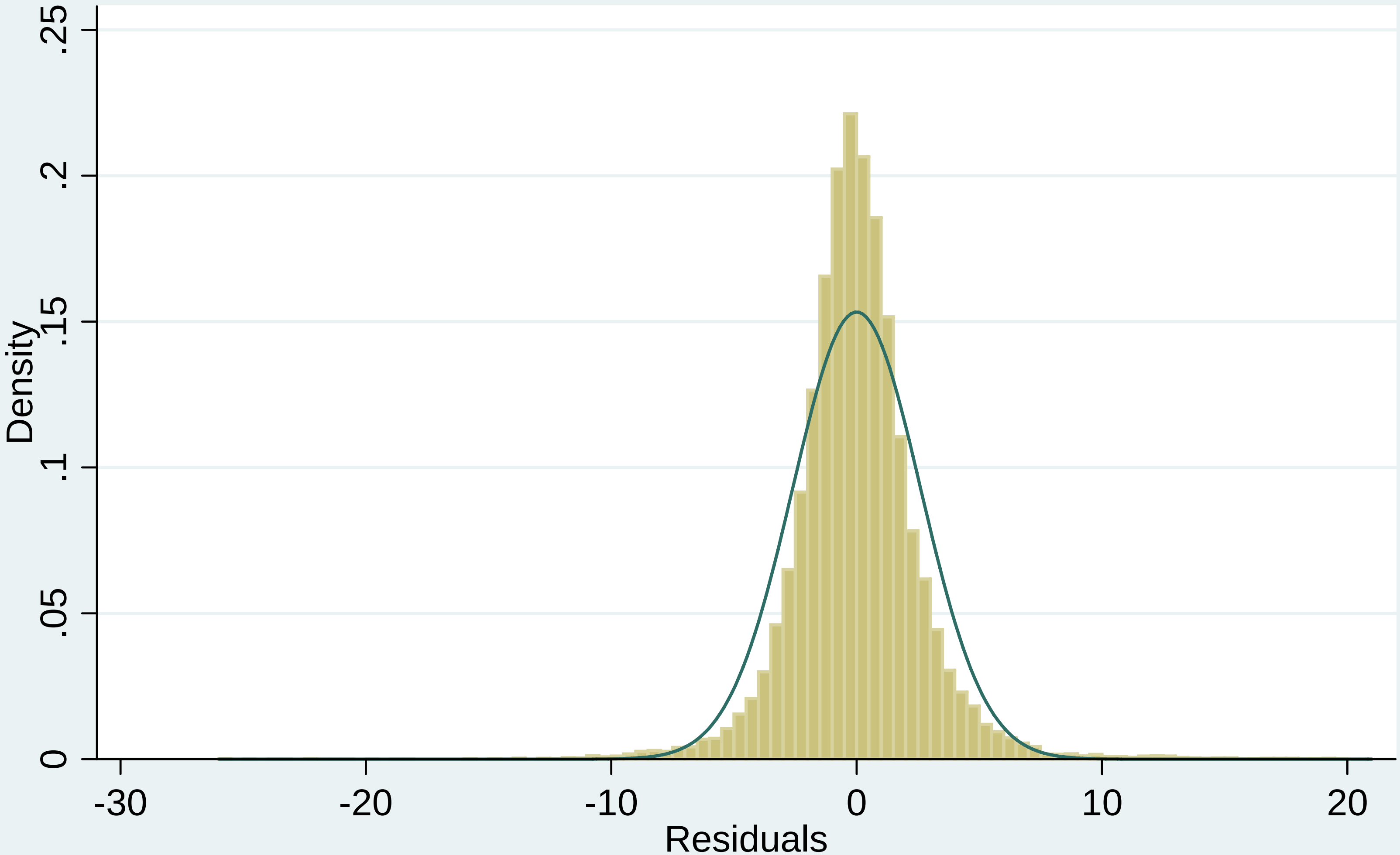
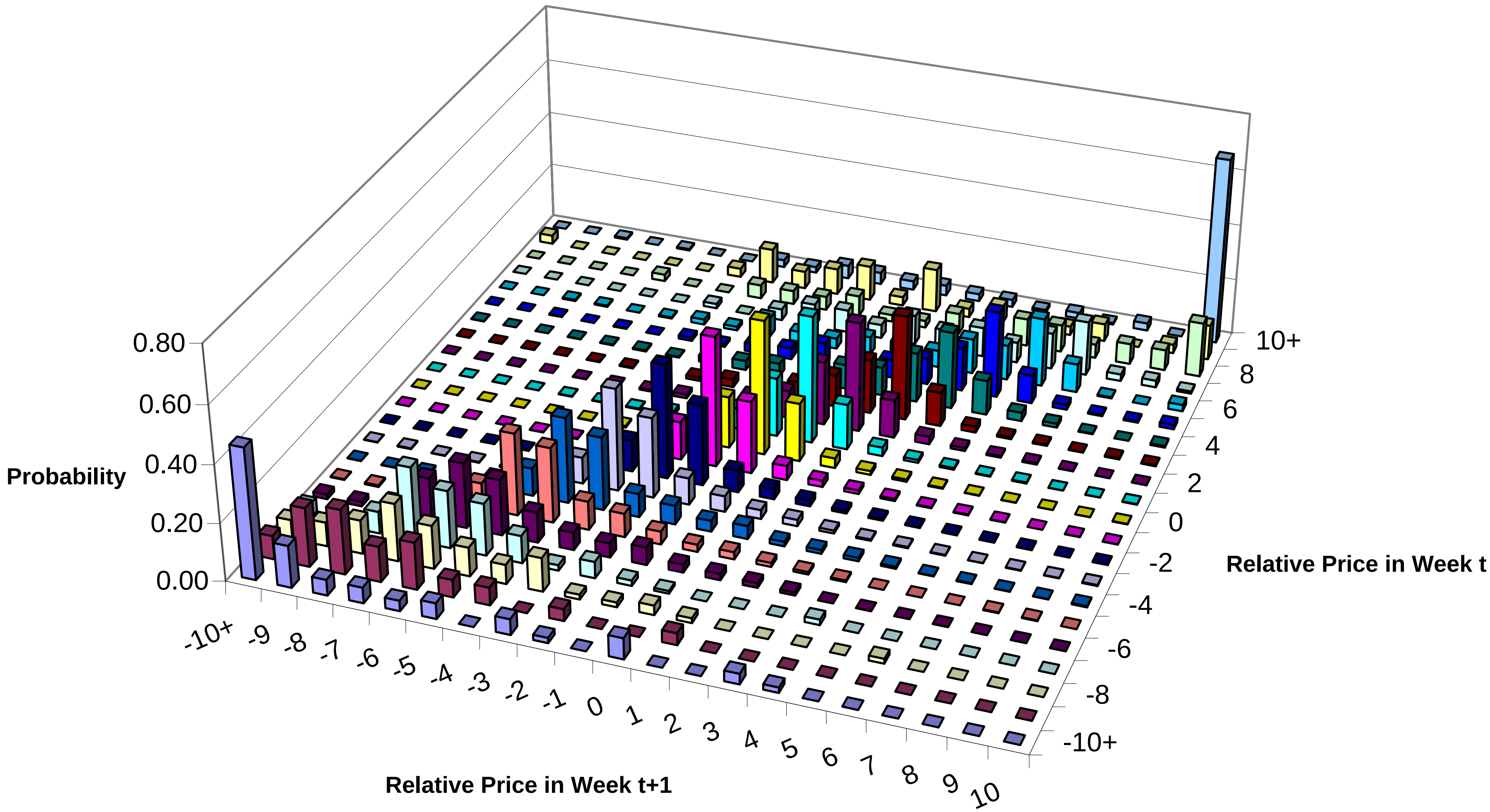


**Figure 6: Single-Period Empirical Markov Transition Matrix**
**(Residuals from Regression of Price on Store and Week Indicators)**



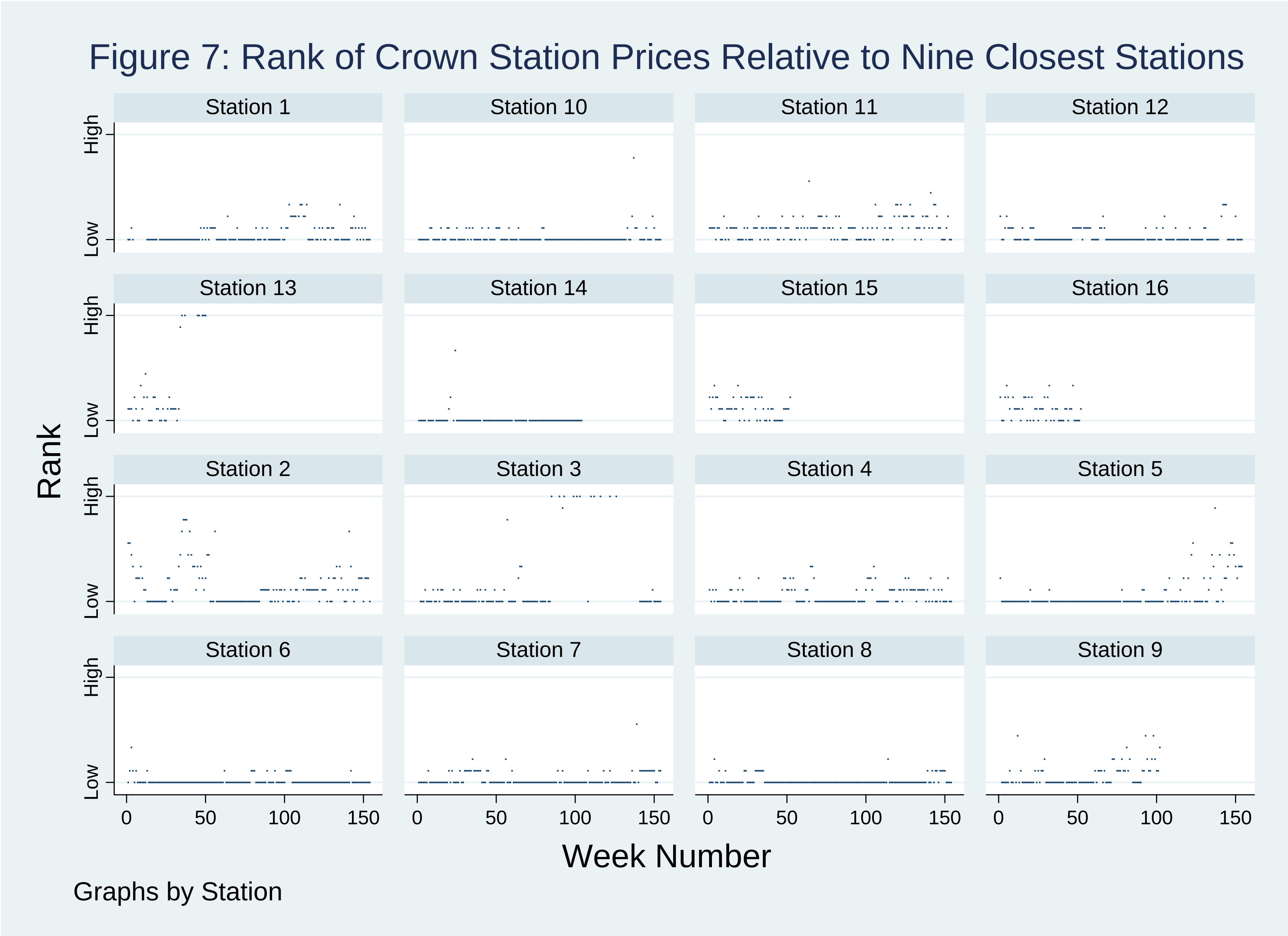


Figure 7: Rank of Crown Station Prices Relative to Nine Closest Stations
Station 1
Station 10
Station 11
Station 12
Station 13
Station 14
Station 15
Station 16
Station 2
Station 3
Station 4
Station 5
Station 6
Station 7
Station 8
Station 9
High
Low
Rank
0
50
100
150
Week Number
Graphs by Station

**Figure 8: Markov Probabilities for Ten Closest Stations:**
**Rank in Pricing Distribution at *t+1* conditional on Rank at *t***

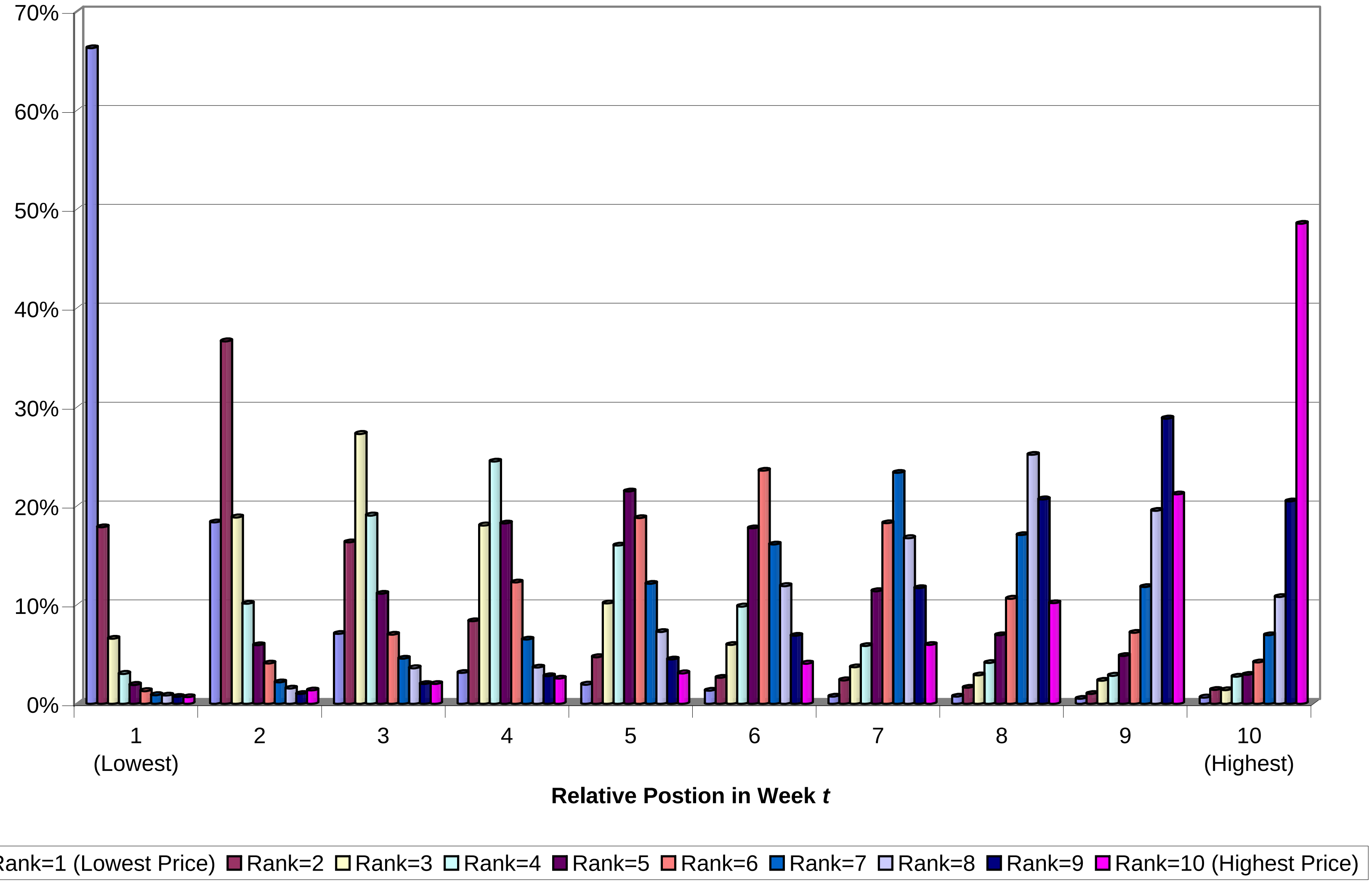
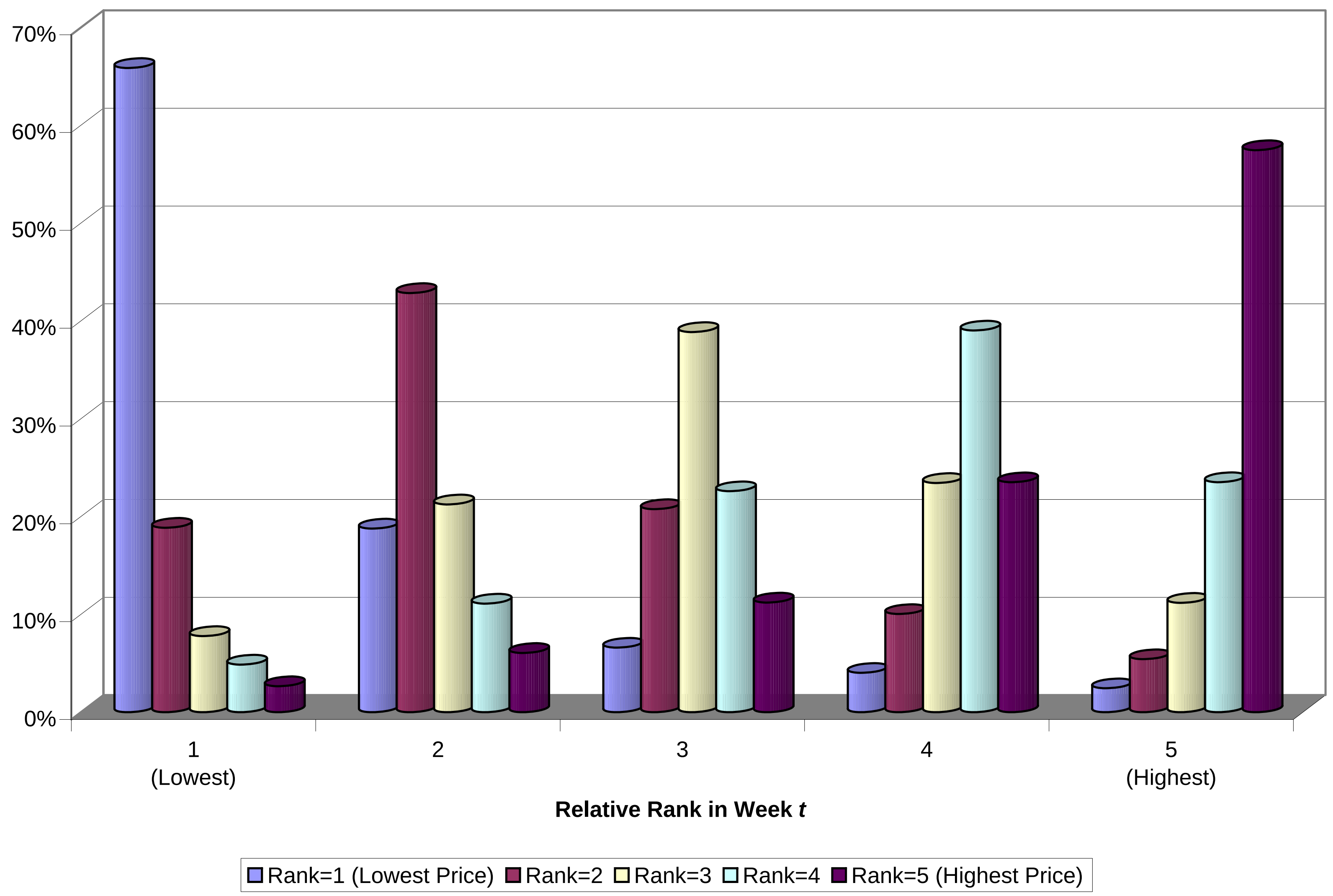


**Figure 9: Markov Probabilities for Five Closest Stations:**
**Rank in Pricing Distribution at *t+1* conditional on Rank at *t***



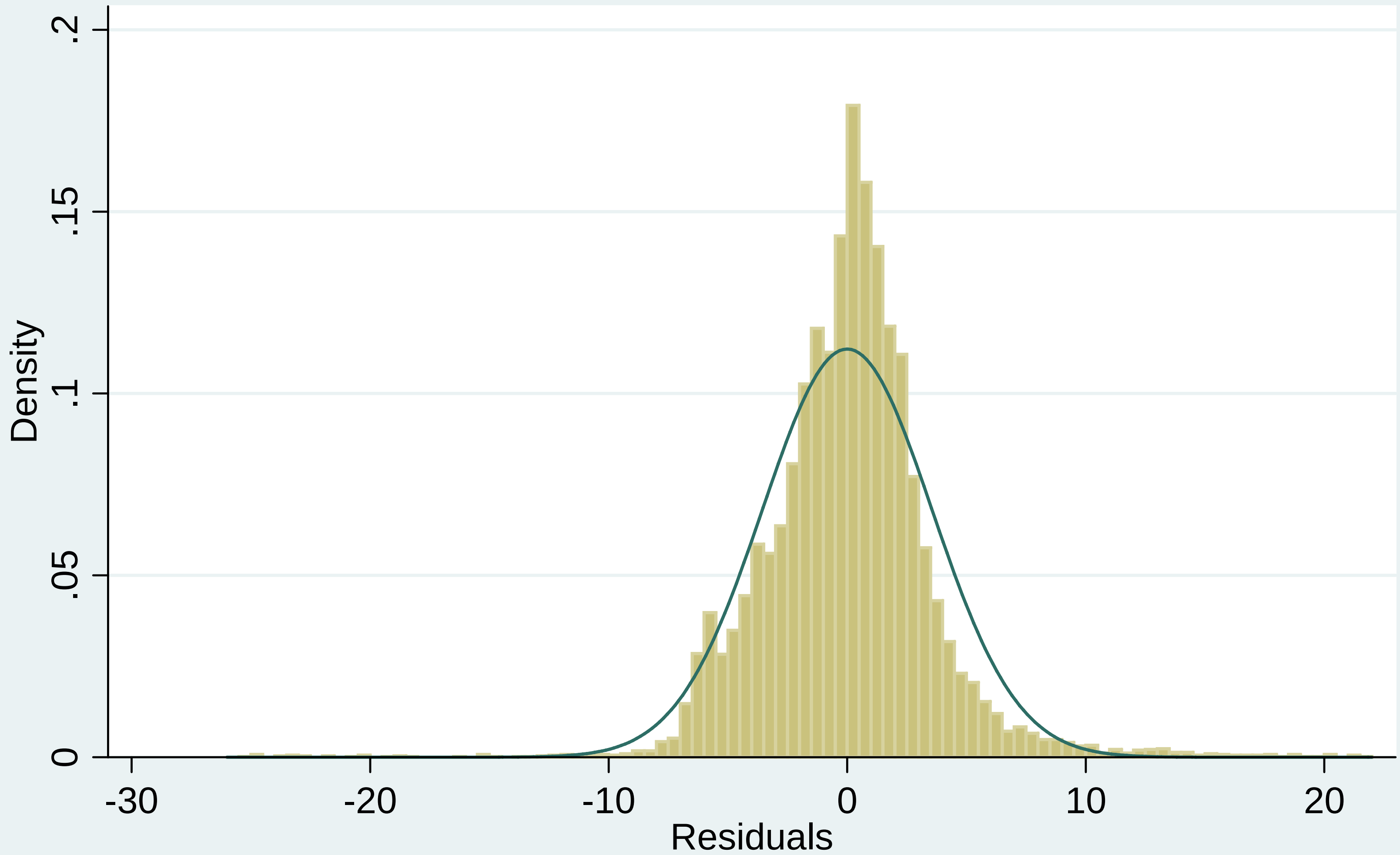
# Appendix Table 1: Single-Period Empirical Markov Transition Matrix
# (Residuals from Regression of Price on Week Indicators)

| | Relative Price at t+1 | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Relative Price at t | -10+ | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10+ |
| -10+ | **0.78** | 0.09 | 0.04 | 0.03 | 0.01 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| -9 | 0.27 | **0.32** | 0.17 | 0.09 | 0.05 | 0.03 | 0.03 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| -8 | 0.09 | 0.15 | **0.30** | 0.23 | 0.11 | 0.05 | 0.03 | 0.03 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| -7 | 0.04 | 0.05 | 0.10 | **0.38** | 0.24 | 0.08 | 0.03 | 0.03 | 0.02 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| -6 | 0.01 | 0.01 | 0.03 | 0.11 | **0.47** | 0.23 | 0.06 | 0.03 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| -5 | 0.01 | 0.01 | 0.01 | 0.03 | 0.15 | **0.43** | 0.24 | 0.06 | 0.02 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| -4 | 0.00 | 0.00 | 0.01 | 0.01 | 0.05 | 0.15 | **0.44** | 0.24 | 0.05 | 0.02 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| -3 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.04 | 0.16 | **0.45** | 0.21 | 0.05 | 0.02 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| -2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.04 | 0.15 | **0.41** | 0.26 | 0.05 | 0.03 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| -1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.04 | 0.14 | **0.43** | 0.24 | 0.06 | 0.03 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.04 | 0.13 | **0.47** | 0.24 | 0.04 | 0.02 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.05 | 0.16 | **0.49** | 0.19 | 0.04 | 0.02 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 |
| 2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.07 | 0.18 | **0.44** | 0.18 | 0.04 | 0.02 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 |
| 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.03 | 0.08 | 0.18 | **0.45** | 0.13 | 0.04 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 |
| 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.03 | 0.07 | 0.11 | 0.19 | **0.37** | 0.12 | 0.04 | 0.01 | 0.01 | 0.01 | 0.01 |
| 5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.02 | 0.04 | 0.04 | 0.09 | 0.12 | 0.17 | **0.34** | 0.11 | 0.02 | 0.01 | 0.01 | 0.02 |
| 6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.03 | 0.06 | 0.09 | 0.13 | 0.11 | 0.15 | **0.26** | 0.10 | 0.04 | 0.01 | 0.01 |
| 7 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.02 | 0.02 | 0.06 | 0.10 | 0.11 | 0.08 | 0.11 | 0.10 | **0.25** | 0.07 | 0.03 | 0.03 |
| 8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.03 | 0.01 | 0.04 | 0.06 | 0.05 | 0.08 | 0.05 | 0.08 | 0.14 | 0.08 | **0.16** | 0.11 | 0.08 |
| 9 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.01 | 0.02 | 0.09 | 0.06 | 0.07 | 0.09 | 0.08 | 0.08 | 0.09 | 0.04 | **0.19** | 0.17 |
| 10+ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.02 | 0.05 | 0.02 | 0.04 | 0.04 | 0.03 | 0.02 | 0.02 | 0.03 | 0.04 | **0.64** |

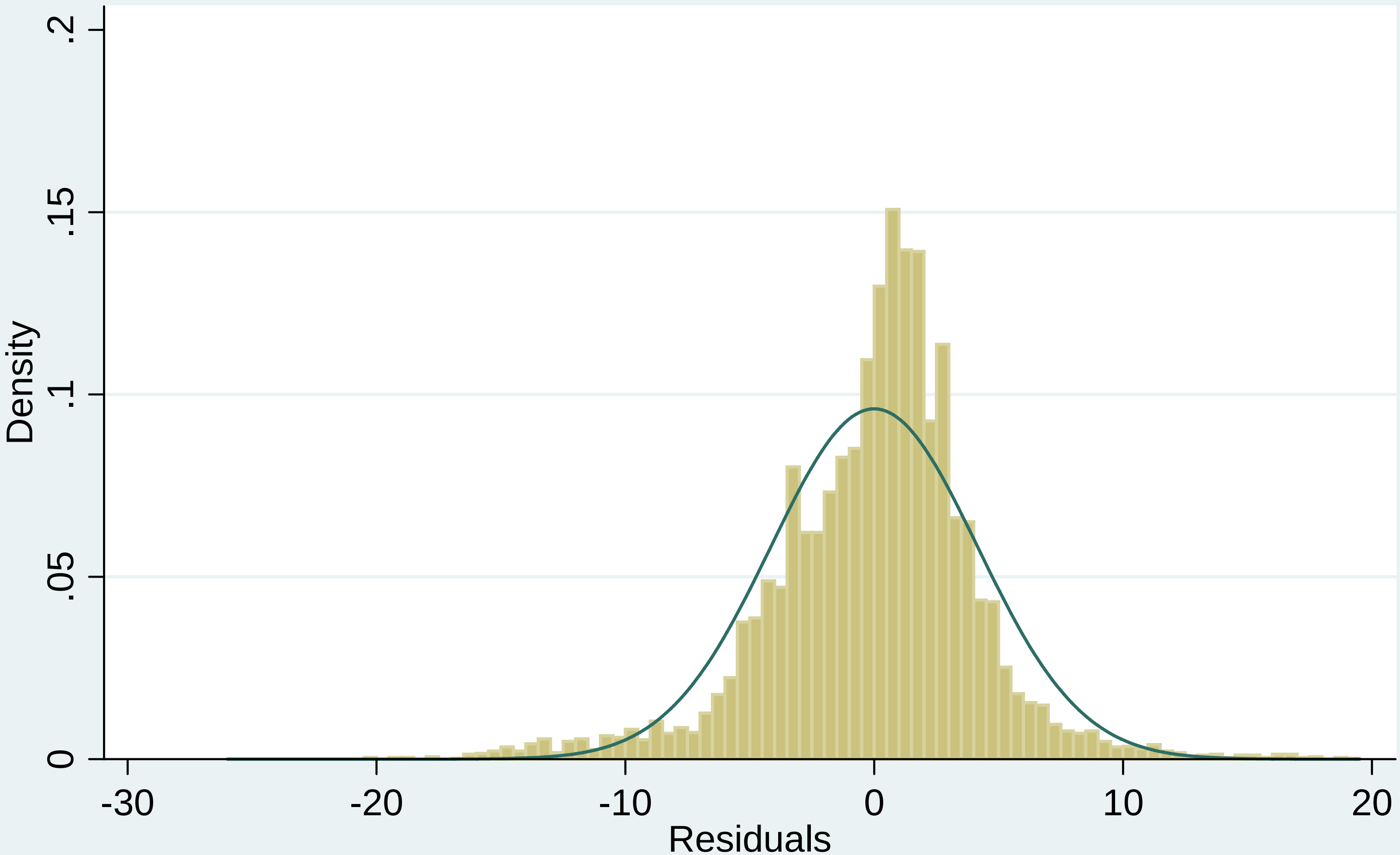
# Appendix Table 2: Single-Period Empirical Markov Transition Matrix
# (Residuals from Regression of Price on Store and Week Indicators)

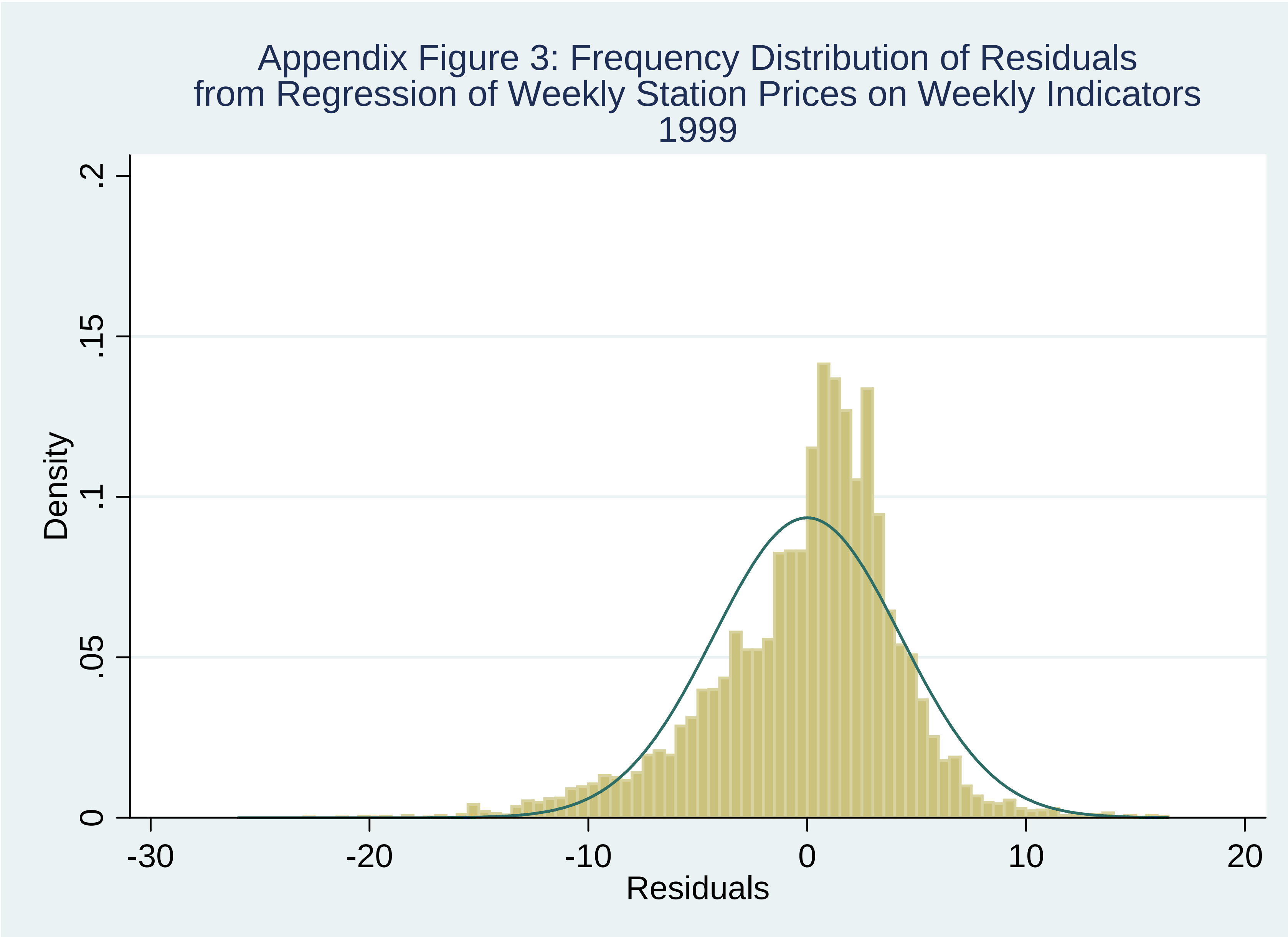
| | Relative Price at t+1 | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Relative Price at t | -10+ | -9 | -8 | -7 | -6 | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| -10+ | **0.45** | 0.15 | 0.05 | 0.05 | 0.04 | 0.05 | 0 | 0.05 | 0.02 | 0 | 0.07 | 0 | 0 | 0.04 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| -9 | 0.08 | **0.20** | 0.22 | 0.12 | 0.16 | 0.06 | 0.06 | 0 | 0.04 | 0 | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| -8 | 0.07 | 0.08 | **0.12** | 0.20 | 0.15 | 0.10 | 0.07 | 0.12 | 0.02 | 0.02 | 0.03 | 0.02 | 0 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| -7 | 0.05 | 0.02 | 0.08 | **0.26** | 0.20 | 0.18 | 0.10 | 0.02 | 0.06 | 0.02 | 0.01 | 0 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| -6 | 0.02 | 0.02 | 0.04 | 0.15 | **0.23** | 0.19 | 0.11 | 0.06 | 0.05 | 0.06 | 0.03 | 0.02 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| -5 | 0.00 | 0.01 | 0.01 | 0.03 | 0.09 | **0.29** | 0.26 | 0.10 | 0.08 | 0.05 | 0.03 | 0.03 | 0.01 | 0.01 | 0.01 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 |
| -4 | 0.00 | 0.00 | 0.01 | 0.01 | 0.04 | 0.10 | **0.30** | 0.26 | 0.08 | 0.07 | 0.04 | 0.05 | 0.02 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| -3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.09 | **0.36** | 0.28 | 0.09 | 0.06 | 0.03 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| -2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.11 | **0.40** | 0.28 | 0.08 | 0.04 | 0.02 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 |
| -1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.03 | 0.13 | **0.46** | 0.25 | 0.05 | 0.02 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.05 | 0.18 | **0.47** | 0.21 | 0.03 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.03 | 0.07 | 0.21 | **0.45** | 0.16 | 0.03 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | 0.00 | 0.00 | 0.001 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.03 | 0.06 | 0.10 | 0.22 | **0.39** | 0.13 | 0.03 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.03 | 0.04 | 0.06 | 0.11 | 0.19 | **0.37** | 0.12 | 0.02 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 |
| 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.03 | 0.05 | 0.07 | 0.09 | 0.10 | 0.18 | **0.27** | 0.12 | 0.03 | 0.01 | 0.00 | 0.00 | 0.01 |
| 5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.03 | 0.04 | 0.08 | 0.06 | 0.07 | 0.09 | 0.15 | **0.31** | 0.10 | 0.02 | 0.01 | 0.01 | 0.02 |
| 6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.01 | 0.07 | 0.04 | 0.04 | 0.06 | 0.06 | 0.06 | 0.12 | 0.12 | **0.24** | 0.10 | 0.00 | 0.00 | 0.02 |
| 7 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.04 | 0.08 | 0.08 | 0.05 | 0.10 | 0.07 | 0.10 | 0.07 | 0.13 | **0.19** | 0.02 | 0.02 | 0.01 |
| 8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.05 | 0.05 | 0.05 | 0.07 | 0.02 | 0.02 | 0.07 | 0.05 | 0.10 | 0.10 | 0.05 | **0.07** | 0.07 | 0.20 |
| 9 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.13 | 0.06 | 0.09 | 0.13 | 0.03 | 0.16 | 0.03 | 0.06 | 0.00 | 0.03 | 0.06 | 0.00 | 0.03 | **0.13** |
| 10+ | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.03 | 0.02 | 0.05 | 0.04 | 0.03 | 0.04 | 0.03 | 0.03 | 0.01 | 0.02 | 0.01 | 0.03 | 0.00 | 0.67 |

Appendix Figure 1: Frequency Distribution of Residuals
from Regression of Weekly Station Prices on Weekly Indicators
1997



Appendix Figure 2: Frequency Distribution of Residuals
from Regression of Weekly Station Prices on Weekly Indicators
1998




Appendix Figure 3: Frequency Distribution of Residuals
from Regression of Weekly Station Prices on Weekly Indicators
1999
Density
0
.05
.1
.15
.2
-30
-20
-10
0
10
20
Residuals