DOE/EIA-0626
February 1999

Price Changes in the Gasoline Market

Are Midwestern Gasoline Prices Downward Sticky?

Energy Information Administration
Washington, DC 20585

This report was prepared by the Energy Information Administration, the independent statistical and analytical agency within the Department of Energy. The information contained herein should not be construed as advocating or reflecting any policy position of the Department of Energy or of any other organization.

Contacts and Acknowledgments

This report was prepared by the Energy Information Administration (EIA) under the direction of Dr. John Cook, Director, Petroleum Division, Office of Oil and Gas, (202) 586-5986, jcook@eia.doe.gov, and Craig Cranston, Team Leader, Petroleum Analysis Team, (202) 586-6023, ccransto@eia.doe.gov. Questions about this report can be directed to:

Dr. Charles Dale (202) 586-1805, cdale@eia.doe.gov

John Zyren (202) 586-6405, jzyren@eia.doe.gov

Dr. Robert Manicke (202) 586-7611, rmanicke@eia.doe.gov

Michael Burdette (202) 586-6649, mburdett@eia.doe.gov

EIA would like to acknowledge the contributions of Jake Bournazian, Charles Riner, Nancy Masterson, Carolyn Mack and Cynthia McLaughlin of the Office of Oil and Gas in preparing this report. In addition, EIA would like to thank the following contract employees for their assistance: Jamie Chan, Professor Robert Trost and Joanne Shore.

Contents

Tables

Figures

Executive Summary

Price asymmetry is the phenomenon whereby prices tend to move differently depending on their direction. To the public, with regard to gasoline, this typically means that retail prices rise faster than they fall. This is sometimes referred to as "downward sticky" prices. Richard Blumenthal, the Connecticut attorney general, was quoted in the December 7, 1998 *Washington Post* as saying the Exxon-Mobil merger will face scrutiny from regulators because "Gas prices go up a lot faster than they go down."

EIA data confirm the notion that retail gasoline prices appear asymmetric, typically rising more quickly than they fall. However, there is significantly more to the question of price asymmetry than just the upward and downward speed of retail price movements. For the most part, retail prices move in response to changes in wholesale (or even raw material) prices further upstream in the manufacturing/distribution chain. Therefore, an examination of price asymmetry must consider the speed and degree to which price changes at one level are passed downstream, i.e. from wholesale toward retail. Two types of price asymmetry are discussed and tested in this paper. These are *amount asymmetry*, in which the magnitude of the eventual price change differs between different market levels such as wholesale and retail, and *pattern asymmetry*, in which the change occurs at a different rate between market levels depending on direction.

Previous studies of gasoline price asymmetry, by the General Accounting Office, the American Petroleum Institute, the Federal Reserve Bank of Dallas, and others have reached differing conclusions on the existence or nonexistence of price asymmetry in gasoline markets. This report discusses how those different conclusions are largely the result of different types of econometric modeling and different frequencies of data, e.g., weekly versus monthly prices.

The report concentrates on regional gasoline prices in the Midwest from October 1992 through June 1998, and reaches the following conclusions:

- Wholesale and retail gasoline price changes in the Midwest during this period are basically symmetric with respect to changes in crude oil prices.
- Retail gasoline prices in the Midwest often rise faster than they fall in response to wholesale gasoline price changes, so the report detected pattern asymmetry. However, after all lagged price adjustments have been completed, wholesale price changes will almost completely pass through to the retail level, so there is little evidence of amount asymmetry.
- The adjustment times between different levels of the gasoline market make it possible for the detection of pattern asymmetry to be only a statistical artifact. The report shows how, because of time lags in the gasoline distribution system, retail prices may continue to rise even after wholesale prices have begun falling, giving the appearance of pattern price asymmetry. However, when allowance is made for the lagged adjustment times, the perceived pattern asymmetry largely disappears.
- The conclusions of this report depend importantly on various characteristics of the data used, including frequency and location specificity. Thus, conclusions about price asymmetry at the city or state level would necessitate a collection of data and an examination of numerous local gasoline markets.

1. Introduction

This report examines a recurring question about gasoline markets: why, especially in times of high price volatility, do retail gasoline prices seem to rise quickly but fall back more slowly? Do gasoline prices actually rise faster than they fall, or does this just appear to be the case because people tend to pay more attention to prices when they're rising? This question is more complex than it might appear to be initially, and it has been addressed by numerous analysts in government, academia and industry. The question is very important, because perceived problems with retail gasoline pricing have been used in arguments for government regulation of prices.

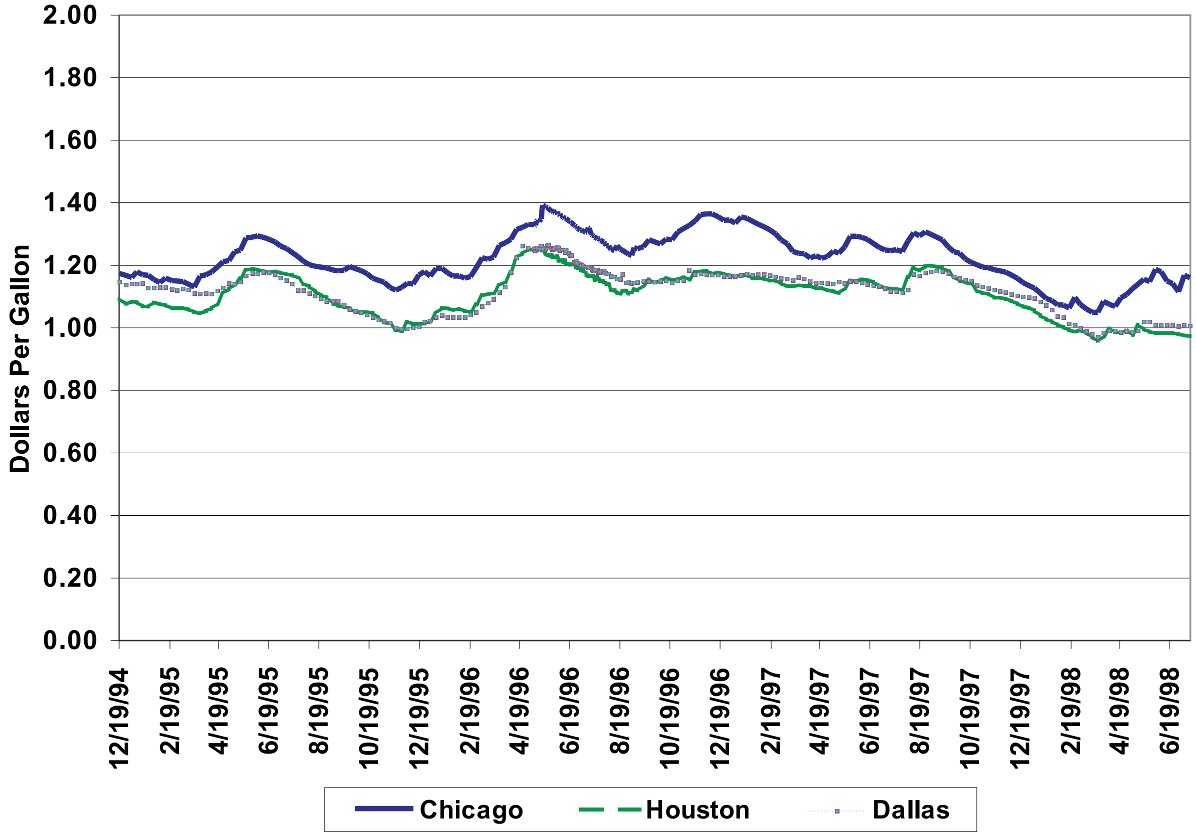
The phenomenon of prices at different market levels tending to move differently relative to each other depending on direction is known as *price asymmetry*. To the public, this typically means simply the notion that retail prices rise faster than they fall, when observed over some period. However, there is significantly more to the question of price asymmetry than just the upward and downward speed of retail price movements. For the most part, retail prices move in response to changes in wholesale (or even raw material) prices further upstream in the manufacturing/distribution chain. Therefore, an examination of price asymmetry must consider the speed and degree to which price changes at one level are passed downstream, i.e. from wholesale toward retail. In previous studies of this phenomenon, researchers have further defined two types of price asymmetry: *amount asymmetry*, in which the amount of the eventual price change differs between wholesale and retail and/or between upward and downward movements, and *pattern asymmetry*, in which the change occurs at a different rate between market levels depending on direction.

This report summarizes the previous work on gasoline price asymmetry and provides a method for testing for asymmetry in a wide variety of situations. The major finding of this paper is that there is some amount asymmetry and pattern asymmetry, especially at the retail level, in the Midwestern states that are the focus of the analysis. Nevertheless, both the amount asymmetry and pattern asymmetry are relatively small. In addition, much of the pattern asymmetry detected in this and previous studies could be a statistical artifact caused by the time lags between price changes at different points in the gasoline distribution system. In other words, retail gasoline prices do sometimes rise faster than they fall, but this is largely a lagged market response to an upward shock in the underlying wholesale gasoline or crude oil prices, followed by a return toward the previous baseline. After consistent time lags are factored out, most apparent asymmetry disappears.

Regional Price Differences. Analysis of retail gasoline pricing is complicated by large price differences in various parts of the country. Figure 1.1 shows retail gasoline prices in Chicago, Houston and Dallas. Not surprisingly, gasoline prices are cheaper in Texas, where stations are closer to both production and refining. Nevertheless, the market trends both upward and downward are fairly similar between the cities shown. It is not immediately apparent from the figure whether or not prices rise faster than they fall. Clearly, some type of statistical testing is necessary.

While Houston and Dallas have similar gasoline prices, it doesn't necessarily follow that intrastate gasoline prices will be similar in most states. This is most dramatically illustrated in California, as

Figure 1.1 Do Gasoline Prices Rise Faster Than They Fall? Regular Unleaded Pump Prices

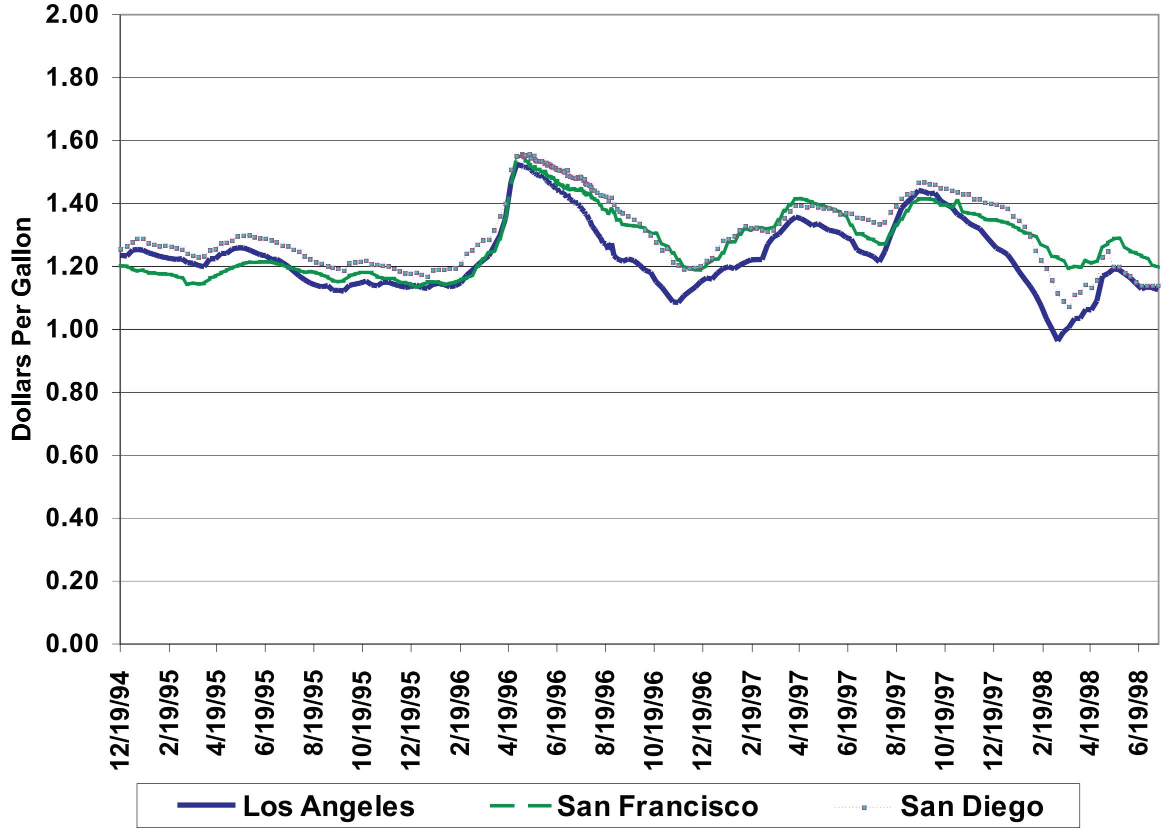


Source: Energy Information Administration, Form EIA-878, "Motor Gasoline Price Survey."

shown in Figure 1.2. Retail gasoline prices among Los Angeles, San Francisco and San Diego may be nearly identical, as they were in spring 1996, or they might vary by nearly 20 cents per gallon, as in early 1998. California is in a unique situation: with more stringent requirements than Federal Government-mandated clean gasolines, it has relatively few supply sources outside the state, and it is very vulnerable to refinery problems. These factors complicate analyses of the California gasoline market.

The Gasoline Market. To understand the approach used in this report, first consider the gasoline market structure shown in Figure 1.3, which shows the various market levels between spot crude oil prices and retail gasoline prices. There are two key concepts to keep in mind when analyzing a gasoline market: "asymmetry" and "passthrough." As noted above, "asymmetry" refers to prices rising and falling at differing rates at different levels in the pricing structure. However, the analysis is complicated by the fact that there are lags between changes in upstream prices and the corresponding changes in downstream prices. The upstream price changes take time to "pass through" to the downstream prices. The passthrough times make it theoretically possible for there to be no real asymmetry in price movements, but because of the time lags a statistical test may show that there is asymmetry.

**Figure 1.2 California Gasoline -- A World Apart
Regular Unleaded Pump Prices**



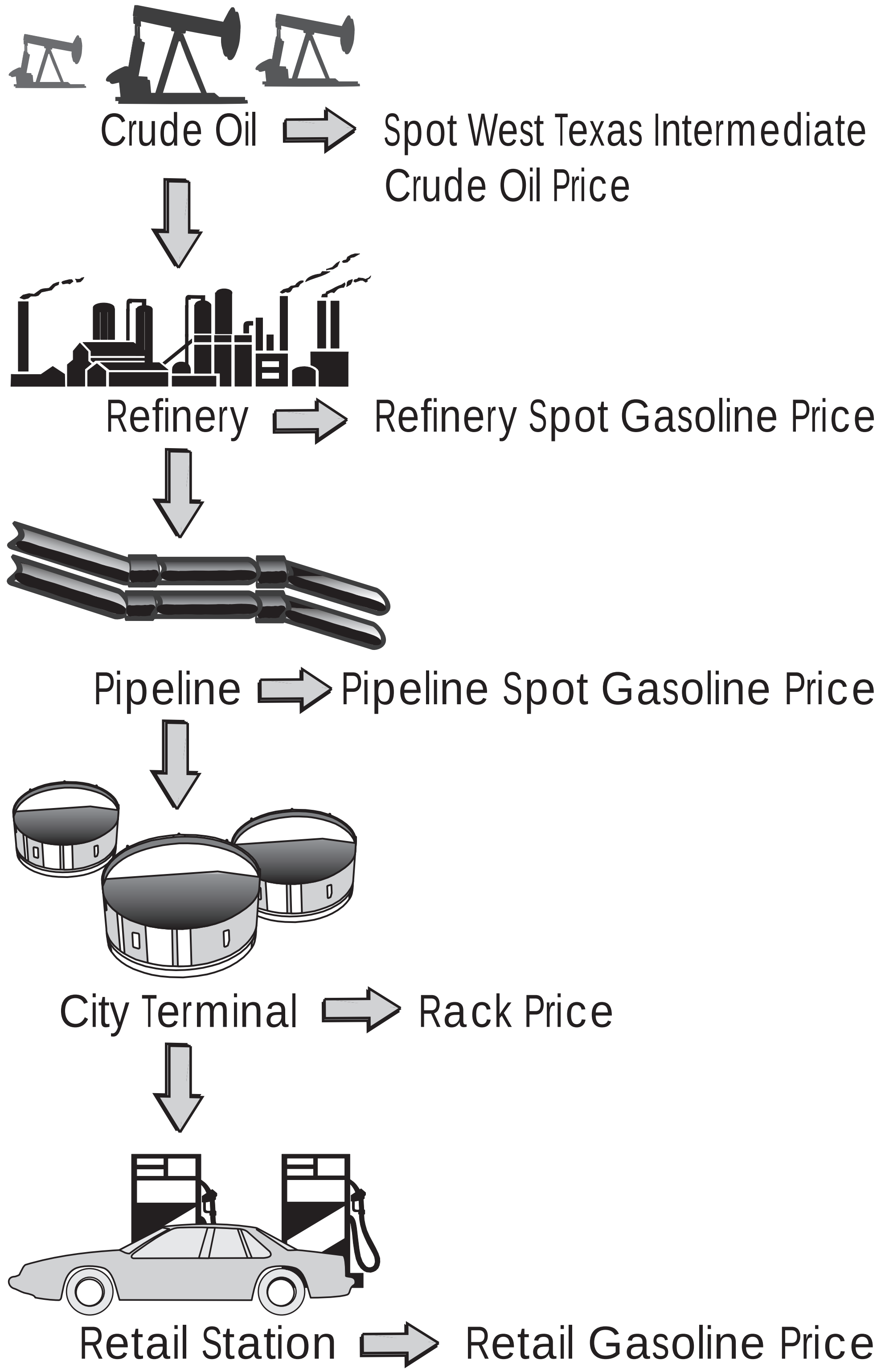
Source: Energy Information Administration, Form EIA-878, "Motor Gasoline Price Survey."

An example of apparent asymmetry due to passthrough lag times is shown in Appendix A. There it is shown that even a very simple price change, such as a symmetrical 5 cents per gallon upstream price increase and decrease spread over 10 weeks, can have unusual consequences because of lags (see Figure A.3). The downstream price peaks 2 weeks after the upstream price maximum, and it takes 4 weeks longer for the downstream price to return to equilibrium than the upstream price. Lags anywhere in the system can therefore give the appearance that prices are sticky downward, when in fact the apparent asymmetry is only an artifact of the lags.

Figure 1.3 shows that there are a number of points where price asymmetry may arise. Spot crude oil prices would be affected by the supply and demand of crude oil and all petroleum products, while refinery spot gasoline prices would be impacted by both crude oil prices and seasonal demands for gasoline. Gasoline typically moves through the system and may also trade at spot prices at a major pipeline delivery point. Further along the distribution system, the terminal, or "rack" price, is a wholesale price that represents about 52 percent of refiners' gasoline sales,[1] so those prices also are a prominent part of any analysis of price asymmetry.

1 Refinery sales data are from *Petroleum Marketing Monthly*, Energy Information Administration, DOE/EIA-0380(98/12) (Washington, DC, December 1998).

Figure 1.3 Simplified Gasoline Market Structure



Source: Adapted from John Zyren, “What Drives Gasoline Prices?,” *Petroleum Marketing Monthly*, Energy Information Administration, DOE/EIA-0380 (Washington, DC, June 1995), p. xiv.

There is also an additional level not shown on Figure 1.3, the dealer tank wagon (DTW) level, which would represent sales from refiners or marketers to retail stations. This represents about 20 percent of refiners' direct sales, and an additional quantity of resales by marketers. That level is omitted here because of problems with the availability and consistency of DTW prices. Finally, the retail price reflects all costs, taxes and profits through the system. Since retail prices are the ones most important to the consumer, they are the primary focus of this report.

Figure 1.3 can also be used to illustrate two terms used throughout this report: "upstream" and "downstream" prices. These terms are used to distinguish the *relative* position of two prices in the distribution system. Upstream prices are commodity prices closer to the production point (top of Figure 1.3) relative to downstream prices which are motor gasoline prices closer to the final consumption point (bottom of Figure 1.3). For example, retail motor gasoline prices are downstream relative to all other commodity prices because they constitute the price the final consumer (motorist) pays. Also, pipeline spot gasoline prices are downstream from U.S. Gulf Coast (USG) spot gasoline prices because they are closer to the consumer. Conversely, USG spot prices are upstream relative to pipeline spot prices because the USG spot prices are further removed from the final consumption of gasoline and are closer to the production side. Crude oil spot prices are upstream of all motor gasoline prices because they are farthest from the final consumer.

Given the simplified market structure shown in Figure 1.3, the decision must be made on where to concentrate the analysis. Since the Energy Information Administration (EIA) had already examined gasoline prices,[2] and detected unusually rapid price passthrough from upstream to downstream prices in the Midwest relative to the rest of the country, this study concentrated on the Midwest. The results, therefore, cannot necessarily be generalized to the rest of the country. In addition, this work was undertaken to determine whether all the numerous problems associated with analyzing price asymmetry could be appropriately modeled. Once the modeling concept has been shown to be workable for the Midwestern region, it could be applied on a case-by-case basis to other regions.

Chapter 2 reviews the numerous previous studies of gasoline price asymmetry and discusses their frequently contradictory results. Chapter 3 describes the EIA's approach to testing for asymmetry in Midwest gasoline prices. The EIA approach also resolves some of the reported earlier problems that produced unexplainable contradictory results. Technical details of the methods used are in the Appendices.

2 See *Assessment of Summer 1997 Motor Gasoline Price Increase*, Energy Information Administration, DOE/EIA-0621 (Washington, DC, May 1998).

2. Previous Studies of Gasoline Price Movements Produced Conflicting Results

The question of whether prices rise and fall at different speeds is not unique to gasoline, and is not by any means a recent concept. Economists have examined relative price movements for decades, and studies of gasoline prices stretch back over 30 years. For purposes of the current study, only those previous studies specifically examining price asymmetry were reviewed. The methods and results of eight such studies are presented here.

Robert W. Bacon. Concern about gasoline price movements is not confined to the United States. In Britain, a government commission reported on gasoline price movements 3 times over the 25-year period from 1965 to 1990. Robert Bacon[1] described their conclusions as comparing gasoline price rises to rockets and price drops to feathers, and he made an early attempt to measure any price asymmetries statistically.

The gasoline market in Britain is very different from the market in the United States. For example, in Europe the major spot market for gasoline, and therefore the best data source, is Rotterdam, where it is priced in U.S. dollars. So, in his analysis Bacon had to contend with dollar/British pound exchange rate changes. Nevertheless, much of his analysis is applicable to the U.S. market.

The data source and frequency are important considerations, since any price adjustments occurring faster than the data is sampled will be not be measured properly. Bacon had retail data available only biweekly, from June 1982 through January 1990. Given the available data, the next question is how to model price asymmetry.

A possible modeling approach is to divide the data series into two parts, one in which there are rising prices and the other in which there are falling prices. This is called a “partitioning” or “switching regimes” model. The rising and falling periods may then be compared econometrically. The difficulty with this approach is that there may be long lags between a cost change before the full effects are passed on through the distribution system. Thus, it is extremely difficult to determine the exact switching points between periods of rising and falling prices unless there is a good prior knowledge of the lag structure. However, determining the lag structure is one of the objectives of the modeling itself, so this technique is very difficult to use.

A second possible modeling approach is to assume that sellers at each step of the distribution chain shown in Figure 1.3 attempt to set their target prices at a particular level reflecting their current costs plus a markup. The difference between the prices they actually receive at a given time and their target prices will result in their adjusting their prices toward their target prices. The speed of price adjustment in the upward and downward direction can be measured, to determine if the price changes occur asymmetrically. This is called an “adjustment” model, and is the method Bacon used to test for price asymmetry.

1 Bacon, R.W., “Rockets and Feathers: The Asymmetric Speed of Adjustment of UK Retail Gasoline Prices to Cost Changes,” *Energy Economics* (July 1991), pp. 211-218.

Bacon concluded from his model that all price changes are eventually fully passed on to the consumer. However, there was a high degree of asymmetry in gasoline prices in Britain, since retail prices rise much faster than they fall in response to cost changes. However, like the government reports before him, he also concluded that the asymmetry was so short-lived that British gasoline markets could still be considered highly competitive.

Bacon's conclusions may be summarized as follows:

- Price asymmetry is difficult to define and model, but it is not an impossible task.
- The shorter the time period between data points, the stronger the conclusions that may be drawn from the analysis.
- Using a price adjustment model, he concluded that there was strong evidence for gasoline price asymmetry in Britain between 1982 and 1990. But, whenever asymmetrical price movements occurred they were short-term in duration, so he couldn't reject the proposition that British gasoline markets are highly competitive.

The rest of the studies summarized below all analyzed U.S. gasoline markets.

Jeffrey D. Karrenbrock. The U.S. gasoline market has several levels where price asymmetry can occur, a point discussed thoroughly by Karrenbrock.[2] He noted that consumers routinely blame quickly rising gasoline prices at the pump on oil companies, but only about 19 percent of refiners' gasoline sales go directly to company owned stations and other end users, with the other 81 percent getting sold either to independent dealers or to jobbers who resell it to gas stations. Thus, there are various ways for asymmetric price movements to arise.

Karrenbrock distinguishes between 3 different types of possible price asymmetries. First, there is "pattern asymmetry," which is the focus of this report and most other asymmetry studies. Pattern asymmetry simply means that an increase in price is passed through from an upstream price, such as a wholesale price to a retail price, faster than a decrease in price is passed through from a wholesale to a retail price. He also defined the term "amount asymmetry," to mean whether total retail price changes either upward or downward might not ever completely reflect wholesale price changes, regardless of the timing involved. Finally, he defined a "combination asymmetry" that would reflect both pattern and amount price differences.

Unlike Bacon, Karrenbrock used a partitioning model instead of an adjustment model, because he needed a partitioning model to test all his asymmetry hypotheses. He notes that price asymmetry had been found in studies of markets in fruits, vegetables, and meats, so he wouldn't be surprised to find it in gasoline markets.

He used monthly data from January 1983 through December 1990. Since he did his study in 1991, he was using up-to-date data. For his starting point, he noted that oil markets were decontrolled by September 1981, so he began using data from a little over a year later, to allow for the complete adoption of any new gasoline marketing procedures.

2 Karrenbrock, J. D., "The Behavior of Retail Gasoline Prices: Symmetric or Not?," *Federal Reserve Bank of St. Louis Review* (July/August 1991), pp. 19-29.

His partitioning model found that there was pattern asymmetry. Wholesale price increases are initially passed through to the retail level much faster than wholesale price decreases are passed through to the retail level. However, there was no "amount asymmetry" from wholesale prices to retail gasoline prices, because after about two months all wholesale price increases or decreases were completely reflected at the retail level. Thus, in spite of initial fast retail price rises, in the long run consumers are harmed very minimally by "pattern asymmetry."

Karrenbrock's report may be summarized as follows:

- He used a partitioning model to analyze monthly data from January 1983 through December 1990, and concluded that in response to wholesale price changes, retail gasoline prices rise faster than they fall.
- If wholesale gasoline prices rise 10 cents per gallon in one month, retail gasoline prices will rise 6.8 cents in the same month and 3.5 cents in the following month. If wholesale gasoline prices instead fall 10 cents per gallon in one month, retail gasoline prices will fall only 3.0 cents in the same month but will then fall 6.9 cents in the following month.
- In spite of the asymmetric price movements, the total length of time for complete retail price passthrough is about the same (2 months) whether wholesale prices are rising or falling, and complete price passthrough is achieved in both cases, so the ultimate effect of the asymmetry on retail consumers is small.

The American Petroleum Institute. In response to attempts to legislate price controls,[3] the American Petroleum Institute (API) analyzed gasoline markets in two separate studies. First, Norman and Shin[4] (hereafter NS) applied Bacon's adjustment model to gasoline prices at several places in the gasoline distribution system. They used monthly data from January 1982 through December 1990 to examine the relationship between crude oil prices, wholesale prices charged by refiners, and average retail gasoline prices. They also used weekly price series of West Texas Intermediate spot prices, New York wholesale gasoline prices, and average weekly retail prices for gasoline.

NS applied their adjustment model to both their API weekly and monthly data series and concluded that retail gasoline markets move symmetrically with respect to both crude oil prices and wholesale gasoline prices. This result was very different from the earlier findings of Bacon in the United Kingdom and Karrenbrock's concurrent study of U.S. markets.

The other American Petroleum Institute study was done by Shin.[5] He reviewed the previous literature and concluded that different price asymmetry conclusions might arise not only because of the different types of models being used, such as adjustment models versus partitioning models, but also because of the different data series being used in the studies.

3 For example, in 1990 the Senate considered a bill, which ultimately did not pass, called the "National Emergency Anti-Profiteering Act of 1990," which could have given the President the power to put price controls on gasoline.

4 Norman, D. A. and Shin, D., "Price Adjustment in Gasoline and Heating Oil Markets," American Petroleum Institute, Research Study #060 (Washington, DC, August 1991).

5 Shin, D., "Do Product Prices Respond Symmetrically to Changes in Crude Prices?," American Petroleum Institute Research Study #068 (Washington, DC, December 1992).

Shin applied the data series used in the previous studies to the different models used. When he combined Karrenbrock's data and the NS model, the NS model results changed from indicating price symmetry to indicating price asymmetry. But when he combined the NS data with Karrenbrock's model, the Karrenbrock model results changed from indicating price asymmetry to indicating price symmetry. This was a dramatic illustration of how choice of data series can affect the results.

Shin then tested an adjustment model, using monthly Energy Information Administration data from January of 1986 through May of 1992. The data series was available from 1982, but he wanted to avoid structural market changes from many small refineries going out of business in the early 1980's. For changes from crude oil prices to wholesale gasoline prices, he concluded that there was no statistical evidence of price asymmetry. However, if asymmetry did exist, the asymmetry was that wholesale prices fall *faster* than they rise in response to crude oil price changes, a result opposite to the conventional wisdom. For gasoline prices at the retail level, he concluded only that results of various asymmetry tests were mixed.

The results of the American Petroleum Institute reports are summarized here:

- Norman and Shin used an adjustment model and concluded that retail gasoline prices do not show any evidence of asymmetry, even at data intervals as short as one week. Theirs is one of the few studies that do not have ambiguous conclusions. They conclude that prices in retail gasoline markets move symmetrically. They attribute their differences from Bacon's results in the United Kingdom to the fact that the U.S. gasoline market is more highly competitive.
- Shin emphasized the importance of data in price asymmetry studies. He used Karrenbrock's and Norman and Shin's data series in each other's models, and reversed the results of both studies. Thus, Norman and Shin's unambiguous results discussed above suddenly became less certain. Shin also estimated another adjustment model using Energy Information Administration data. He concluded that wholesale prices actually *fall* faster than they rise, but that the tests for gasoline price asymmetry at the retail level are still inconclusive.

The U.S. General Accounting Office. In March 1993, in response to numerous requests from the Congress, the U.S. General Accounting Office (hereafter GAO) issued a report on gasoline pricing.[6] The GAO was especially interested in gasoline price adjustments during a period of shocks, since most of the Congressional interest was the result of the Persian Gulf War in 1990 and 1991.

The GAO began by interviewing experts in the petroleum industry. The experts noted that the existence of viable futures markets in crude oil and gasoline on the New York Mercantile Exchange made it possible for rapid price changes in crude oil prices to be reflected very quickly in spot gasoline prices. The immediacy of futures price changes gave sophisticated buyers information that can be quickly used when buying and selling wholesale gasoline. Retail prices were another matter. All but a few of the industry experts concluded that there are probably some asymmetric price movements between wholesale and retail gasoline price movements.

6 U.S. General Accounting Office, "Energy Security and Policy: Analysis of the Pricing of Crude Oil and Petroleum Products," Report GAO/RCED-93-17, U.S. Government Printing Office (Washington, DC, March 1993).

The GAO then reviewed the gasoline price asymmetry literature. Most of the work they reviewed is summarized above. Since that work gave conflicting results on the existence of gasoline price asymmetry, they decided to construct their own model.

The GAO built a partitioning model, expressly to analyze periods of market price shocks. They defined a market shock as a rise in the price of crude oil of 8.25 percent in 1 week, a value obtained from a statistical analysis of their data series, which was weekly data from January 1984 to March 1991. Unlike prior studies, they also constructed their model to incorporate crude oil stocks, gasoline stocks, and refinery utilization rates, all of which could be especially important in a period following a market shock. Theoretically, including these additional important variables in their model should make their asymmetry estimates more reliable.

The GAO model found price asymmetry during market shocks, but only in the price of wholesale gasoline in response to a change in the crude oil price. They concluded that crude oil price increases would be reflected in wholesale gasoline prices within 1 week, the smallest interval that the frequency of their data would permit. However, they found that there was no price asymmetry at the level from wholesale to retail gasoline prices, and that at the retail level the price adjustment could last as long as 17 weeks. Their results, concluding that retail gasoline prices move up and down symmetrically in response to wholesale price movements, contradicted all prior studies except the Norman and Shin study.

The results of the GAO study may therefore be summarized:

- The GAO used a partitioning model to analyze market shocks. Analyzing weekly data from January 1984 to March 1991, they concluded that wholesale gasoline prices rise faster than they fall with respect to crude oil prices. For every 10 cent per gallon rise in the spot price of crude oil during a shock, within 1 week wholesale gasoline prices would rise by 10.2 cents. However, for every 10 cents per gallon fall in the price of crude oil during a shock, within 1 week wholesale gasoline prices would fall by only 8 cents per gallon.
- The GAO concluded that during a market price shock, retail gas prices would rise and fall in price symmetrically, with over half the price adjustment occurring in the first month, but with complete price adjustment to shocks taking as long as 17 weeks. This result contradicted the opinions of most of the industry experts they had interviewed, and also contradicted all previous research except the report by Norman and Shin.
- Like Shin before them, the GAO concluded that their results might have differed from most previous research because of differences in data, differences in emphasis because they were primarily interested in market shocks, and some differences in the way they constructed their econometric model.

Kevin T. Duffy-Deno. The studies discussed above concentrated on gasoline prices at the national level. Kevin Duffy-Deno attempted to sort out those studies' mixed results by concentrating on gasoline prices in Salt Lake City.[7] He recognized that local market conditions could make the use of national averages inappropriate for his analysis. For example, there are 12 suppliers of wholesale gasoline to the Salt Lake City market, and 5 of them have refineries in the Salt Lake City area. This availability of gasoline could have a significantly different impact on gasoline pricing compared to

7 Duffy-Deno, K. T., "Retail Price Asymmetries in Local Gasoline Markets," *Energy Economics* 18 (1996), pp. 81-92.

an area with a more limited number of suppliers, which could also be reflected in different types of contractual relationships between the different levels of the gasoline distribution chain.

Duffy-Deno built a partitioning model similar to Karrenbrock's and analyzed the linkage between weekly wholesale and retail prices in the Salt Lake City area from 1989 through 1993. His price series included the market shocks from both the *Exxon Valdez* oil spill in 1989 and the Persian Gulf War in 1990 and 1991. Average regular unleaded retail gasoline prices in Salt Lake City varied between 95 cents per gallon and $1.29 per gallon in that time period. He did not also use crude oil prices in his analysis because of the absence of an appropriate local area data series.

Interestingly, like the GAO before him, he concluded that there was not gasoline price asymmetry at the retail level during market shocks. But, like most other studies he concluded that there was retail price asymmetry during normal times. But in Duffy-Deno's analysis, the complete effect of a price rise took *longer* than the complete effect of a price drop.

Duffy-Deno's study may be summarized as follows:

- It is necessary to examine price asymmetry questions in individual markets, because national data cannot reflect important regional differences in the gasoline market. For example, there is a much better match between wholesale and retail prices at the local level than at the national level.
- He built a partitioning model similar to Karrenbrock's to examine weekly price data from 1989 through 1993. Like the GAO report before him, he found no evidence of retail gasoline price asymmetry during market shocks. When there was a market shock, complete price adjustment for both rising and falling prices occurred within 3 weeks of the shock.
- Like most other studies, he found retail gasoline price asymmetry during normal times. But, his results showed the complete effect of a price rise took *longer* than the effect of a price drop. On average, a 10 cents per gallon rise in the wholesale price of gasoline would take 4 weeks to be reflected as a maximum of 8 cents per gallon increase in the retail gasoline price. On the other hand, a 10 cents per gallon drop in the wholesale price of gasoline would only take two weeks to be reflected as a maximum of 4.6 cents per gallon fall in the retail price. Net retail gasoline price rises in Salt Lake City took longer than price drops, but they went farther.

Severin Borenstein, A. Colin Cameron and Richard Gilbert. Explanation of asymmetric gasoline price movements requires a careful analysis at many possible market levels. A detailed analysis of numerous levels of gasoline prices was first undertaken by Borenstein, Cameron and Gilbert.[8] They constructed a special type of partial adjustment model called an error-correction model to examine weekly or biweekly gasoline prices at the national level from March 1986 through the end of 1992.

They used their model to examine numerous relationships in the gasoline marketing chain. They searched for asymmetric price movements between the usual crude oil to spot gasoline prices, and also between crude oil to retail prices, but also spot gasoline to terminal prices, crude oil to terminal prices, and terminal to retail prices. This enabled them to determine more closely where price asymmetries may arise.

8 Borenstein, S., Cameron, A. C. and Gilbert, R., "Do Gasoline Prices Respond Asymmetrically to Crude Oil Price Changes?," *Quarterly Journal of Economics* (February 1997), pp. 305-339.

They found price asymmetry at the level of crude oil prices to spot gasoline prices, and from wholesale gasoline price changes to retail price changes. They attributed some of the asymmetry to the costs of inventory adjustments. Relative shortages of gasoline can be handled by higher prices, but oversupplies of gasoline must be gradually worked off through the physical distribution system.

Their results may be summarized as follows:

- An error-correction model was applied to weekly or biweekly data from March 1986 to the end of 1992. The results supported the common belief that retail gasoline prices respond more quickly to increases in crude oil prices than to decreases.
- Pattern asymmetries occur at the crude oil to spot gasoline level, and at the terminal to retail level. Several hypotheses have been advanced to explain these asymmetries, but none are completely satisfactory. Gasoline prices may be controlled by a few sellers. Or, there may be production and inventory lags that affect pricing. Finally, in a time of volatile prices, consumers may assume higher retail prices they observe at a particular retail station are being reflected everywhere, so they will not bother to do comparison shopping, making it easier for retail stations to maintain higher prices.

Nathan S. Balke, Stephen P. A. Brown and Mine K. Yucel. Recently, Balke, Brown and Yucel (hereafter BCY) revisited the gasoline price asymmetry question.[9] They used a modified version of Borenstein, Cameron and Gilbert's (hereafter BCG) error-correction model.

To search for asymmetry, they could have also used Bacon's adjustment model. But, that type of model contains an implicit behavioral assumption, that retail gasoline prices adjust partially in each time period toward a target price. That assumption is not critical to use such models to try to detect price asymmetry. Partitioning models, on the other hand, are primarily statistical models that attempt to estimate the effect on retail prices of current and lagged wholesale prices or crude oil prices, without assuming any underlying theory. Since BCY were not interested in explaining asymmetry, but just determining whether or not it exists, they used a partitioning model.

BCY used weekly data from January 1987 through August 1996. They modified the BCG model to permit them to search for price asymmetry considering two forms of models, one with price *levels* and the other with price *changes*, the latter they called an "error-correction" model. If there is no asymmetry, the two types of model are identical. They could not distinguish between the levels model and the changes model on any theoretical basis.

Unfortunately, their two model types produced opposite results. The levels model showed very little evidence of price asymmetry, while the error-correction model showed asymmetry is pervasive. They cannot explain these anomalous results, other than to note that asymmetry tests can be very model dependent.

The conclusions of this study may be summarized:

9 Balke, Norman S., Brown, Stephen P. A. and Yucel, M. K., "Crude Oil and Gasoline Prices: An Asymmetric Relationship?," *Federal Reserve Bank of Dallas Economic Review* (First Quarter 1998), pp. 2-11.

- The authors use weekly price data from January 1987 through 1996. They developed a type of partitioning model for price changes called an "error correction model," and they also used a model for price levels, and tested both models for evidence of asymmetry.
- Their model in price levels indicates that any price asymmetry very rarely occurs, and is small. However, their model in price changes shows that price asymmetry occurs frequently and is large. They cannot explain the differences in their results, nor can they provide any economic interpretation for the differences between their models either theoretically or empirically, nor can they provide any explanation for why price asymmetry occurs, whether or not it is ever really present.

Thus, nearly a decade after Bacon did his pathbreaking quantitative work on gasoline price asymmetry in the United Kingdom, American economists have refined and expanded price asymmetry research. The American economists have advanced from Bacon's rather fuzzy conclusions to produce instead completely contradictory results. The question of whether or not price asymmetry occurs in gasoline markets is clearly not a closed issue, and is the reason the Energy Information Administration did its own study of gasoline prices, as described in the next chapter.

3. The Energy Information Administration's Study of Gasoline Price Changes

In constructing any analysis of price asymmetry, the first consideration is which retail prices should be studied. As discussed in Chapter 2 in the review of Duffy-Deno's paper, the local infrastructure and supply and demand conditions are important. However, a study of multiple cities and/or several regions is beyond the scope of this report, which is to try to resolve some of the contradictions in the existing literature as well as to develop a method for price analysis that may confidently be applied in the future to individual questions when needed. As a result, this report only analyzes average retail prices in the Midwest.[1] The market from crude oil spot prices at Cushing, Oklahoma, through Gulf Coast refineries and pipelines to the Chicago terminals and from there throughout the Midwest, provides a consistent series of prices for analysis.[2]

Understanding retail gasoline price movements requires an understanding of its cost components. As Figure 3.1 shows, retail gasoline prices can be divided into 3 main components: crude oil prices, manufacturing and marketing costs and profits, and taxes. Of these components, crude oil prices are the most important and most volatile and hold the key for the analysis in this report. Taxes certainly may change, but usually in discrete jumps that are spaced far apart compared to the weekly price data that are being analyzed here. Similarly, while manufacturing and marketing costs are certainly not fixed, they change relatively slowly. Crude oil prices, on the other hand, can be extremely volatile[3] even on a daily basis. Thus, for the purpose of analyzing short-term retail gasoline price movements, it is important to track the prices of crude oil and of gasoline as it moves through the market structure that was shown in Figure 1.3.

The Energy Information Administration collects much of the data needed for analysis of gasoline price movements. A first step toward formally searching for price asymmetry in gasoline prices is simply to look at the data series. Figures 3.2 through 3.6 show prices at various points in the gasoline distribution chain.

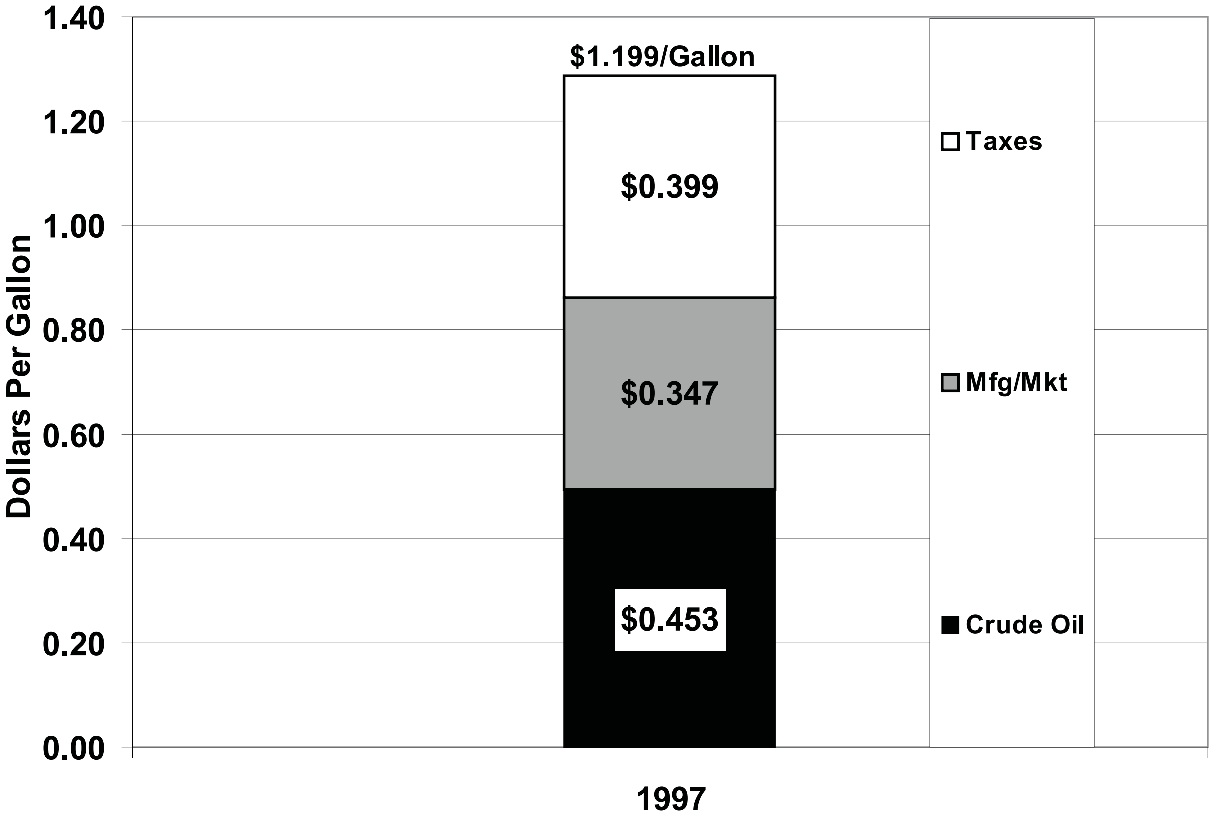
Figure 3.2 shows the price of spot West Texas Intermediate (WTI) crude oil, a popular benchmark price, at Cushing, Oklahoma, compared to EIA's average gasoline pump price, including taxes, in the Midwest. (WTI was chosen because it is widely traded, is an important crude to refineries in the region, and is used to index the price of many other crude streams.) The similarity of these two price series is striking, and there is no clear pattern of prices rising faster than they fall on the chart. Two conclusions are therefore immediately apparent from Figure 3.2. First, crude oil prices are critical to any analysis of retail gasoline prices. Second, if asymmetry is present, it will require a sensitive statistical technique to find it.

1 The term "Midwest" here equates to Petroleum Administration for Defense (PAD) District 2, which includes the states of Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, Oklahoma, South Dakota, Tennessee and Wisconsin.

2 In addition, a previous EIA report detected an unusually rapid price passthrough in Midwest gasoline prices relative to other areas of the country, which invited further study. See *Assessment of Summer 1997 Motor Gasoline Price Increase*, Energy Information Administration, DOE/EIA-0621 (Washington, DC, May 1998).

3 "Volatility" is an annualized measure of the size of the price changes.

Figure 3.1 Components Of Retail Regular Gasoline Prices Crude Oil Prices Are Significant and Variable



Source: Energy Information Administration, Form EIA-878, "Motor Gasoline Price Survey," and Form EIA-782, "Monthly Petroleum Product Sales Report."

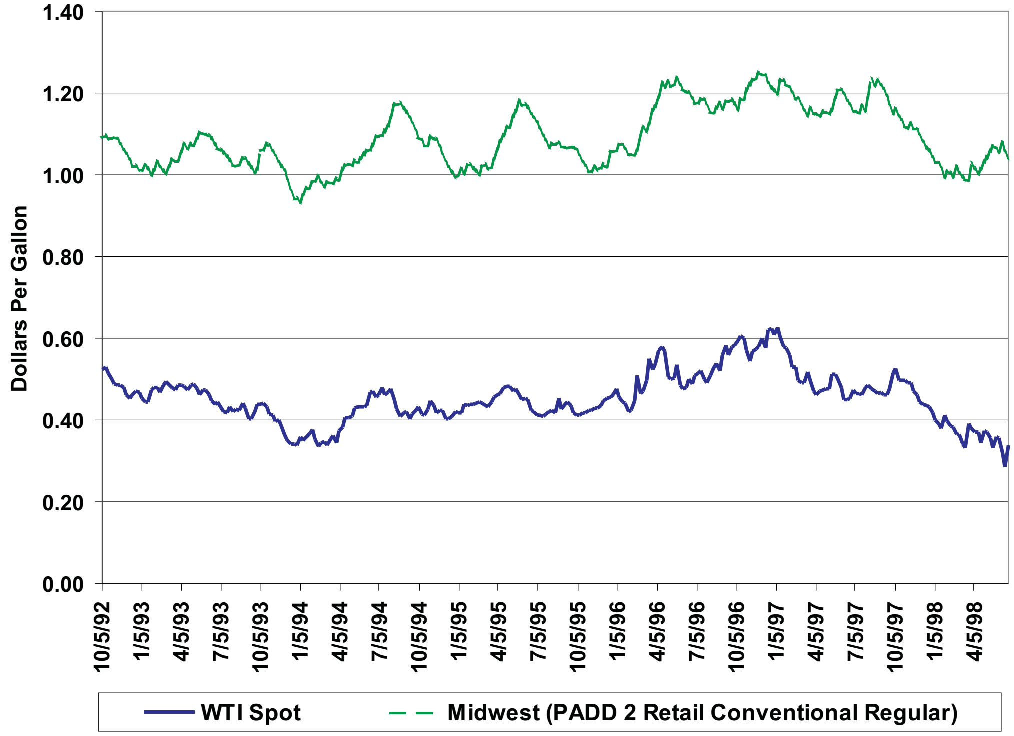
Figure 3.3 shows the relationship between spot crude oil prices and spot gasoline prices at the refinery. At this level, most previous studies found that the spot gasoline prices moved symmetrically in response to crude oil price changes. The market is very competitive at this level, and the existence of a futures market for domestic crude oil permits the knowledge of actual prices to be disseminated very quickly.

Figures 3.4 and 3.5 show gasoline prices further down the distribution chain. Figure 3.4 shows two types of spot prices, so it is not surprising that they are closely related. Figure 3.5 shows the close relationship between pipeline spot prices and rack prices at city terminals in Chicago.

Figure 3.6 shows the relationship between Chicago rack prices and Midwest retail prices. Previous studies typically found price asymmetry at the retail level.

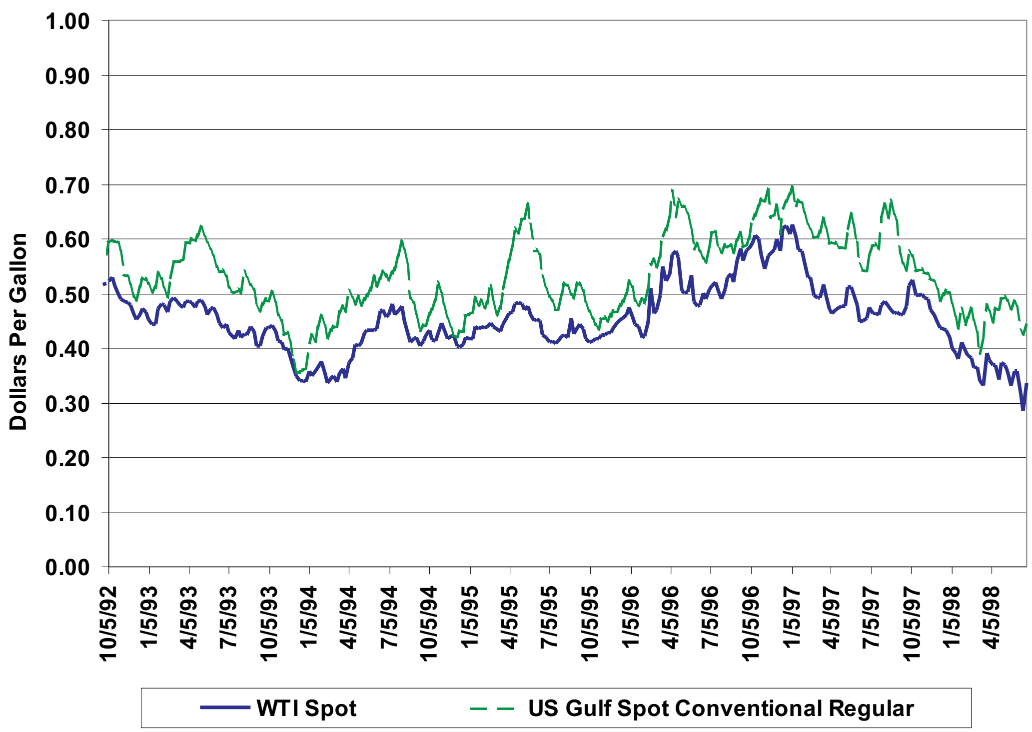
Finally, is there anything that might be learned from any of EIA's related models and data series that could be applied to this study? Figure 3.7 provides an answer. It shows a national average of actual and forecasted retail gasoline prices. The next week's changes in the national price are predicted from a symmetrical response model which consists of a moving average of prior wholesale gasoline

Figure 3.2 Do Midwest Gasoline Retail Prices Move With Crude Oil Prices? Regular Pump Prices



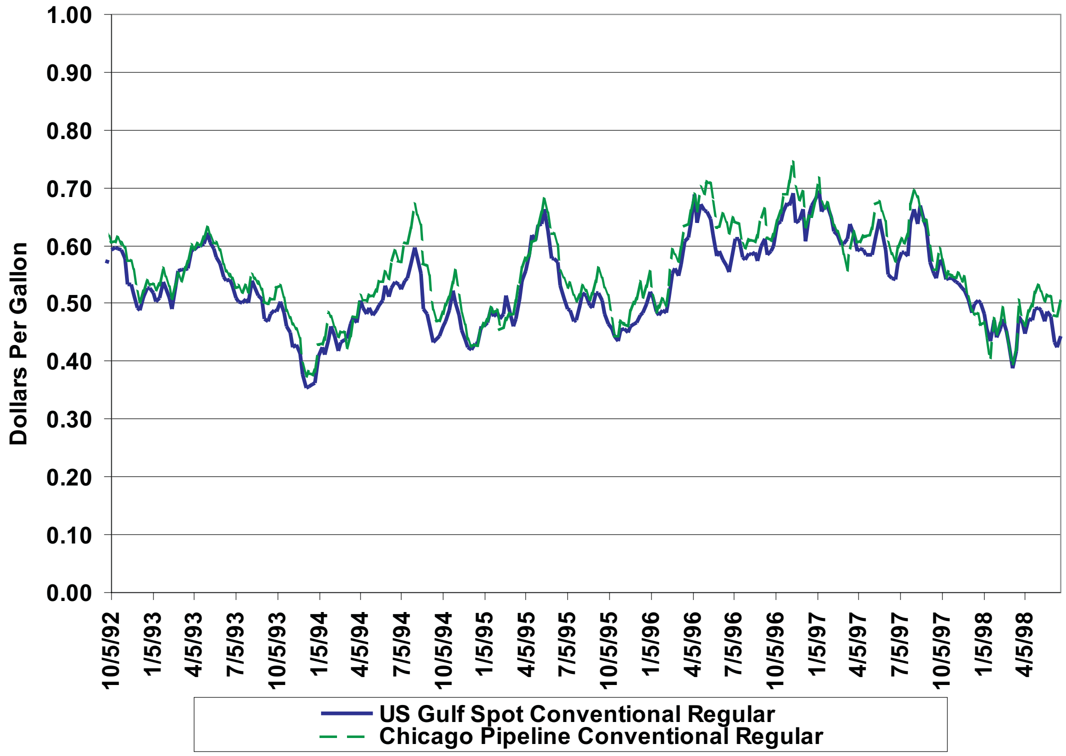
Source: DRI, Inc. and Energy Information Administration, Form EIA-878, "Motor Gasoline Price Survey."

Figure 3.3 Crude Oil Prices and Spot Gasoline Prices Move Together



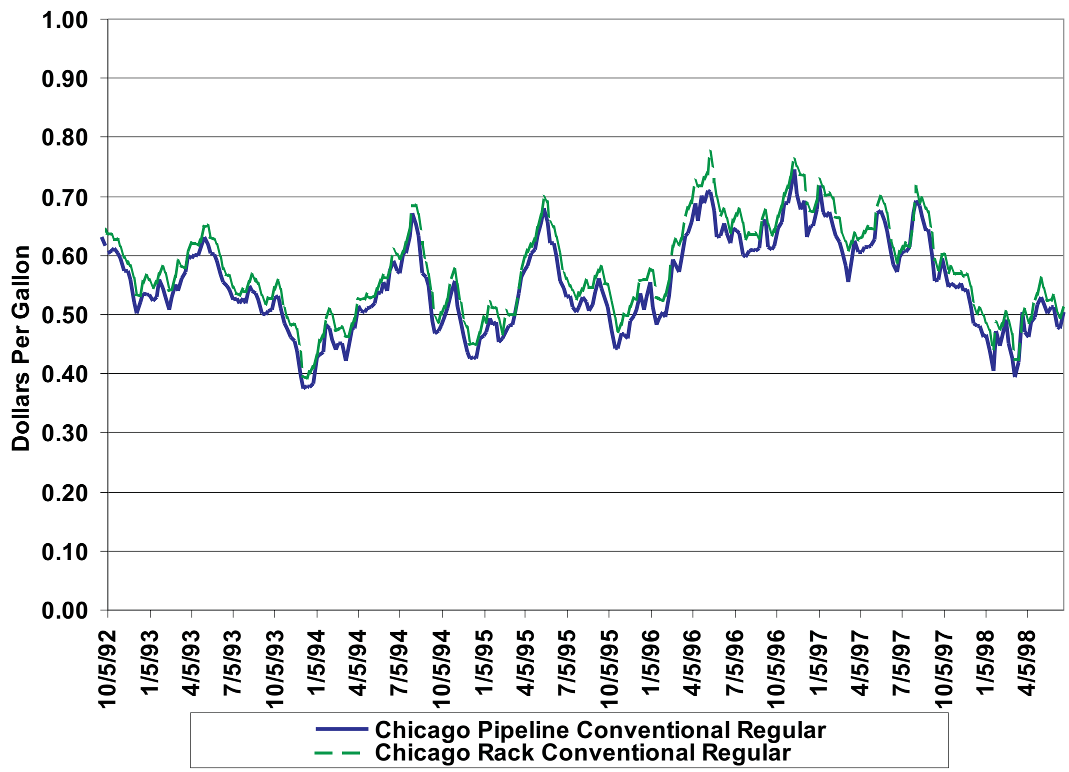
Source: DRI, Inc.

Figure 3.4 Refinery and Pipeline Spot Prices Are Closely Correlated



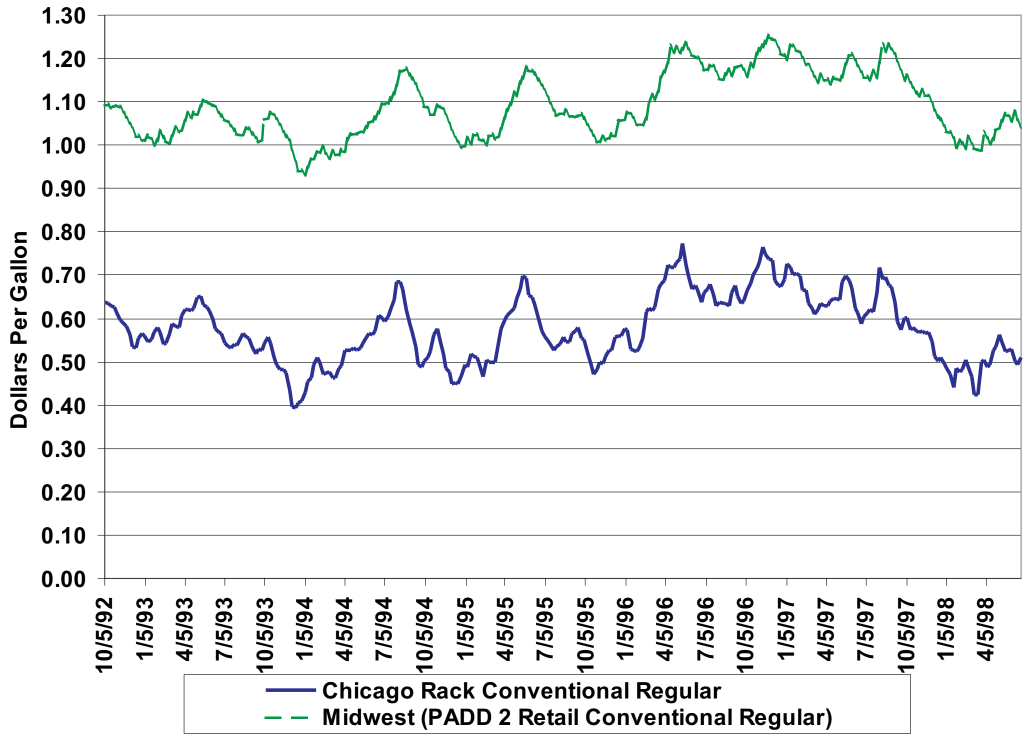
Source: DRI, Inc.

Figure 3.5 Pipeline Spot and Rack Prices



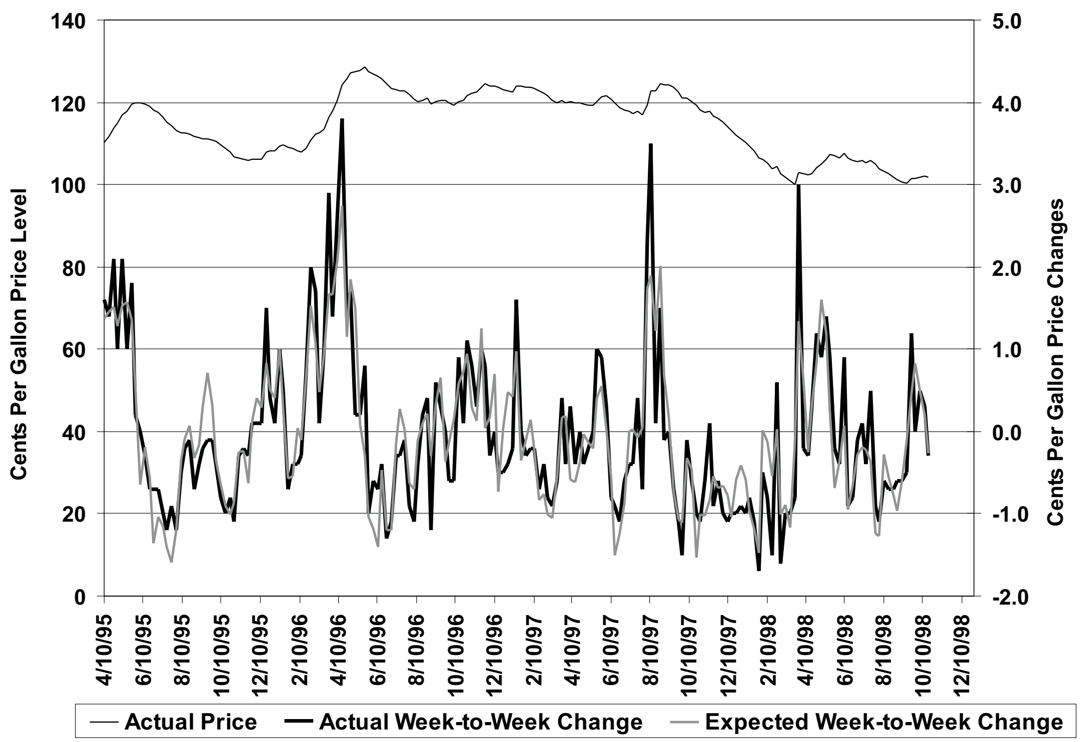
Source: DRI, Inc. and Oil Price Information Service.

Figure 3.6 Rack Prices and Retail Prices. A Source of Asymmetry?



Source: Oil Price Information Service and Energy Information Administration, Form EIA-878, "Motor Gasoline Price Survey."

Figure 3.7 Lagged Wholesale Prices Predict Retail Prices at the National Level



Source: Energy Information Administration calculations from Form EIA-878, "Motor Gasoline Price Survey."

prices. The lower part of Figure 3.7 shows that this simple model provides excellent estimates of the weekly price changes at the retail level. The lessons of Figure 3.7 are clear: the closeness of the predicted estimates to the actual values shows that at least for the national level, wholesale and retail gasoline prices are very closely linked, which helps explain why it is difficult to explain any asymmetric price movements.

Pattern Asymmetry Tests. EIA began by following the methods of Balke, Brown and Yucel (BBY), who in turn modified techniques developed by Borenstein, Cameron and Gilbert (BCG). Their tests were for "pattern asymmetry," in which prices would rise and/or fall at different rates. The previous chapter discussed BBY's paradoxical results. When they estimated their models using price levels, they got little evidence of price asymmetry. When they estimated their models using price changes, they got pervasive and strong evidence of asymmetry. In addition to testing for asymmetry, EIA was aware of this paradox.

Table 3.1 shows the statistical correlations between price levels at the various points in the distribution chain shown in Figure 1.3. Table 3.2 shows the corresponding correlations for price changes. Correlation coefficients close to 1.0 generally mean that using those variables together as explanatory variables in a multivariate regression estimation can give incorrect results. While there is no precise definition of "close to 1.0," Table 3.1 clearly shows that all prices (levels) in the gasoline distribution chain are highly correlated. This is a well known problem in econometrics, because good explanatory, or "independent," variables are often related.[4]

Tables 3.1 and 3.2 show that upstream and downstream prices are highly correlated. This correlation can cause multicollinearity problems with the BBY (price level) and BCG (price difference) models because they utilize both upstream and downstream prices as explanatory variables. Another potential problem is that the time frame for their analyses includes the Gulf War period when crude oil and petroleum product markets were extremely volatile, which could affect the stability of their models. Thus, this report limited itself to the post-Gulf War period, using

Table 3.1 Gasoline Price *Levels* Move Together, Creating Statistical Headaches

	Midwest Pump Prices	Chicago Rack Prices	Chicago Pipeline Prices	Gulf Coast Spot Prices	Crude Oil Spot Prices
Midwest Pump Prices	1.0	.88	.85	.81	.74
Chicago Rack Prices		1.0	.99	.95	.83
Chicago Pipeline Prices			1.0	.96	.82
Spot Gulf Coast Prices				1.0	.86
Crude Oil Spot Prices					1.0

Note: Correlation coefficient values of 1.0 means the variables move in exactly the same way. A value of zero means the price series move independently. Weekly data from October 1992 through June 1998.

Source: Correlation coefficients from Energy Information Administration calculations.

4 In an econometric model highly correlated explanatory variables may violate the standard modeling assumption of independence, because they possess approximately the same information that will cause the model to produce unreliable estimates. This very common situation is called "multicollinearity." Highly correlated explanatory variables need to be checked for potential multicollinearity problems.

Table 3.2 Gasoline Price *Changes* Have Less Concurrent Correlation Than Levels

	Midwest Pump Prices	Chicago Rack Prices	Chicago Pipeline Prices	Gulf Coast Spot Prices	Crude Oil Spot Prices
Midwest Pump Prices	1.0	.21	-.02	-.07	-.06
Chicago Rack Prices		1.0	.80	.74	.49
Chicago Pipeline Prices			1.0	.82	.59
Spot Gulf Coast Prices				1.0	.59
Crude Oil Spot Prices					1.0

Note: Correlation coefficients with values of 1.0 means the variables change in exactly the same way. A value of -1.0 means that a rise in one price change is always accompanied by an identical fall in the other price change. A value close to zero indicates the price changes move independently in the same time period. Weekly data from October 1992 through June 1998.

Source: Correlation coefficients from Energy Information Administration calculations.

weekly price data from October 1992 through June 1998 to test for pattern and amount asymmetry between Midwest downstream (e.g. wholesale and retail gasoline) prices resulting from upstream (e.g. crude oil and spot gasoline) price changes. Also, having found that multicollinearity was a problem during estimation and because the pattern asymmetry test results depended on lag length, this study used a modified version of the BBY model, where lags of the dependent variable were eliminated from the specification. (See Appendix C, EQN C.2 for the estimated equation and Appendix D for the mathematical derivation.) The results of the pattern asymmetry testing are shown in Table 3.3.

Table 3.3 shows that there is no evidence of pattern asymmetry between crude oil price changes and gasoline price changes at all levels (far right column). However, that result is complicated by the fact that there is much more seasonality in gasoline than there is in crude oil. There was strong evidence of pattern asymmetry between wholesale and retail gasoline prices (bottom row). Midwest retail prices rise faster than they fall with respect to changes in Gulf Coast gasoline spot prices, Chicago pipeline prices, and Chicago rack prices.

Price Passthrough Analysis. An equally important question to whether or not there is "pattern asymmetry" is whether or not there is "amount asymmetry," i.e., whether changes in crude oil prices or wholesale gasoline prices are ultimately reflected fully in retail gasoline prices. For these tests EIA used the passthrough models developed by Zyren.[5] The passthrough models for this analysis are described in Appendix B. Passthrough models were developed in order to determine the amount of time it takes for upstream cost changes to be reflected in downstream price changes. Price passthrough models use (weekly) lags of upstream prices to account for the length of time required for downstream markets to adjust to upstream price changes. Table 3.4 shows the results of a passthrough model analysis from upstream prices to Midwest retail prices.

5 See, for example, *Motor Gasoline Assessment: Spring 1997,* Energy Information Administration, DOE/EIA-0613 (Washington, DC, July 1997), and *Assessment of Summer 1997 Motor Gasoline Price Increase*, Energy Information Administration, DOE/EIA-0621 (Washington, DC, May 1998).

Table 3.3 Statistical Tests Show "Pattern Asymmetry" of PADD 2 Price Changes at the Retail Level

	Chicago Rack Prices	Chicago Pipeline Prices	Gulf Coast Spot Prices	Crude Oil Spot Prices
Gulf Coast Spot Prices				0.852 (0.531)
Chicago Pipeline Prices			2.615** (0.036)	1.128 (0.344)
Chicago Rack Prices		1.359 (0.259)	0.988 (0.433)	1.533 (0.193)
Midwest Retail Prices	5.407*** (0.000)	2.346*** (0.019)	3.150*** (0.003)	0.721 (0.673)

Notes: Dependent variables are on the left. Numbers in the table are Wald Test F-statistic for pattern asymmetry; p-values appear in parenthesis below test statistic. Tests are on difference form of pattern asymmetry equation.
** = statistically significant at the .05 level.
*** = statistically significant at the .01 level.
Source: Appendix tables C.1-C.3.

The results shown in Table 3.4 demonstrate that about 60 percent of upstream price changes are fully reflected in Midwest retail gasoline price changes in about two weeks, about 75 percent of the changes are reflected after 4 weeks, and the price passthrough is completed in 8 or 9 weeks.[6] The fact that the estimated coefficients show a steady, cumulative price effect over time, and that the price passthrough is eventually fully reflected at retail, makes market sense. Also, rack prices, which are the closest to retail, have the most rapid passthrough (54 percent, versus 35 percent for the other upstream prices), which is also a reasonable result. Passthrough results are discussed in more detail in Appendix B.

Table 3.5 shows price passthrough models from the important spot crude oil level to wholesale levels. Changes in crude oil prices are fully reflected at Gulf Coast gasoline prices, Chicago pipeline prices, and Chicago rack prices in about 4 weeks. Again, the results of the model are consistent and show eventual complete price passthrough, or amount symmetry, which provides some evidence of model validity.

Table 3.6 shows passthrough models at the wholesale level, an illustration of the robustness of the model formulation. Prices between Gulf Coast gasoline prices and Chicago pipeline prices, between Chicago pipeline prices and Chicago rack prices, and between Gulf Coast spot prices to Chicago rack prices all have complete passthrough in from 1 to 5 weeks. The complete price passthrough, in shorter times than passthrough to retail because of shorter distances, again provides evidence for the reasonableness of the price passthrough models.

The results of statistical testing for amount asymmetry are shown in Table 3.7. The values shown in the table are downstream (dependent variable) cumulative percentages for the passthrough of upstream (independent variable) price changes. A value of 100.0 indicates exact 100 percent passthrough (after an appropriate number of weeks) of upstream price changes to the downstream

6 These results are consistent with previous work. See *Motor Gasoline Assessment: Spring 1997,* Energy Information Administration, DOE/EIA-0613 (Washington, DC, July 1997).

Table 3.4 Price Passthrough Analysis to Midwest Retail Prices

Lagged Weeks	Chicago Rack Prices	Chicago Pipeline Prices	Gulf Coast Spot Prices	Crude Oil Spot Prices
1	53.6%	34.4%	36.0%	36.0%
2	60.7%	60.2%	60.8%	57.0%
4	75.7%	78.0%	79.2%	77.6%
6	80.3%	87.0%	92.6%	91.9%
8	92.6%	97.5%	100.7%	103.7%
Total	92.6%	97.5%	100.7%	110.6%

Notes. Numbers in table are cumulative percentages. Crude oil total is for 9-week lags.
Source: Energy Information Administration calculations based on Appendix Table B.1.

price. The values in the table show that amount symmetry is prevalent throughout most of the gasoline distribution system. There are only two out of ten cases which indicate the presence of significant amount asymmetry: there appears to be less than 100 percent passthrough of rack prices to retail, and greater than 100 percent passthrough of spot prices to rack prices.

In summary, these results consistently show that there is little evidence of amount asymmetry but substantial evidence of pattern price asymmetry in the Midwest retail motor gasoline markets. However, even the pattern asymmetry may be a statistical artifact, as can be seen in Figure 3.8. In the summer of 1995, the spot price appears to be falling faster than the retail price, but a lagged market adjustment would make this apparent pattern asymmetry disappear. Similarly, in the fall of 1996, spot prices dropped sharply while retail prices continued to rise, but lagged price passthrough to the retail markets shows this pattern asymmetry may only have been an illusion. This possibility is further considered in Appendix A (Figure A.5). In such cases, however, since after all lagged price adjustments have been completed the wholesale price increases will be almost completely reflected in retail prices, there is little evidence of "amount asymmetry," i.e., the consumer in the Midwest normally will ultimately have lower spot market costs reflected at retail.

Table 3.5 Price Passthrough from West Texas Intermediate Crude Oil

Lagged Weeks	WTI To Midwest Retail Prices	WTI To Chicago Rack Prices	WTI To Chicago Pipeline Prices	WTI To Gulf Coast Spot Prices
0		59.3%	79.1%	78.8%
1	36.0%	89.7%	79.2%	85.7%
2	57.0%	86.8%	84.3%	98.1%
4	77.6%	106.1%	113.8%	106.0%
6	91.9%			
8	103.7%			
Total	110.6%	106.1%	113.8%	106.0%

Note: Numbers in table are cumulative percentages.
Source: Energy Information Administration calculations based on Appendix Table B.2.

Table 3.6 Wholesale Price Passthrough. Levels and Differences Produce Stable Results

Lagged Weeks	Gulf Coast Spot To Chicago Rack		Chicago Pipeline To Chicago Rack		Gulf Coast Spot To Chicago Pipeline	
	Price Changes	Price Levels	Price Changes	Price Levels	Price Changes	Price Levels
0	65.2%	63.8%	62.9%	63.2%	83.0%	88.4%
1	101.9%	100.3%	102.2%	102.3%	88.1%	87.3%
2	101.3%	99.4%			91.8%	90.0%
3	108.2%	103.2%			99.1%	98.0%
4	108.0%	102.7%				
5	117.2%	111.8%				

Note: Numbers in table are cumulative percentages.
Source: Energy Information Administration calculations based on Appendix Table B.3.

Whether or not all these results would also hold up in other regions of the country is an open question. Drawing conclusions about other regions would require a separate consideration of the market infrastructure and a choice of appropriate data series to perform the statistical tests.

Conclusions. This report has analyzed weekly gasoline price changes in the Midwest, from October 1992 through June 1998, and has reached the following conclusions.

- Wholesale gasoline price rises and price drops are basically symmetric with respect to changes in crude oil prices.
- Retail gasoline prices in the Midwest can rise much faster than they fall in response to wholesale gasoline price changes. This is called *pattern asymmetry*. Also, after all lagged price

Table 3.7 Statistical Tests Show Widespread "Amount Symmetry" of Price Changes

	Chicago Rack Prices	Chicago Pipeline Prices	Gulf Coast Spot Prices	Crude Oil Spot Prices
Gulf Coast Spot Prices				106.0% (0.626)
Chicago Pipeline Prices			99.1% (0.859)	113.8% (0.281)
Chicago Rack Prices		102.2%* (0.085)	117.2%*** (0.002)	106.1% (0.636)
Midwest Retail Prices	92.6%** (0.027)	97.5% (0.432)	101.0% (0.905)	110.6% (0.506)

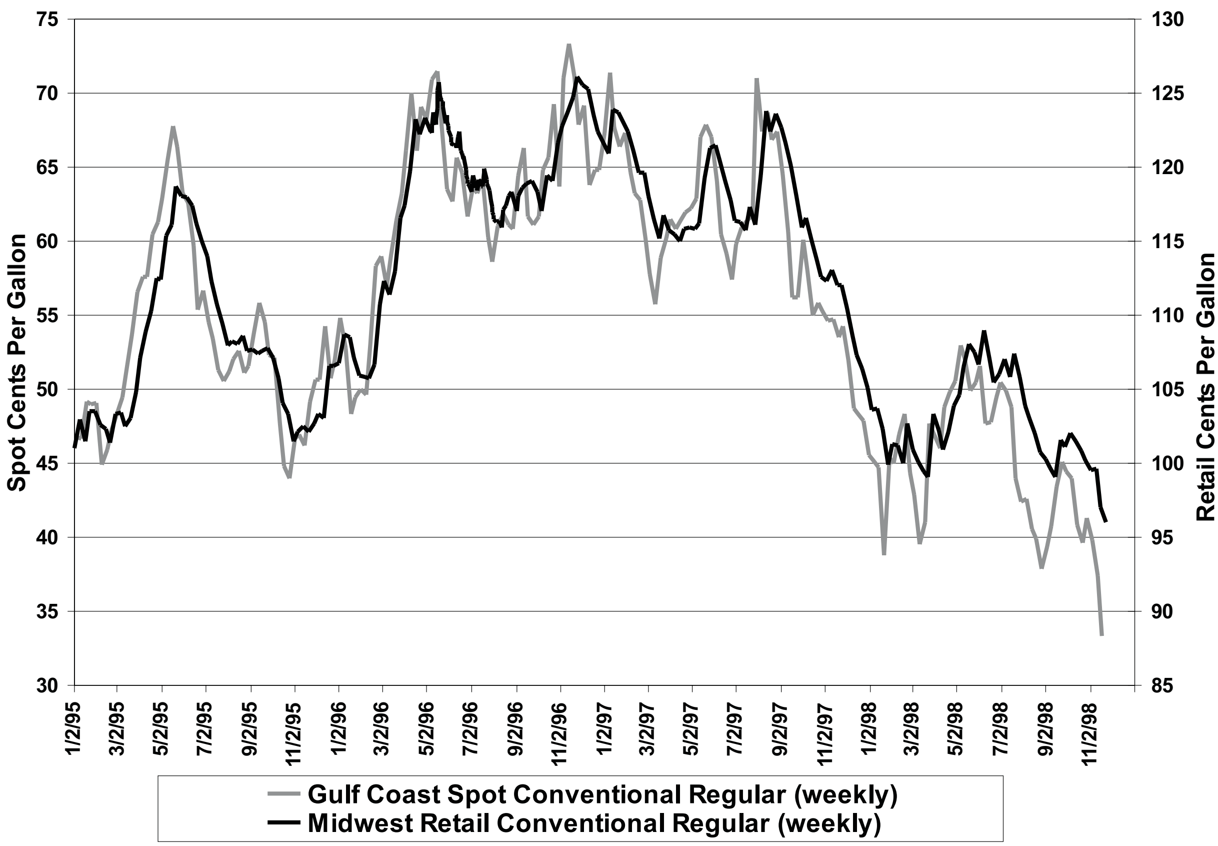
Notes: Dependent variables are on the left. Numbers in the table are cumulative passthrough percentages of independent variable price changes passed through to the dependent variable. The p-values for the Wald test F-Statistic of the cumulative percentage value being equal to 100.0 are shown in parentheses. Tests are on difference form of passthrough equations for weekly data from October 1992 through June 1998. * = statistically significant at the .10 level. ** = statistically significant at the .05 level. *** = statistically significant at the .01 level.

Source: Energy Information Administration calculation based on appendix Tables B.1 - B.3.

adjustments have been completed the wholesale price increase or decrease will almost completely pass through to the retail level, so there is little evidence of *amount asymmetry*.

- The very rapid price passthrough from upstream to downstream wholesale markets indicates that future studies should use daily instead of weekly prices.
- The conclusions of this type of analysis depend importantly on various characteristics, including frequency and location specificity, of the data used in the models. Thus, conclusions about price asymmetry at the city or state level would necessitate a collection of data and an examination of the structure of the local gasoline market on a case-by-case basis, so debates about the overall dynamics of gasoline prices will probably continue indefinitely until all markets have been investigated.

Figure 3.8 Lags Between Spot and Retail Prices Can Create Pattern Asymmetry



Source: DRI, Inc. and Energy Information Administration, Form EIA-878, "Motor Gasoline Price Survey."

Appendix A
A Moving Average / Symmetry Primer

The idea behind symmetric or asymmetric downstream price responses caused by upstream price changes can be illustrated with a simulation using a moving representation of the price response:

$$y_t = 5 + 0.35 * x_{t-1} + 0.25 * x_{t-2} + 0.10 * x_{t-3} + 0.15 * x_{t-4} + 0.10 * x_{t-5} + 0.05 * x_{t-6} \quad \text{EQN A.1}$$

where y_t is the downstream price at time t.

x_{t-i} are the lagged upstream price changes.

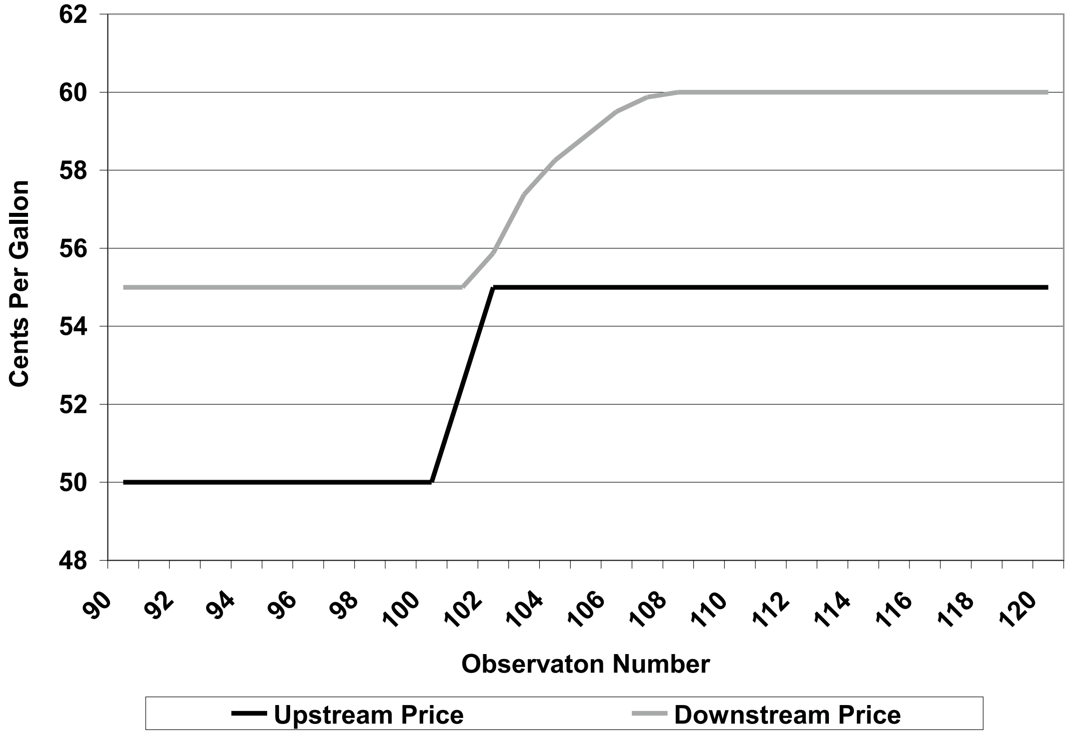
The coefficients were chosen to have declining weights and to sum exactly to 1.0, thus y_t is modeled by a weighted sum of the lagged upstream price changes. The weighting coefficients in EQN A.1 are very similar to the regression estimated coefficients for the U.S. Gulf Coast spot motor gasoline price passthrough to PADD 2 retail prices (see column 3 in Table B.1).

The first application for this model is to demonstrate the concept of AMOUNT symmetry, which is illustrated in Figure A.1. The "simulated" upstream price was constructed to be a simple step function, beginning at a constant value of 50 cents per gallon, uniformly increasing by 2.5 cents for each of two periods (#101 and #102) and then remaining constant at 55 cents thereafter. The resulting downstream price behavior shown in the figure shows a lagged one period response after the initial downstream price increase, and shows a complete response 6 periods (#108) after the downstream price movement, after which the value is constant at 60 cents. The property of amount symmetry is preserved because the 5 cent total upstream price increase eventually results in the downstream price increasing by 5 cents per gallon, given a sufficiently long time period for the lag response. The concept of amount symmetry was incorporated into the model (EQN A.1) by having the coefficients of the lagged independent variables sum to 1.0.

The second application of this model is to demonstrate the concept of PATTERN symmetry, which simply means that the response pattern of downstream price to a positive or a negative change in the upstream price will be identical, although opposite in direction. Figure A.2 illustrates the case of pattern symmetry. Note that the downstream response pattern to an upstream price increase and decrease can be seen to be equal and opposite. The upstream price changes used are similar to those used in the previous example, i.e., a 2.5 cent increase/decrease for two consecutive time periods for an overall 5 cent change. The positive price changes shown in Figure A.1 are replicated in Figure A.2, along with the upstream and downstream paths for a price decrease. Close examination of the downstream price shows that the response to an upstream price decrease is equal and opposite to that for the upstream price increase. This illustrates the concept of a downstream PATTERN symmetry price response.

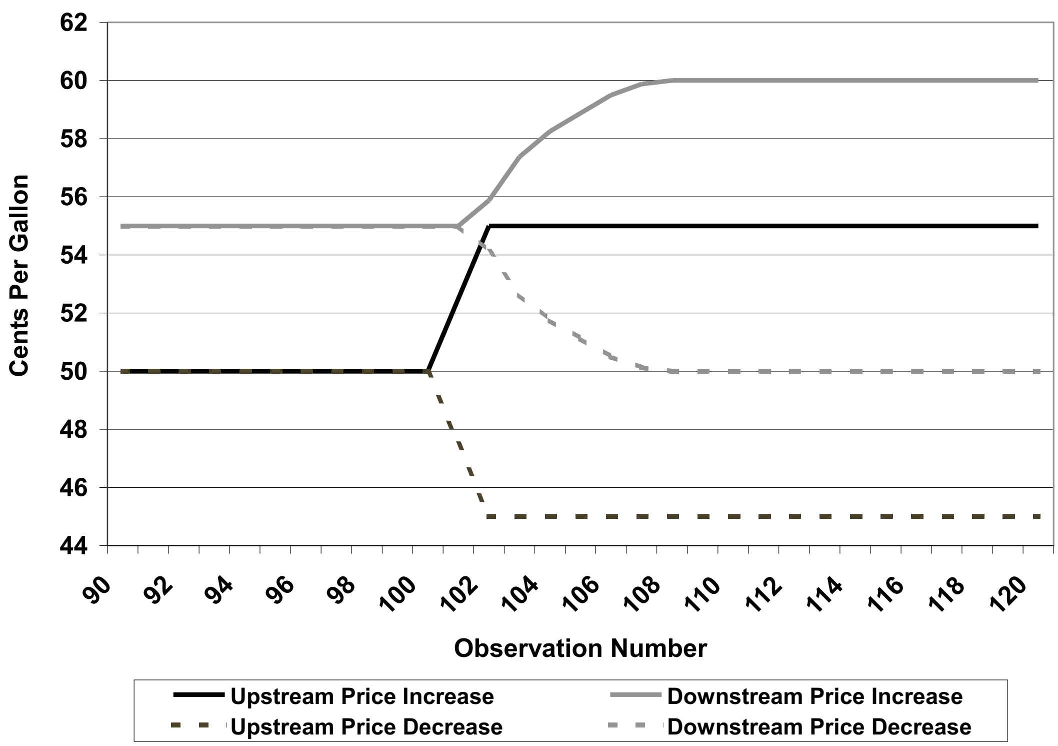
Furthermore, a third application of this model is to demonstrate that pattern asymmetry can be an artifact of time lags in the system, and that this occurs when there is a temporary peaking of the

Figure A.1 Example of Amount Symmetry



Source: Energy Information Administration simulation.

Figure A.2 Example of Pattern Symmetry



Source: Energy Information Administration simulation.

Figure A.3 Example of Apparent Pattern Asymmetry Caused by a Lagged Response

Source: Energy Information Administration simulation.

upstream price. The specification of this downstream price model assumes a declining lagged response, with 60 percent of the passthrough during the first two time periods and complete passthrough after 6 weeks (EQN A.1). The upstream price was chosen to provide a **symmetrical** 5 cent price increase and decrease spread over 10 time periods: the upstream price was assumed constant at 50 cents until period #100 when the price increased by 1 cent per period for 5 periods (i.e. 5 cent rise), and then declined at the rate of 1 cent per period until the old equilibrium level was reached after 5 periods (#106 to #110). This peak was followed by a symmetrical price decrease of the same magnitude. These symmetrical upstream price changes are shown in Figure A.3, along with the simulated downstream price passthrough. The response on the downstream pricing, which is seen to be identical regardless of the direction of the initial movement, shows a number of **asymmetric** properties:

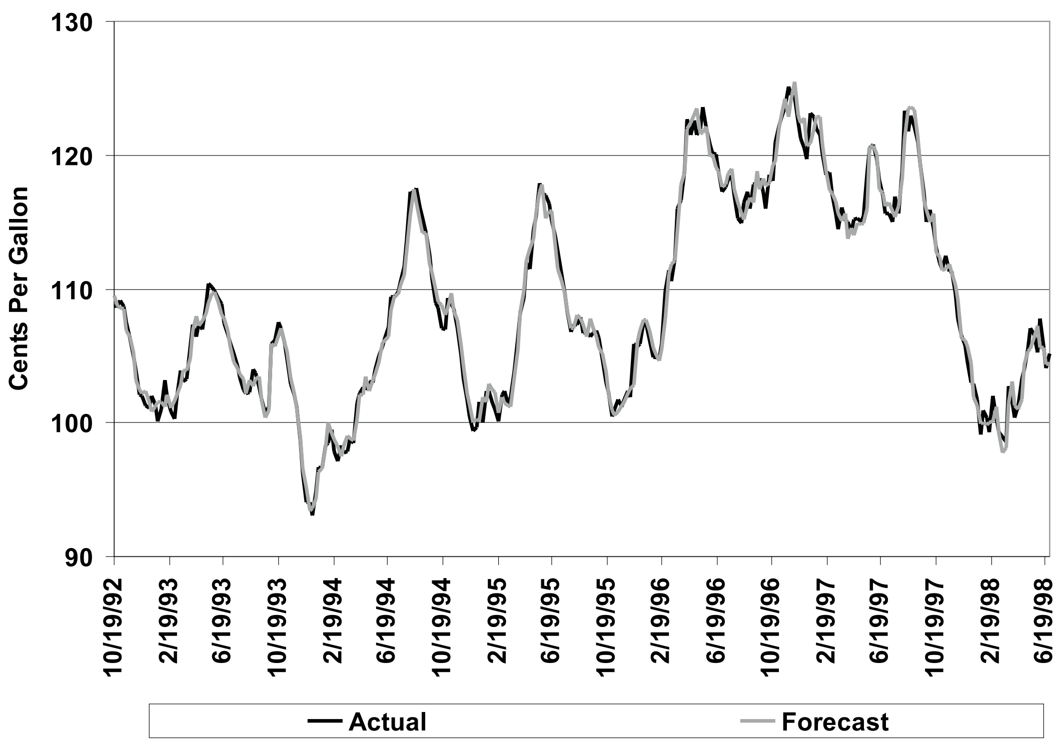
- The downstream price responds with a 1 period lag to the initial upstream price change.
- The downstream price requires 6 periods to reach its maximum (minimum), whereas the upstream price takes only 5 periods.
- The downstream price peaks 2 periods after the upstream price maximum (minimum).
- The downstream price takes longer to return to equilibrium, requiring a full 9 time periods after the price maximum (minimum), whereas the upstream price took only 5 periods to return to the original level.

- The downstream price has a peak value of approximately 59 cents for the price increase (or 51 cents for the price decrease), nearly 4 cents greater (smaller) than the equilibrium value, whereas the upstream price peaked (bottomed) at the full 5 cent above (below) equilibrium. This occurs even though the model is amount symmetric.
- The downstream price peak has an asymmetric (skewed to the right) shape, with an up slope steeper than the down slope (or downslope steeper than the upslope for the price decrease) and with a larger area under the curve to the right of the peak maximum (minimum) than to the left, whereas the upstream price curve is symmetric. This is an example of PATTERN ASYMMETRY.

In conclusion, this simulation shows that by using a *symmetric* upstream price spike and *symmetric* market responses to upstream price increases and decreases, THAT IT IS POSSIBLE TO EMPIRICALLY INDUCE PATTERN ASYMMETRY IN THE DOWNSTREAM PRICE RESPONSE.

The finding of an asymmetrical price response at the retail market, whatever its possible cause, does not seem to have great significance. This is demonstrated in Figure A.4, which compares the actual Midwest retail prices with those from the regression fitted model. The fitting equation used was the USG spot to retail price passthrough equation in Appendix B (Table B.1) which assumes a symmetrical market response. The extremely high correlation between an asymmetric price series and a fitted symmetric model indicates that even if there is some evidence that there is price

Figure A.4 Actual and Forecasted Midwest Retail Gasoline Prices

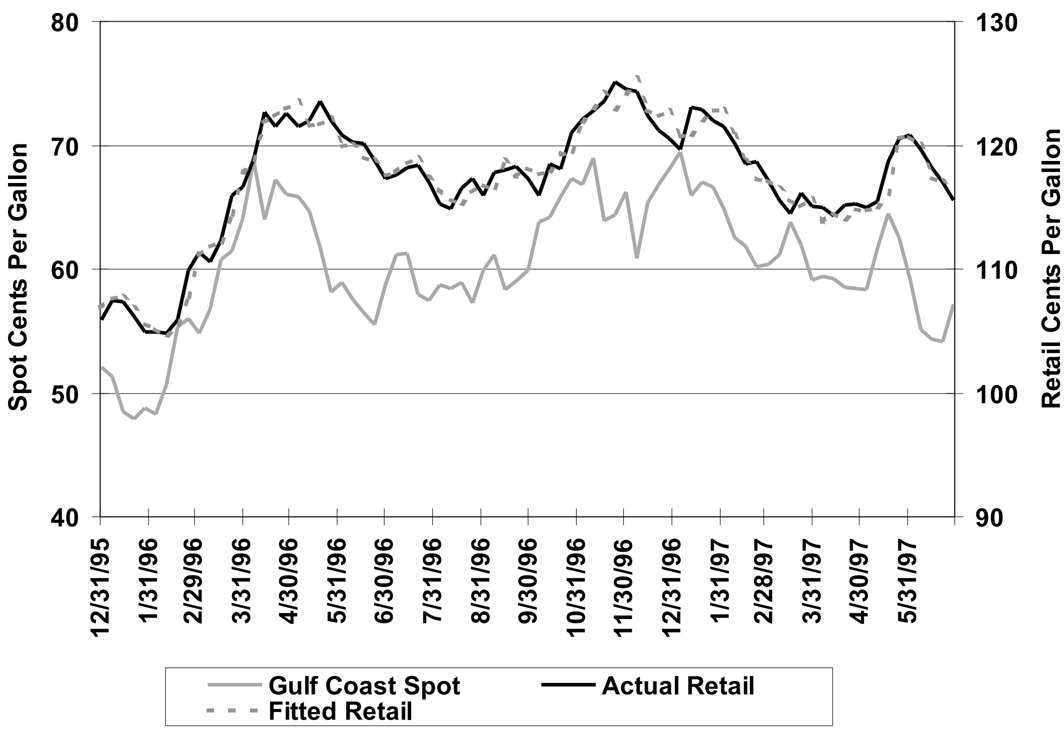


Source: Energy Information Administration Form EIA-878, "Motor Gasoline Price Survey."

asymmetry between the refinery spot price and the PADD 2 retail price, the amount actually due to an asymmetric market response rather than a symmetric lagged response is not large.

A further illustration of the response of (downstream) motor gasoline retail prices to changes in USG spot prices is illustrated in the next figure, which expands Figure A.4 for the 01JAN96 to 30JUN97 time period and also includes the spot price; both the retail and fitted retail price series are identical to those in Figure A.4. Figure A.5 clearly shows for a number of time periods that the actual retail price is still rising when spot prices fall after reaching a peak, and also that actual (downstream) retail prices show a slower downward response than the "corresponding" (upstream) spot price declines. The crucial point of Figure A.5 is that a symmetrical lag regression model explains this seemingly slow downstream price response to upstream price declines. The SYMMETRICAL price passthrough model in Table B.1 provides a close fit for both upward AND downward retail price response to upstream price movements. Figure A.5 provides strong visual evidence that even if pattern asymmetry actually exists in downstream price movements, that the overall effects on the market are minimal. Actual quantification of this effect will be left for the next study.

Figure A.5 Gulf Coast Spot and Midwest Retail Gasoline Prices Model of Symmetrical Retail Market Response



Source: Energy Information Administration Form EIA-878, "Motor Gasoline Price Survey."

Appendix B
Quantitative Explanation of Motor Gasoline Market Price Passthrough

As part of the asymmetry study, an analysis was undertaken using industry and EIA data to explore the speed of price change passthroughs from the various upstream spot markets to the retail market for individual regions of the U.S. The results reported below update the results published in the previous report[1] and will be used to form the basis for further research on pricing mechanisms in petroleum product markets.

Estimates showed that the price passthrough from various spot markets to the retail level is complete by two months with price passthrough to the various spot markets taking substantially less time. The unusually rapid Gulf Coast spot to retail price passthrough speed for PADD 2 (80 percent within 4 weeks vs. 50 percent in the other PADD's) found in the previous study was verified and is consistent with the other results of this study.

An attempt was made to estimate the speed of adjustment of motor gasoline retail prices as a function of lagged downstream spot prices by using weekly EIA data from the Form EIA-878, "Motor Gasoline Price Survey." The gasoline price used was that of PADD 2 conventional regular gasoline (RETPADD2). Weekly averages of West Texas intermediate crude oil (WTISPOT) spot price, the U.S. Gulf Coast (USGSPOT) conventional motor gasoline, Chicago pipeline (CHIPIPE) and Chicago rack (CHIRACK) conventional regular prices were calculated from daily values. The daily WTISPOT, USGSPOT, and CHIPIPE prices were obtained from DRI, Inc. and the CHIRACK prices were obtained from Oil Price Information Service. Investigation of the time series properties of the price data was performed in order to assist in specifying the appropriate form of the model; for example, data with unit root properties are best analyzed using first differences, whereas stationary series can be estimated in level form. Phillips-Perron and Augmented Dickey-Fuller tests could not reject the hypothesis that the retail gasoline and averaged WTI spot data had a unit root, whereas the averaged spot gasoline data rejected the unit root hypothesis (USGSPOT at the 10 percent level, CHIPIPE and CHIRACK at the 5 percent level but not at the 1 percent level). Since all series had a strong autoregressive component, first differences were used for the regression analysis. The retail prices and the weekly averages of the spot prices were defined to correspond to the same week, so that the retail prices were estimated as a function of lagged spot prices.

The interpretation of the regression model depends on the form of the lag parameters in the model. For example, the estimated model has the form:

$$\Delta y_t = b_1 \Delta x_{t-1} + b_2 \Delta x_{t-2} + \cdots + b_k \Delta x_{t-k} + c_o z_t + e_t$$

1 Energy Information Administration, *Assessment of Summer 1997 Motor Gasoline Price Increase*, DOE/EIA-0621 (Washington, DC, May 1998), Appendix E, p. 81.

or, more succinctly

$$\Delta y_t = \sum_{i=1}^{k} b_i \Delta x_{t-i} + c_o z_t + e_t$$

This model can be interpreted as follows. The lagged form shown in this model means that a change (Δ) in the independent variable (X) will affect the change in the dependent variable (Y) for a number of time periods. In particular, a change in X during the time period (t-k) not only affects the change in Y during the period (t-k), but also for a number of time periods in the future (i.e., (t-k+1), (t-k+2), and all the way to (t)). More formally, ΔX_{t-k} affects not only the change in ΔY_{t-k}, but also in ΔY_{t-k+1}, ΔY_{t-k+2}, ..., ΔY_t. The other parameter Z_{t-k} has an immediate effect on the change in ΔY_{t-k} and a permanent change in the level of Y_{t-k} during time period (t-k).

The equation actually estimated for this study is

$$\Delta DOWN_t = \sum_{i=1}^{k} \beta_i \Delta UP_{t-i} + D04OCT93 + AR, MA \ \ Terms + e_t \qquad \text{EQN B.1}$$

Where:

Δ	is the week to week change
$DOWN_t$	is the downstream (relative to the upstream) motor gasoline price (in cents per gallon) for week t
UP_t	is the upstream gasoline or crude oil spot price (in cents per gallon) for week t
D04OCT93	is the dummy variable for the retail Federal tax increase in October, 1993
e_t	is the random error term at time t
AR, MA	are autoregressive and moving average terms

Amount asymmetry in the passthrough models can be checked by determining whether the sum of the current and lagged upstream variables sum to one. The statistical test for amount asymmetry is to test the hypothesis:

$$\sum \beta_i = 1.0 \qquad \text{EQN B.2}$$

where the sum is taken over all k upstream price lags. It should be noted that large p-values mean that the null hypothesis of amount symmetry CANNOT be rejected. Tables B.1 - B.3 show the parameter estimates for the various market levels. The estimation method used was Ordinary Least Squares (OLS). The AR, MA terms are used to make the regression residuals test as random. The lag length was chosen by using the one which minimized the Akaike Information Criterion (AIC) value; this also provided parameter estimates for the spot price which did not increase when another lag was added to the equation. *A priori*, one would expect to see an approximately 1:1 eventual pass-through of spot price changes in a perfectly competitive market and would also expect the influence of a spot price change to decrease monotonically over time after the first or second time period. The estimation results reported in the table are reasonable and are very similar to those appearing in the previous study (see footnote 1). These results show, depending on the market level, that anywhere between 93 to 117 percent of a spot price change is passed through to retail within two months and that the lag effect does tend to decrease over time.

When interpreting the results shown in the tables (especially Table B.2) it is important to remember the definition of the lagged variables: the retail price is a Monday morning open-of-business price, whereas the other variables are defined as the weekly average price for the current week. Thus current downstream prices other than retail would be explained by current and lagged upstream prices, whereas the current retail price is only explained by lagged upstream prices.

The coefficient estimates shown in Table B.3 indicate a rapid price passthrough; this is especially true for the USGSPOT to CHIPIPE analysis, where about 85 percent a change in the upstream spot price is passed through during the *same* week. This very rapid passthrough and the complex ARMA structure required to make the residuals pass as white noise indicate that the weekly time frequency utilized for this spot market analysis is too long, and that further analysis should be performed using daily prices.

Table B.1 OLS Regression Results for Retail Price Passthrough Weekly Prices from October 5, 1992 to June 29, 1998

Independent Variable	CHIRACK	CHIPIPE	USGSPOT	WTISPOT
	Change in Downstream Price (dependent variable): PADD 2 Retail Price, conventional regular gasoline			
Parameter				
CONSTANT	0.011 (0.028)	0.009 (0.023)	0.018 (0.055)	0.875** (0.436)
ΔUP(t-1)	0.536*** (0.023)	0.344*** (0.021)	0.360*** (0.026)	0.360*** (0.043)
ΔUP(t-2)	0.071*** (0.027)	0.258*** (0.025)	0.248*** (0.027)	0.210*** (0.043)
ΔUP(t-3)	0.067** (0.027)	0.070*** (0.025)	0.069** (0.027)	0.078* (0.044)
ΔUP(t-4)	0.083*** (0.027)	0.108*** (0.025)	0.114*** (0.027)	0.128*** (0.046)
ΔUP(t-5)	0.055** (0.027)	0.024 (0.025)	0.064** (0.027)	0.043 (0.046)
ΔUP(t-6)	-0.009 (0.027)	0.066*** (0.025)	0.070*** (0.026)	0.100** (0.046)
ΔUP(t-7)	0.123*** (0.023)	0.032 (0.025)	0.081*** (0.026)	0.009 (0.045)
ΔUP(t-8)		0.072*** (0.021)		0.108** (0.045)
ΔUP(t-9)				0.069 (0.045)
D04OCT93	4.759*** (0.700)	4.893*** (0.721)	4.800*** (0.889)	5.428*** (1.234)
WEEKLY DUMMY	NO	NO	NO	YES*** (1.680)
AR(1)		0.192 (0.125)	-0.920*** (0.034)	
MA(1)	-0.346*** (0.055)	-0.603** (0.101)	0.825*** (0.054)	
AR(2)				0.080 (0.065)
MA(3)			0.159*** (0.048)	0.170*** (0.065)
AMOUNT ASYMMETRY F-STATISTIC p-value	4.923** (0.027)	0.619 (0.432)	0.014 (0.905)	0.445 (0.506)
Sum of Spot Lags	0.926	0.975	1.007	1.106
AIC	2.268181	2.437354	2.687731	3.226603
Adj. R^2	0.734	0.688	0.599	0.409
F-Statistic	92.2	60.5	41.3	4.25
D.W. Statistic	1.99	2.00	2.08	2.00

Table B.1 Continued

Notes:

The general form of the linear model is shown in Equation B.1.
All prices are in cents per gallon.
"Δ" is the weekly price change.
The (t-1), (t-2), ..., (t-9) refer to lagged values.
UP refers to the weekly average price for regular, conventional motor gasoline at U.S. Gulf Coast (USGSPOT); Chicago Pipeline price (CHIPIPE); Chicago Rack price (CHIRACK); or it refers to the weekly average spot price for West Texas Intermediate Crude Oil (WTISPOT)
D04OCT93 is a dummy variable corresponding to the change in Federal tax on motor gasoline.
WEEKLY DUMMY refers seasonal variables, the joint test F-statistic is reported in parentheses.
AMOUNT ASYMMETRY F-STATISTIC refers to the joint hypothesis test:

$\Delta UP(t-1)+\Delta UP(t-2)+ \ldots +\Delta UP(t-k) = 1.0$.

A p-value < 0.05 indicates rejection of the joint hypothesis.

Standard errors appear in parentheses below the parameter estimates.
*** indicates significant at 1% criteria (p-value < 0.01)
** indicates significant at 5% criteria (p-value < 0.05)
* indicates significant at 10% criteria (p-value < 0.10)

Table B.2 OLS Regression Results for Price Passthrough from WTI Weekly Prices from October 5, 1992 to June 29, 1998

Independent Variable	WTISPOT	WTISPOT	WTISPOT	WTISPOT
	Change in Downstream Price (dependent variable):			
Parameter	**ΔUSGSPOT** *conv/reg*	**ΔCHIPIPE** *conv/reg*	**ΔCHIRACK** *conv/reg*	**ΔRETPADD 2** *conv/reg*
CONSTANT	0.633 (0.599)	0.149 (0.621)	1.311** (0.621)	0.875** (0.436)
ΔWTI(t)	0.788*** (0.060)	0.791*** (0.055)	0.593*** (0.052)	
ΔWTI(t-1)	0.070 (0.059)	0.002 (0.056)	0.304*** (0.055)	0.360*** (0.043)
ΔWTI(t-2)	0.123** (0.060)	0.051 (0.056)	-0.029 (0.055)	0.210*** (0.043)
ΔWTI(t-3)	0.197*** (0.061)	0.295*** (0.056)	0.193*** (0.054)	0.078* (0.044)
ΔWTI(t-4)	-0.117* (0.060)			0.128*** (0.046)
ΔWTI(t-5)				0.043 (0.046)
ΔWTI(t-6)				0.100** (0.046)
ΔWTI(t-7)				0.009 (0.045)
ΔWTI(t-8)				0.108** (0.045)
ΔWTI(t-9)				0.069 (0.045)
D04OCT93				5.428*** (1.234)
WEEKLY DUMMY	YES*** (1.688)	YES*** (2.668)	YES*** (1.867)	YES*** (1.680)
AR(1)			0.218*** (0.060)	
MA(1)		0.129** (0.065)		
AR(2)	-0.135** (0.063)			0.080 (0.065)
AR(6)	-0.151** (0.066)	-0.165*** (0.062)	-0.307*** (0.062)	
OTHER ARMA TERMS	AR(7,14)	AR(4,7)	AR(3,13)	MA(3)
AMOUNT ASYMMETRY F-STATISTIC p-value	0.238 (0.626)	1.167 (0.281)	0.225 (0.636)	0.445 (0.506)
Sum of Spot Lags	1.06	1.138	1.061	1.106
AIC	3.855444	3.839309	3.768162	3.226603
Adj. R^2	0.484	0.568	0.494	0.409
F-Statistic	5.64	7.62	5.90	4.25
D.W. Statistic	1.99	2.01	2.08	2.00

Table B.2 (Continued)

Notes:

The general form of the linear model is shown in Equation B.1.
All prices are in cents per gallon.
"Δ" is the weekly price change.
The (t), (t-1), (t-2), ..., (t-9) refer to current and lagged values.
WTI refers to the weekly average price for West Texas Intermediate crude oil.
D04OCT93 is a dummy variable corresponding to the change in Federal tax on motor gasoline.
WEEKLY DUMMY refers seasonal variables, the joint F-statistic is reported in parentheses.
AMOUNT ASYMMETRY F-STATISTIC refers to the joint hypothesis test:

$\Delta WTI(t)+\Delta WTI(t-1)+ ... +\Delta WTI(t-k) = 1.0$.

A p-value < 0.05 indicates rejection of the joint hypothesis.

Standard errors appear in parentheses below the parameter estimates.
*** indicates significant at 1% criteria (p-value < 0.01)
** indicates significant at 5% criteria (p-value < 0.05)
* indicates significant at 10% criteria (p-value < 0.10)

Table B.3 OLS Regression Results for Wholesale Price Passthrough Weekly Prices from October 5, 1992 to June 29, 1998

Independent Variable	ΔCHIPIPE	ΔUSGSPOT	ΔUSGSPOT	CHIPIPE	USGSPOT	USGSPOT
	Downstream Price (dependent variable): ←-----PRICE CHANGE-----→			Downstream Price (dependent variable) ←-----PRICE LEVEL-----→		
	ΔCHIRACK *con/reg*	ΔCHIRACK *con/reg*	ΔCHIPIPE con/reg	CHIRACK *con/reg*	CHIRACK *con/reg*	CHIPIPE *con/reg*
CONSTANT	-0.001 (0.010)	0.012 (0.049)	-0.630 (0.472)	1.155 (0.710)	-1.584 (2.701)	2.691 (2.269)
UP(t)	0.629*** (0.018)	0.652*** (0.029)	0.830*** (0.036)	0.632*** (0.018)	0.638*** (0.030)	0.844*** (0.036)
UP(t-1)	0.393*** (0.018)	0.367*** (0.029)	0.051 (0.037)	0.391*** (0.018)	0.366*** (0.029)	0.030 (0.037)
UP(t-2)		-0.007 (0.029)	0.036 (0.037)		-0.010 (0.029)	0.027 (0.037)
UP(t-3)		0.069** (0.029)	0.073** (0.037)		0.038 (0.029)	0.080** (0.036)
UP(t-4)		-0.002 (0.030)			-0.005 (0.029)	
UP(t-5)		0.092*** (0.030)			0.091*** (0.030)	
WEEKLY DUMMY	NO	NO	YES** (1.587)	NO	NO	YES* (1.351)
AR(1)			-0.113* (0.063)	0.656*** (0.091)	.956*** (0.044)	0.684*** (0.062)
MA(1)	-0.652*** (0.047)			-0.305*** (0.116)		0.140* (0.081)
AR(3)	-0.226*** (0.061)	-0.228*** (0.057)			-0.123*** (0.043)	
AR(6)	-0.179*** (0.059)	-0.196*** (0.057)	-0.203*** (0.063)			
Other ARMA terms		AR(12)	AR(2,4,5,7,9)	AR(5,9)	MA(12)	AR(11,14), MA(3)
AMOUNT ASYMMETRY F-STATISTIC p-value	2.972* (0.085)	9.490*** (0.002)	0.032 (0.859)	3.547* (0.061)	5.461** (0.020)	0.248 (0.619)
Sum of Spot Lags	1.022	1.172	0.991	1.023	1.118	0.9803
AIC	2.182498	2.952505	3.343235	2.184916	2.935670	3.308240
Adj. R^2	0.879	0.741	0.739	0.992	0.983	0.977
F-Statistic	431.2	95.6	14.6	5945.7	1872.7	215.8
D.W. Statistic	1.96	2.05	2.02	2.04	2.04	1.98

Table B.3 (Continued)

Notes:

The general form of the linear model is shown in Equation B.1.
All prices are in cents per gallon.
"Δ" is the weekly price change.
The (t), (t-1), (t-2), ..., (t-5) refer to current and lagged values.
UP refers to the weekly average price (or price change) for regular, conventional motor gasoline at U.S. Gulf Coast (USGSPOT); or Chicago Pipeline price (CHIPIPE).
WEEKLY DUMMY refers seasonal variables, the joint test F-statistic is reported in parentheses.
AMOUNT ASYMMETRY F-STATISTIC refers to the joint hypothesis test:

$\Delta UP(t)+\Delta UP(t-1)+ ... +\Delta UP(t-k) = 1.0$

A p-value < 0.05 indicates rejection of the joint hypothesis.

Standard errors appear in parentheses below the parameter estimates.
*** indicates significant at 1% criteria (p-value < 0.01)
** indicates significant at 5% criteria (p-value < 0.05)
* indicates significant at 10% criteria (p-value < 0.10)

Appendix C
Methodology for Asymmetry Testing

Previous investigators (see BBY and BCG in Chapter 2) used a transfer function model:

$$y_t = a_o + A(L)y_{t-1} + C(L)z_t + B(L)e_t$$

where A(L), B(L), and C(L) are polynomials in the lag operator L;

and y_t and z_t are sequences of time series data.

This report could not use a transfer function model because the data series violated one of the critical assumptions for transfer analysis: "that $\{z_t\}$ is an exogenous process that evolves independently of the $\{y_t\}$ sequence. Innovations in $\{y_t\}$ are assumed to have no effect on the $\{z_t\}$ sequence, ..."[1] In the majority of market pairs in the data series, Granger Causality tests and Variance Decomposition tests, as described by BBY, indicated bi-directional causality.

This being the case, this study did not use the model which the other studies estimated:

$$\begin{aligned}\Delta DOWN_t &= C + \sum \beta_i \Delta UP_{t-i} + \sum \alpha_i \Delta DOWN_{t-i} \\ &+ \sum \gamma_i (U_{t-i} * \Delta UP_{t-i}) + \sum \delta_i (D_{t-i} * \Delta DOWN_{t-i}) + e_t \qquad \text{EQN C.1}\end{aligned}$$

where

Δ	is the week-to-week change.
$DOWN_t$	is the downstream price at time t.
UP_t	is the upstream price at time t.
U_t	is 1.0 if $UP_t > UP_{t-1}$, and 0.0 otherwise.
D_t	is 1.0 if $DOWN_t > DOWN_{t-1}$, and 0.0 otherwise.

The summation for the UP_{t-i} terms is from 0 to n (the lag length) and the summation for the $DOWN_{t-i}$ terms is from 1 to n.

Instead of EQN C.1, after finding that multicollinearity was a significant problem and that the asymmetry test results depended on the lag length, this study used a modified version of the BBY

1 Enders, Walter, *Applied Econometric Time Series*, Wiley (New York, 1995), p. 277.

test equation where the lags of the dependent variable were eliminated from the model specification (i.e. a price passthrough model with asymmetry test terms):

$$\Delta DOWN_t = C + \sum \beta_i \Delta UP_{t-i} + \sum \gamma_i ASSYM_{t-i} + e_t \qquad \text{EQN C.2}$$

where

$ASSYM_t$ equals (U_t * ΔUP_t)

See Appendix D for the derivation. The elimination of the lagged endogenous variables decreases the likelihood that multicollinearity will be a problem. Investigations using the transfer function model indicated that multicollinearity was a pervasive problem, preventing reliable estimation of the model regression coefficients. However, use of this simpler model allows only for the testing of the downstream price variable for an asymmetrical price response from price changes in the upstream price variable, rather than an asymmetrical response from either the upstream price innovation or the induced downstream price response. The actual testing for pattern asymmetry consists of a joint F-test of parameter coefficients on the ASSYM terms:

H_0: all of the γ_i are jointly equal to zero

H_A: not all the γ_i are equal to zero

Tables C.1 to C.3 show the parameter estimates and pattern asymmetry test results for the various market levels. The estimation method used was Ordinary Least Squares; the AR, MA terms are used to make the regression residuals test as random. The lag length (and AR, MA terms) was chosen by using the estimation which minimized the Akaike Information Criterion (AIC) value; the lag length and AR, MA terms were usually, but not always the same as those shown in Tables B.1 - B.3.

The results of the statistical test for pattern asymmetry for the response of retail prices to changes in upstream prices are shown in Table C.1. The test results show evidence for pervasive pattern asymmetry for retail prices except when crude oil (WTI) spot prices is the explanatory variable. There is no easy explanation for this seemingly anomalous lack of pattern asymmetry from WTI prices other than that whenever weekly seasonal dummy variables were required for model specification, the standard errors of all the estimated coefficients were uniformly larger (often by a factor of 2) than those in estimated models which did not require the use of seasonal dummy variables. It is possible that the seasonal component in the data adds noise to the price data and thus reduces the testing significance relative to prices (and models) without a seasonal component.

The pattern asymmetry test results for downstream gasoline price responses to WTI crude oil price changes are shown in Table C.2. These results show no evidence for pattern asymmetry. Table C.3 shows the test results for pattern asymmetry in the wholesale gasoline markets. This table shows the results form both the first difference and level models of wholesale price responses. The only market which demonstrates pattern asymmetry is the pipeline price response to USG spot price changes, where both the level and first difference models indicate the existence of significant pattern asymmetry. The other wholesale markets (USG spot→rack, and pipeline→rack) do not indicate the presence of pattern asymmetry.

In conclusion, pattern asymmetry appears to be pervasive only for retail price responses and does not usually occur in spot and wholesale markets. The actual importance of this finding of retail pattern asymmetry to the idea of market imperfection is unclear, because the discussion in Appendix A demonstrates that it may be possible for lagged downstream market price adjustments to upstream price changes to induce price response patterns which appear pattern asymmetric.

Table C.1 OLS Test Equation for Retail Pattern Asymmetry Weekly Prices from October 5, 1992 to June 29, 1998

Independent Variable	WTISPOT	USGSPOT	CHIPIPE	CHIRACK
	Change in Downstream Price (dependent variable): PADD 2 Retail Price, conventional regular gasoline			
Parameter				
CONSTANT	0.821	0.059	-0.099	-0.110
	(0.502)	(0.152)	(0.085)	(0.099)
ΔUP(t-1)	0.249***	0.196***	0.222***	0.333***
	(0.083)	(0.049)	(0.041)	(0.040)
ΔUP(t-2)	0.244***	0.279***	0.264***	0.149***
	(0.083)	(0.050)	(0.047)	(0.045)
ΔUP(t-3)	0.022	0.173***	0.141***	0.048
	(0.085)	(0.051)	(0.047)	(0.045)
ΔUP(t-4)	0.194**	0.114**	0.111**	0.086*
	(0.088)	(0.051)	(0.048)	(0.045)
ΔUP(t-5)	0.077	0.129**	0.062	0.108**
	(0.087)	(0.051)	(0.047)	(0.045)
ΔUP(t-6)	0.119	0.039	0.036	-0.043
	(0.088)	(0.051)	(0.047)	(0.045)
ΔUP(t-7)	-0.075	0.083*	0.007	0.148***
	(0.087)	(0.048)	(0.047)	(0.041)
ΔUP(t-8)	0.182**		0.056	
	(0.086)		(0.041)	
ASSYM(t-1)	0.216	0.318***	0.236***	0.386***
	(0.133)	(0.083)	(0.067)	(0.065)
ASSYM(t-2)	-0.085	-0.092	-0.026	-0.131*
	(0.137)	(0.085)	(0.074)	(0.067)
ASSYM(t-3)	0.085	-0.203**	-0.140*	0.032
	(0.137)	(0.085)	(0.074)	(0.067)
ASSYM(t-4)	-0.130	-0.027	-0.008	-0.019
	(0.139)	(0.086)	(0.074)	(0.067)
ASSYM(t-5)	-0.048	-0.124	-0.075	-0.100
	(0.139)	(0.085)	(0.074)	(0.067)
ASSYM(t-6)	-0.033	0.073	0.067	0.047
	(0.140)	(0.085)	(0.074)	(0.068)
ASSYM(t-7)	0.136	0.002	0.039	-0.063
	(0.138)	(0.082)	(0.074)	(0.065)
ASSYM(t-8)	-0.142		0.026	
	(0.138)		(0.067)	
WEEKLY DUMMY	YES**	NO	NO	NO
	(1.585)			
D04OCT93	5.673***	4.913***	5.047***	4.943***
	(1.274)	(0.887)	(0.725)	(0.680)
AR(1)		-0.242	0.182	
		(0.350)	(0.133)	
MA(1)		0.084	-0.579***	-0.301***
		(0.356)	(0.110)	(0.057)
OTHER ARMA TERMS	AR(2,3)	MA(3)		
PATTERN ASYMMETRY F-STATISTIC	0.721	3.150***	2.346**	5.407***
p-value	(0.673)	(0.003)	(0.019)	(0.000)
AIC	3.267785	2.658656	2.425713	2.189069
Adj. R^2	0.397	0.619	0.699	0.759
F-Statistic	3.8	27.8	37.3	59.8
D.W. Statistic	1.97	1.99	2.00	1.99

Table C.1 (Continued)

Notes:

The general form of the linear model is shown in Equation C2.
All prices are in cents per gallon.
"Δ" is the weekly price change.
The (t-1), (t-2), ..., (t-8) refer to lagged values.
UP refers to the weekly average price for regular, conventional motor gasoline at U.S. Gulf Coast (USGSPOT); Chicago Pipeline price (CHIPIPE); Chicago Rack price (CHIRACK); or it refers to the weekly average spot price for West Texas Intermediate Crude Oil (WTISPOT)
ASSYM is the defined variable to test for asymmetry.
D04OCT93 is a dummy variable corresponding to the change in Federal tax on motor gasoline.
WEEKLY DUMMY refers seasonal variables, the joint test F-statistic is reported in parentheses.
PATTERN ASYMMETRY F-STATISTIC refers to the hypothesis test: ASSYM(t)=ASSYM(t-1)=ASSYM(t-2)= ... = 0. A p-value < 0.05 indicates rejection of the joint hypothesis.
Standard errors appear in parentheses below the parameter estimates.
*** indicates significant at 1% criteria (p-value < 0.01)
** indicates significant at 5% criteria (p-value < 0.05)
* indicates significant at 10% criteria (p-value < 0.10)

Table C.2 Test Equation for WTI Passthrough Pattern Asymmetry Weekly Prices from October 5, 1992 to June 29, 1998

Independent Variable	WTISPOT	WTISPOT	WTISPOT	WTISPOT
	Change in Downstream Price (dependent variable):			
Parameter	**ΔUSGSPOT**	**ΔCHIPIPE**	**ΔCHIRACK**	**ΔRETPADD2**
CONSTANT	0.584 (0.638)	0.186 (0.655)	1.235* (0.654)	0.821 (0.502)
ΔWTI(t)	0.741*** (0.109)	0.654*** (0.101)	0.466*** (0.097)	
ΔWTI(t-1)	0.008 (0.110)	0.033 (0.100)	0.312*** (0.094)	0.249*** (0.083)
ΔWTI(t-2)	0.213* (0.110)	0.022 (0.100)	-0.116 (0.093)	0.244*** (0.083)
ΔWTI(t-3)	0.281** (0.113)	0.446*** (0.104)	0.367*** (0.100)	0.022 (0.085)
ΔWTI(t-4)	-0.068 (0.113)			0.194** (0.088)
ΔWTI(t-5)	-0.083 (0.111)			0.077 (0.087)
ΔWTI(t-6)				0.119 (0.088)
ΔWTI(t-7)				-0.075 (0.087)
ΔWTI(t-8)				0.182** (0.086)
ASSYM(t)	0.096 (0.172)	0.269* (0.160)	0.261* (0.154)	
ASSYM(t-1)	0.099 (0.179)	-0.073 (0.158)	-0.022 (0.146)	0.216 (0.133)
ASSYM(t-2)	-0.213 (0.176)	0.030 (0.159)	0.137 (0.145)	-0.085 (0.137)
ASSYM(t-3)	-0.165 (0.178)	-0.277* (0.166)	-0.326** (0.159)	0.085 (0.137)
ASSYM(t-4)	-0.066 (0.181)			-0.130 (0.139)
ASSYM(t-5)	0.296 (0.179)			-0.048 (0.139)
ASSYM(t-6)				-0.033 (0.140)
ASSYM(t-7)				0.136 (0.138)
ASSYM(t-8)				-0.142 (0.138)
WEEKLY DUMMY	YES*** (1.656)	YES*** (2.557)	YES*** (1.860)	YES** (1.585)
D04OCT93				5.673*** (1.274)
AR(1)			0.225*** (0.061)	
MA(1)		0.136** (0.065)		
AR(2)	-0.149 (0.064)			0.066 (0.066)

Table C.2 (Continued)				
Independent Variable	**WTISPOT**	**WTISPOT**	**WTISPOT**	**WTISPOT**
	Change in Downstream Price (dependent variable):			
	ΔUSGSPOT	**ΔCHIPIPE**	**ΔCHIRACK**	**ΔRETPADD2**
OTHER ARMA TERMS	AR(6,7,14)	AR(4,6,7)	AR(3,6,13)	AR(3)
PATTERN ASYMMETRY F-STATISTIC	0.852	1.128	1.533	0.721
p-value	(0.531)	(0.344)	(0.193)	(0.673)
AIC	3.874764	3.847062	3.769134	3.267785
Adj. R^2	0.482	0.569	0.499	0.397
F-Statistic	5.1	7.2	5.7	3.8
D.W. Statistic	1.98	2.01	2.07	1.97

Notes:

The general form of the linear model is shown in Equation C2.
All prices are in cents per gallon.
"Δ" is the weekly price change.
The (t), (t-1), ..., (t-8) refer to lagged values.
WTI refers to the weekly average spot price for West Texas Intermediate crude oil (WTISPOT).
ASSYM is the defined variable to test for asymmetry.
D04OCT93 is a dummy variable corresponding to the change in Federal tax on motor gasoline.
WEEKLY DUMMY refers seasonal variables, the joint test F-statistic is reported in parentheses.
PATTERN ASYMMETRY F-STATISTIC refers to the hypothesis test: ASSYM(t)=ASSYM(t-1)=ASSYM(t-2)= ... = 0.
A p-value < 0.05 indicates rejection of the joint hypothesis.
Standard errors appear in parentheses below the parameter estimates.
*** indicates significant at 1% criteria (p-value < 0.01)
** indicates significant at 5% criteria (p-value < 0.05)
* indicates significant at 10% criteria (p-value < 0.10)

Table C.3 OLS Test Equation for Wholesale Pattern Asymmetry
Weekly Prices from October 5, 1992 to June 29, 1998

Independent Variable	ΔCHIPIPE conv/reg	ΔUSGSPOT *conv/reg*	ΔUSGSPOT conv/reg	CHIPIPE conv/reg	USGSPOT *conv/reg*	USGSPOT *conv/reg*
	Downstream Price (dependent variable): <-------------------PRICE CHANGE----------------->			**Downstream Price (dependent variable): <----------------PRICE LEVEL--------------->**		
	ΔCHIRACK *conv/reg*	**ΔCHIRACK** *conv/reg*	**ΔCHIPIPE** *conv/reg*	**CHIRACK** *conv/reg*	**CHIRACK** *conv/reg*	**CHIPIPE** *conv/reg*
CONSTANT	-0.018 (0.034)	0.137 (0.148)	-0.565 (0.480)	1.079 (0.738)	-1.624 (2.803)	2.105 (1.946)
UP(t)	0.580*** (0.034)	0.596*** (0.056)	0.767*** (0.065)	0.651*** (0.029)	0.658*** (0.048)	0.982*** (0.049)
UP(t-1)	0.430*** (0.034)	0.425*** (0.056)	0.127** (0.067)	0.375*** (0.028)	0.388*** (0.045)	0.043 (0.048)
UP(t-2)		0.014 (0.056)	-0.036 (0.066)		-0.007 (0.044)	-0.009 (0.048)
UP(t-3)		0.047 (0.056)	0.205*** (0.065)		-0.011 (0.044)	
UP(t-4)		0.038 (0.057)			-0.029 (0.045)	
UP(t-5)		0.127** (0.056)			0.122*** (0.047)	
ASSYM(t)	0.093* (0.056)	0.105 (0.093)	0.142 (0.110)	-0.002 (0.002)	-0.001 (0.004)	-0.011*** (0.004)
ASSYM(t-1)	-0.074 (0.056)	-0.111 (0.093)	-0.172 (0.113)	-0.001 (0.002)	-0.003 (0.005)	-0.011*** (0.004)
ASSYM(t-2)		-0.048 (0.093)	0.141 (0.112)		-0.004 (0.005)	-0.009*** (0.002)
ASSYM(t-3)		0.034 (0.093)	-0.262** (0.110)		0.001 (0.005)	
ASSYM(t-4)		-0.074 (0.094)			0.003 (0.004)	
ASSYM(t-5)		-0.056 (0.093)			-2.8E-05 (0.002)	
WEEKLY DUMMY	NO	NO	YES*** (1.690)	NO	NO	NO
AR(1)			-0.104* (0.063)	0.662*** (0.092)	.961*** (0.044)	0.715*** (0.050)
MA(1)	-0.658*** (0.047)			-0.310*** (0.116)		0.160** (0.070)
AR(3)	-0.228*** (0.061)	-0.235*** (0.057)			-0.127*** (0.044)	
AR(6)	-0.191*** (0.059)	-0.196*** (0.058)	-0.219*** (0.063)			
Other ARMA terms		AR(12)	AR(2,4,5,7,9)	AR(5,9)	MA(12)	AR(11,14),MA(3)
PATTERN ASYMMETRY F-STATISTIC p-value	1.359 (0.259)	0.988 (0.433)	2.615** (0.036)	1.192 (0.193)	0.610 (0.723)	6.305*** (0.000)
AIC	2.186592	2.971967	3.325789	2.195707	2.963053	3.196083
Adj. R^2	0.879	0.741	0.746	0.992	0.983	0.977
F-Statistic	309.2	57.7	14.2	4440.4	1114.7	1138.7
D.W. Statistic	1.96	2.04	2.04	2.04	2.04	1.98

Table C.3 (Continued)

Notes:
The general form of the linear model is shown in Equation C.2.
All prices are in cents per gallon.
"Δ" is the weekly price change.
The (t), (t-1), (t-2), ..., (t-5) refer to current and lagged values.
UP refers to the weekly average price (or price change) for regular, conventional motor gasoline at U.S. Gulf Coast (USGSPOT); or Chicago Pipeline price (CHIPIPE).
WEEKLY DUMMY refers seasonal variables, the joint test F-statistic is reported in parentheses.
PATTERN ASYMMETRY F-STATISTIC refers to the hypothesis test: ASSYM(t)=ASSYM(t-1)=ASSYM(t-2)= ... = 0. A p-value < 0.05 indicates rejection of the joint hypothesis.
Standard errors appear in parentheses below the parameter estimates.
*** indicates significant at 1% criteria (p-value < 0.01)
** indicates significant at 5% criteria (p-value < 0.05)
* indicates significant at 10% criteria (p-value < 0.10)

Appendix D
Derivation of Pattern Asymmetry Test Equation

The following is a demonstration of the model that was used to test for pattern and amount asymmetry:

Let downstream (e.g. retail) motor gasoline price changes during periods of RISING upstream (e.g. USG spot motor gasoline) prices be given by the model:

$$\Delta y_t = c + \alpha_1 \Delta x_{t-1} + \alpha_2 \Delta x_{t-2} + \alpha_3 \Delta x_{t-3} + \ldots + \alpha_\tau \Delta x_{t-\tau} + e_t \qquad \text{EQN D.1}$$

where Δy_t is the change in downstream price at time t, and Δx_{t-i} is the change in upstream price at time period t-i. Similarly, during periods of STABLE and FALLING upstream prices the model becomes:

$$\Delta y_t = c + \gamma_1 \Delta x_{t-1} + \gamma_2 \Delta x_{t-2} + \gamma_3 \Delta x_{t-3} + \ldots + \gamma_\tau \Delta x_{t-\tau} + \varepsilon_t \qquad \text{EQN D.2}$$

where Δy_t and Δx_{t-i} are similarly defined for periods of stable or falling upstream prices. If $\alpha_i = \gamma_i$ for all i, then these two equations can be combined to form:

$$\Delta y_t = c + \beta_1 \Delta x_{t-1} + \beta_2 \Delta x_{t-2} + \beta_3 \Delta x_{t-3} + \ldots + \beta_\tau \Delta x_{t-\tau} + \varepsilon_t. \qquad \text{EQN D.3}$$

where the model assumes pattern symmetry. The concept of amount symmetry can be tested by the hypothesis $\sum \beta_i = 1.0$. The results of the Wald test for amount asymmetry are reported in Appendix B; EQN B.1 has the same form as EQN D.3 with the test results shown in Tables B.1 to B.3.

However, *if we assume* $\alpha_i \neq \gamma_i$ *for some i,* then EQN D.1 and D.2 can be combined to form:

$$\Delta y_t = c + \beta_1 \Delta x_{t-1} + \beta_2 \Delta x_{t-2} + \beta_3 \Delta x_{t-3} + \ldots + \beta_\tau \Delta x_{t-\tau} \qquad \text{EQN D.4}$$
$$+ \delta_1 D_{t-1} \Delta x_{t-1} + \delta_2 D_{t-2} \Delta x_{t-2} + \delta_3 D_{t-3} \Delta x_{t-3} + \ldots + \delta_\tau D_{t-\tau} \Delta x_{t-\tau} + \varepsilon_t.$$

where for all $i=1,\tau$, $D_{t-i} = 1$ if upstream prices are rising and $D_{t-i} = 0$ otherwise. A statistical test for pattern asymmetry is to test the joint hypothesis $\delta_i = 0$ for $i=1,\tau$. The results for the Wald test for pattern asymmetry are reported in Appendix C; EQN C.2 has the same form as EQN D.4, with the test results shown in Tables C.1 to C.3.