

# Oil price volatility and the asymmetric response of gasoline prices to oil price increases and decreases

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## Abstract

This paper analyzes the effect of volatility in oil prices on the degree of asymmetry in the response of gasoline prices to oil price increases and decreases. Several time series measures of the asymmetry between the responses of gasoline prices to oil price increases and decreases and several measures of the oil price volatility are constructed. In all models, the degree of asymmetry in gasoline prices declines with an increase in oil price volatility. The results support the oligopolistic coordination theory as a likely explanation of the observed asymmetry and are not consistent with the standard search theory and the search theory with Bayesian updating.

Keywords: *gasoline price response, asymmetric response, search theory*

# 1 Introduction

There has been a lot of attention and controversy from economists to the asymmetric response of gasoline prices to changes in crude oil prices. Karrenbrock (1991) finds that wholesale gasoline price increases for leaded regular gasoline are passed on to the consumer faster than price decreases. In an influential paper, Borenstein *et al.* (1997) present evidence that gasoline prices respond asymmetrically to oil price increases and decreases. That is, gasoline prices adjust faster when oil prices increase than when they decrease. This is further confirmed by Galeotti *et al.* (2003) who document evidence of widespread differences in the adjustment of gasoline price to changes in input price.

Godby *et al.* (2000) are skeptical of this view. Applying a threshold regression model, the authors are unable to find evidence of the asymmetric adjustment in the Canadian gasoline market. Bachmeier and Griffin (2003) find no evidence of asymmetry between daily spot gasoline prices and crude oil prices. Bettendorf *et al.* (2003) study the retail price adjustment in the Dutch gasoline market. These authors argue that conclusions on the asymmetry are dependent on the choice of the day when the prices are observed.

Peltzman (2000) shows that the problem of an asymmetric response of output prices to changes in input prices is not specific to the gasoline market. He analyzes 77 consumer and 165 producer goods and finds that output prices tend to respond faster to input price increases than to decreases. This finding is present in two of every three markets examined.

Several explanations of the asymmetry have been proposed and tested. Borenstein *et al.* (1997) suggest three possible explanations for the asymmetric response of gasoline prices: (i) the oligopolistic coordination theory, (ii) the production and inventory cost of adjustment, and (iii) the search theory. Borenstein and Shepard (2002) argue that the cost of adjustment of production and inventory cause the asymmetric response of gasoline prices. Similar results are obtained by Kaufmann and Laskowski (2004) who support an idea that

asymmetries in the gasoline price response are generated by refinery utilization rates and inventory. Another explanation was offered by Johnson (2002) who argues that search models with Bayesian updating can generate asymmetric price responses. According to this theory, an increase in the retail price of gasoline raises incentives to search for a lower priced retail outlet, while a decrease in the price lowers the incentive to search. Different search rules of consumers influence the elasticity of a retailer's demand and this leads to the asymmetric response of gasoline prices.<sup>1</sup> However, Brown and Yucel (2000) conclude that market power is not responsible for the asymmetry. Any effect of market power attributed to search costs and locational advantages may be viewed as the costs of product differentiation under monopolistic competition.

A broad descriptive approach was taken by Peltzman (2000). The author examines how the measures of imperfect competition, inventory cost, inflation-related asymmetric menu costs, and input price volatility influence the degree of asymmetry. In this study, Peltzman finds a negative correlation between the degree of asymmetry and input price volatility, but he finds no relationship between the degree of asymmetry and proxies for market power, inventory cost, and asymmetric menu costs.

In this paper, I discuss the implications of oligopolistic coordination theory, search theory, and search theory with Bayesian updating on the relationship between oil price volatility and the degree of gasoline price asymmetry. Then I empirically examine the relationship between oil price volatility and the degree of asymmetry. To my knowledge, this kind of analysis has not been done before.<sup>2</sup>

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<sup>1</sup>Kaufmann and Laskowski (2004) find that asymmetry in the response of heating oil price to a change in crude oil price may be generated by contractual arrangements between retailers and consumers. These agreements reduce consumer search for the lowest price.

<sup>2</sup>Economists have studied the effect of oil price volatility on different economic variables. Pindyck (2004a) studies the relationship between the volatility of a commodity, its price and inventory level. Pindyck (2004b) examines the behavior of natural gas and crude oil price volatility in the last decade. Sadorsky (1999) finds

According to oligopolistic coordination theory, an increase in the price volatility leads to a faster response of gasoline prices to an oil price decrease and a reduction in the degree of asymmetry in the gasoline price response. Standard search theory implies that volatile crude oil prices create a signal-extraction problem for consumers; it encourages consumers to search less and makes retailers less competitive. In this model, an increase in crude oil price volatility leads to an increase in the market power of retail outlets causing a slower response of the gasoline prices to an oil price decline. This implies that one should observe an increase in the degree of asymmetry. According to search theory with Bayesian updating, consumers are likely to search less when oil price volatility is high than when it is low. As a result, consumers are less likely to switch to different retail outlets. Because this does not cause an increase in demand for outlets that charge a low price relative to the market, retailers do not adjust prices to an oil price increase as fast as when consumers are engaged in search. In this case, an increase in oil price volatility should lead to a decline in the degree of asymmetry of the gasoline price response.

Using several measures of oil price volatility and asymmetry of gasoline price response, I examine how oil price volatility influences the degree of asymmetry in the gasoline price response and give empirical evidence on the validity of the three possible explanations of gasoline price asymmetry. I use the vector autoregressive (VAR) approach in the analysis. In the VAR model, I show that an increase in oil price volatility leads to a decrease in the degree of asymmetry in the response of gasoline prices. This behavior is consistent with the oligopolistic coordination theory and the search theory with Bayesian updating.

To distinguish between two competing explanations, I check whether a decline in asymmetry after an oil price change is attributed to a slower gasoline price response after an oil price increase or a faster gasoline price response after an oil price decrease. To achieve this, 

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that oil price volatility seems to affect real stock returns. Lee *et al.* (1995) use the univariate GARCH model for oil price volatility to show that oil price shocks influence macroeconomic activity.

I divide the sample into two subsamples and estimate gasoline price responses for a period with low volatility and a period with high volatility of crude oil prices. I find that the decline in the degree of asymmetry is attributed to a faster response of gasoline prices to a decline in crude oil prices. This result points to the oligopolistic coordination theory as a likely explanation of asymmetry.

Another reason for the analysis of oil price volatility and the degree of gasoline price asymmetry is that Peltzman (2000) finds a negative correlation between input price volatility and the degree of output price asymmetry. Given the growth in the literature on gasoline price asymmetry, it is instructive to check how robust Peltzman's finding is for the gasoline market.

The main conclusions from the study of the relationship between oil price volatility and the gasoline price asymmetry are as follows. First, the oligopolistic coordination theory is the most likely explanation among the three possible explanations considered. Second, using many different measures of the degree of gasoline price asymmetry and oil price volatility, I confirm a finding of Peltzman (2000) that there is a negative relationship between oil price volatility and the gasoline price asymmetry.

The structure of the paper is as follows. In Section 2, I present three possible explanations of the asymmetric response in gasoline prices and their implications for the relationship between oil volatility and gasoline asymmetry. The econometric model for testing the explanations is presented in Section 3. I discuss the results on the relationship between oil price volatility and the gasoline price asymmetry in Section 4. In Section 5, I present the difference in the gasoline price response across two periods with high and low oil price volatility. Concluding remarks are in Section 6.

## 2 Asymmetry explanations and oil price volatility

Before I explain the asymmetry explanations examined in the paper, I present a typical asymmetric response of gasoline prices to changes in crude oil prices in Figure 1. Panel (a) exhibits two features of gasoline price response: a faster response of gasoline prices to an oil price increase than decrease and a lag in responses. In panels (b) and (c) of Figure 1, I show that a decline in the degree of asymmetry may be a consequence of either a faster response of gasoline prices to an oil price decrease or a slower response to an oil price increase. Once I find a negative relationship between oil price volatility and the degree of asymmetry, I check whether a decline in the asymmetry is described by Figure 1b or 1c.

Several explanations for the asymmetric response of gasoline prices have been suggested. I present empirical evidence about the validity of the oligopolistic coordination theory proposed by Borenstein *et al.* (1997), the search theory with Bayesian updating originally developed by Benabou and Gertner (1993) and applied by Johnson (2002) to the gasoline market, and the standard search theory.<sup>3</sup> The implication of these models for the relation between oil price volatility and the degree of asymmetry are summarized in Figure 2.

One of the asymmetry explanations proposed by Borenstein *et al.* (1997) is that "prices are sticky because when input prices fall the old price offers a natural focal point for oligopolistic sellers". This theory is based on the assumption that the observed asymmetry in the response of gasoline prices is evidence of imperfect competition among retailers.<sup>4</sup> In the retail gasoline market, firms have imperfect knowledge about the price charged by other competitors and retailers may charge a price above the competitive level if their sales remain above a threshold level. In this case, price reduction occurs only if there is a significant drop

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<sup>3</sup>See Peltzman (2000) for a broad overview of suggested explanations for the observed asymmetry in the response of output prices to input price changes.

<sup>4</sup>Borenstein and Shepard (1994) present evidence consistent with tacit collusion in retail gasoline markets.

in sales indicating price cutting by other retailers.<sup>5</sup>

Borenstein *et al.* (1997) argue that an oil price increase would trigger an immediate gasoline price adjustment because, otherwise, retail margins may become negative. There is no such restraint when crude oil prices decline. In this case, retailers would decrease their prices slowly over time in an equilibrium response to the threat of price cutting by competitors. As a result, gasoline prices adjust faster to oil price increases than decreases.

This model does not explain how retailers will coordinate on a particular price. Borenstein *et al.* (1997) argue that a price that firms charge before an oil price reduction is a focal point for coordination, but it is not a unique equilibrium. A consequence of this model is that when coordination breaks down, retailers immediately lower prices to the competitive level.<sup>6</sup> As a result, there should be a faster adjustment of gasoline prices to an oil price reduction when oligopolistic coordination fails. Because firms face many competitors which can not be monitored at low cost, I assume that an increase in oil price volatility increases uncertainty and impedes the coordination among retailers and raises the likelihood of coordination failure. This assumption implies that, according to the oligopolistic coordination theory, an increase in oil price volatility leads to a *faster* response of gasoline prices to an oil price *decline*. Because there is no change in the response of gasoline prices to an oil price increase, the increase in oil volatility results in the overall gasoline asymmetry reduction of the shape presented in Figure 1b.

Depending on the assumed transmission mechanism, an increase in the oil price volatility may have two opposite effects in search theory models: (i) increase the gasoline price asymmetry and (ii) decrease the degree of gasoline price asymmetry. The search theory model

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<sup>5</sup>Green and Porter (1984) study the nature of cartel self-enforcement in the presence of demand uncertainty.

<sup>6</sup>Green and Porter (1984) conclude that in such models competitive and collusive behavior will be observed at various times.



with Bayesian updating of Benabou and Gertner (1993) or Johnson (2002) leads to a decline in the gasoline price asymmetry when oil price volatility increases, while standard search theory models have an opposite implication.

Johnson (2002) argues that a faster adjustment of gasoline prices to an oil price increase is attributed to increased search when gasoline prices start rising and decreased search when prices fall. He assumes that consumers employ Bayesian updating (learning) of the prior probabilities about the distribution of prices at different retail stations. These probabilities are adjusted as new information becomes available. The author argues that an increase in oil prices causes consumers to form a new probability distribution about retail prices. If search costs are low relative to the gains determined by the new probabilities, consumers will search for lower-priced outlets. A decrease in gasoline price will reduce incentives to search.<sup>7</sup>

Retailers may be reluctant to raise prices fast after an oil price increase, but an increase in consumer search leads to jumps in demand for lower-priced retail stations that do not increase gasoline prices immediately. To meet the increased demand, retail stations are forced to increase gasoline prices leading to a fast response of gasoline prices to an oil price increase. When gasoline prices start declining, consumers search less so that there is no change in the demand for higher-priced retailers and they adjust prices slower.

The fact that this model predicts an increased search when price rises and decreased search when price declines explains the asymmetry, but I am interested in the relation between oil price volatility and asymmetry. To examine this question, I need to make an assumption about the relationship between oil price volatility and consumer search. In this framework, Benabou and Gertner (1993) show that the effect of increased price volatility on consumer search depends on the correlation and variance effects of volatility.<sup>8</sup> I assume that the correlation effect dominates the variance effect and search declines when oil price

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<sup>7</sup>Benabou and Gertner (1993) show that in some cases lower prices may increase the search.

<sup>8</sup>See Benabou and Gertner (1993) for details.

volatility rises. Then, according to the transmission mechanism, a lower consumer search should result in a *slower* adjustment of gasoline prices in response to an oil price *increase*. This leads to a lower degree of asymmetry of gasoline prices of the shape presented in Figure 1c.

The assumption that search declines in response to higher oil price volatility is important for distinguishing the search theory with Bayesian updating from the oligopolistic coordination theory. Note that in the framework of search theory with Bayesian updating, an assumption of an increase in search when oil price volatility rises would lead to a *faster* response of gasoline prices in response to an oil price *decrease* resulting in the asymmetry decline depicted in Figure 1b. This would be the same effect as for the oligopolistic theory which makes two theories indistinguishable.

An alternative search theory explanation without learning is that an increase in oil volatility increases search costs creating a signal-extraction problem for consumers. Search behavior of consumers is based on the relative variability of idiosyncratic (retailer specific) and common oil shocks. When retail outlets are subject to common oil price shocks and consumers know that the volatility of these shocks increased, consumers are less likely to search for lower-priced retailers as price rises because they believe that gasoline price changes reflect movements in the market oil price and are not specific to an outlet. An increased volatility results in temporary reduction in search and an increase in market power of retailers. This should lead to a higher degree of asymmetry because, according to this model, retailers should respond even *slower* to oil price *decreases* and *faster* to oil price *increases*.

The considered transmission mechanisms of an increase in oil price volatility on the gasoline asymmetry are summarized in Figure 2. The oligopolistic coordination theory and the search theory with Bayesian updating both predict a negative relationship between oil price volatility and the degree of gasoline asymmetry, while the standard search theory predicts a positive relationship. This implies that the finding of a positive relationship between oil price

volatility and the gasoline price asymmetry speaks in favor of the standard search theory explanation. A negative relationship does not give a clear answer as to which model offers an appropriate explanation of the observed asymmetry: oligopolistic coordination theory or search theory with Bayesian updating. In this case, I conduct further analysis to distinguish the two theories and check whether a decline in the asymmetry has the shape of Figure 1b (oligopolistic coordination theory) or Figure 1c (search theory with Bayesian updating).

### 3 The Econometric Approach

This section describes the econometric model for the analysis of oil price volatility and the gasoline price asymmetry. First, I present a bivariate vector autoregressive model (VAR) of oil price volatility and the gasoline price asymmetry measures and explain how impulse responses are used to answer the question of interest. Next, different approaches for the construction of oil volatility measures and the computation of the gasoline asymmetry measures are presented and discussed.

#### 3.1 The VAR model of oil price volatility and the gasoline price asymmetry

To study the influence of oil price volatility on the degree of gasoline price asymmetry, I estimate the following bivariate VAR model:

$$\begin{bmatrix} y_t \\ x_t \end{bmatrix} = c + \Phi(L) \begin{bmatrix} y_t \\ x_t \end{bmatrix} + e_t \quad (1)$$

where  $y_t$  is a scalar representing a measure of oil price volatility at time period  $t$ ,  $x_t$  is a scalar corresponding to a measure of gasoline price asymmetry in the response to oil price increases

and decreases at period  $t$ ,  $\Phi(L)$  is a lag polynomial of order  $p$ ,  $\Phi(L) = \Phi_1 L + \Phi_2 L^2 + \dots + \Phi_p L^p$ ,  $c$  is a  $2 \times 1$  vector of constant terms,  $e_t$  is a bivariate white noise.

To construct orthogonalized impulse response functions, I use Cholesky decomposition. The identification is achieved through the variable ordering. It is assumed that a measure of oil price volatility affects the gasoline price asymmetry contemporaneously, while the asymmetry in gasoline response influences the oil price volatility only with a lag. Based on the impulse response functions exhibiting the response of gasoline price asymmetry measures to a shock in oil price volatility, I make conclusions about the relationship between the oil volatility and gasoline asymmetry.

Preceding the analysis of model (1) is the construction of oil volatility and gasoline price asymmetry proxies which are discussed next.

### 3.2 Construction of the oil price volatility proxies

I consider three proxies for oil price volatility. Two measures are constructed using the rolling standard deviation of oil prices, and the remaining proxy is computed using a generalized autoregressive conditional heteroskedasticity (GARCH) model.

The first constructed measure is a standard deviation of oil prices during the last half of a year. Because I use the weekly data in the analysis, this corresponds to an estimation window of twenty six observations. The choice of window is ultimately subjective in this approach and I have constructed the second measure of oil price volatility with thirteen observations (one quarter) for the robustness check.

By using a standard deviation as a measure of oil price volatility, I give the same weight to the observations used in the estimation. This may be less appealing compared to the GARCH model, but Campbell *et al.* (2001) point out that the benefit of this approach is

that it does not require a parametric model describing the evolution of volatility over time.<sup>9</sup> Pindyck (2004a) uses sample standard deviations of adjusted daily log changes in spot and futures prices as estimates of volatility.

The next measure of oil price volatility is based on a generalized autoregressive conditional heteroskedasticity model of order one, GARCH(1,1). Even though the GARCH(1,1) volatility model is a parsimonious model, its performance seems to be as good as that of more complex models.<sup>10</sup> Sadorsky (1999), Lee *et al.* (1995), and Pindyck (2004b) use the GARCH(1,1) model for the computation of oil price volatility.

The estimated GARCH(1,1) model is formulated as follows:

$$\begin{aligned}\Delta o_t &= \phi_0 + \sum_{i=1}^p \phi_i \Delta o_{t-i} + e_t, \quad e_t \sim N(0, \sigma_t^2), \quad t = 1, \dots, T \\ \sigma_t^2 &= \alpha_0 + \alpha_1 e_{t-1}^2 + \beta_1 \sigma_{t-1}^2\end{aligned}\tag{2}$$

where  $\Delta o_t$  is the log-differenced oil price. The estimated standard deviations  $\{\sigma_t\}_{t=1}^T$  are used as the proxy of oil price volatility. Oil price observations receive different weights in volatility computation and it makes this measure more attractive compared to the rolling standard deviation measure.<sup>11</sup> I use the Bayesian estimation technique developed by Nakatsuma (2000) for estimation of the GARCH model.<sup>12</sup>

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<sup>9</sup>Campbell *et al.* (2001) use the rolling standard deviations approach to study the volatility of individual stocks.

<sup>10</sup>Hansen and Lunde (2001) argue that the best volatility models do not provide a significantly better forecast than the GARCH(1,1) model.

<sup>11</sup>See Engle (2001).

<sup>12</sup>I would like to thank Teruo Nakatsuma for sharing the GAUSS code for estimation of the GARCH model.

### 3.3 Gasoline price asymmetry measures

Gasoline price asymmetry measures are computed in two steps. In the first step, an econometric model is used to estimate the impulse response functions (IRF) of gasoline prices to oil price increases and decreases. In the second step, the estimated gasoline response functions are used to construct the gasoline price asymmetry measures.

In the first stage, there are two questions involved in the construction of the gasoline impulse response functions. The first question is the choice of the partial adjustment model (PAM) or the vector autoregressive (VAR) model for the construction of gasoline responses. The second question is the choice of estimation window for an econometric model.

I use both the VAR and PAM models to construct the gasoline price impulse response measures and the corresponding gasoline price asymmetry measures. This is made mainly to check the robustness of the results on the relationship between oil price volatility and the asymmetry of gasoline prices. Another reason is that Radchenko (2004) shows that the gasoline price responses from the PAM and VAR models measure the adjustment of gasoline prices to different kinds of oil price changes. The gasoline responses from the PAM model exhibit the response of gasoline prices to anticipated and unanticipated oil price changes when they are restricted to have the same effect on gasoline prices. The VAR based gasoline responses show the adjustment of gasoline prices to unanticipated oil price changes.

The estimation windows in the construction of asymmetry measures are the fixed rolling sample of observations (a fixed number of observations is used in the estimation), and the increasing or recursive sample (the sample is increased by one observation as it becomes available). I use rolling 150 and 200 week fixed and increasing windows (subsamples) for a robustness check. Using a fixed 150 week window or increasing window gives 480 observations of asymmetry measures for a period 12/06/1993 - 02/17/2003, while using a 200 fixed window gives 430 observations of asymmetry measures for a period 11/21/1994 - 02/17/2003.

By using 150 and 200 week fixed windows, I allow that the system may be evolving over time.<sup>13</sup> The use of an increasing window of data is justified if one is not concerned with tracking an evolving system in the sense of time-varying parameters, but is concerned with tracking the system that evolves gradually over time to some final form.<sup>14</sup> Because I am interested in the variation of asymmetry measures, this implies that using the recursive sample to examine the impact of oil price volatility on the degree of gasoline price asymmetry may be inferior to using the fixed estimation window. As the sample size increases in a recursive approach, the variation in the estimates of the VAR model parameters declines which decreases the variation in the estimated impulse response functions. A low variation in the estimated impulse response functions leads to a low variation in the asymmetry measures which makes the analysis of oil price volatility on the asymmetry measures meaningless. I still construct asymmetry measures using the recursive estimation window for the robustness check.

I construct three measures of the degree of the gasoline price asymmetry using the VAR models. Two measures of gasoline price asymmetry are computed using the impulse response function from the VAR models and one measure is constructed using the cumulative impulse response function (CIRF) from the VAR models.

Let  $N$  denote the sample size of the estimation window in the construction of the gasoline price asymmetry measures,  $N = \{150, 200, recursive\}$ . For each period  $\tau = N, N + 1, \dots, T$ , the following three-variable VAR model is estimated:

$$\begin{bmatrix} \Delta C_t^+ \\ \Delta C_t^- \\ \Delta R_t \end{bmatrix} = \mu + B(L) \begin{bmatrix} \Delta C_{t-1}^+ \\ \Delta C_{t-1}^- \\ \Delta R_{t-1} \end{bmatrix} + v_t \quad t = \tau_0, \dots, \tau \quad (3)$$

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<sup>13</sup>See Swanson (1998) for more details.

<sup>14</sup>See Thoma (1994) for details.

where  $R$  is the retail price of gasoline per gallon,  $C$  is the price of crude oil per gallon,  $\Delta C_t = C_t - C_{t-1}$ ,  $\Delta C_t^+ = \max\{\Delta C_t, 0\}$ ,  $\Delta C_t^- = \min\{\Delta C_t, 0\}$ ,  $\mu$  and  $B(L)$  are defined similarly to  $c$  and  $\Phi(L)$  in model (1),  $v_t$  is a white noise process, and  $\tau_0$  and  $\tau$  determine the endpoints of the estimation window,  $\tau_0 = \tau - N + 1$ .

Let  $\{IRF_{j,\tau}^+\}_{j=1}^S$  and  $\{IRF_{j,\tau}^-\}_{j=1}^S$  be the impulse response functions that show the response of gasoline price changes to oil price increases and decreases, respectively, for  $j = 1, \dots, S$  periods after the oil price change for the model estimated at time period  $\tau$ . I denote  $\{CIRF_{j,var,\tau}^+\}_{j=1}^S$  and  $\{CIRF_{j,var,\tau}^-\}_{j=1}^S$  as the adjustment functions that show the cumulative responses of gasoline prices to oil price increases and decreases, respectively, for  $j = 1, \dots, S$  periods after the oil price movement for the model estimated at period  $\tau$ . The cumulative impulse response function for an oil price increase is defined as follows:

$$CIRF_{j,var,\tau}^+ = \sum_{i=1}^j IRF_{i,\tau}^+$$

The cumulative response function for an oil price decline is defined similarly. The time series of the first measure of the gasoline price asymmetry is constructed as follows:

$$AM_{1,\tau}^{var} = \max\{IRF_{j,\tau}^+ - IRF_{j,\tau}^-\}_{j=1}^S, \quad \tau = N, N + 1, \dots, T \quad (4)$$

To clarify how the measure is constructed, assume that I want to compute the asymmetry measure for the period  $\tau = N$  and  $N = 150$ . I use the observations from  $t = 1, 2, \dots, N$  to estimate the VAR model in (3). Then impulse response functions for  $S$  periods are constructed and used to compute  $AM_{1,150}^{var}$ . Then, I set  $\tau = N + 1$ , update the estimation window, and repeat the computations. In this way, I recover the asymmetry series  $\{AM_{1,\tau}^{var}\}_{\tau=N}^T$ .

The second measure is computed as



$$AM_{2,\tau}^{var} = \sum_{j=1}^S (IRF_{j,\tau}^+ - IRF_{j,\tau}^-), \quad \tau = N, N+1, \dots, T \quad (5)$$

While the first asymmetry measure considers the difference between the gasoline price response to oil price increases and decreases for one period of time, the second measure looks at the difference in the gasoline price response over the entire horizon for which IRFs are constructed.

The third asymmetry measure is constructed using the cumulative impulse response function. This measure considers the largest difference in the cumulative response over the IRF horizon and is defined as:

$$AM_{3,\tau}^{var} = \max\{CIRF_{j,var,\tau}^+ - CIRF_{j,var,\tau}^-\}_{j=1}^S, \quad \tau = N, N+1, \dots, T \quad (6)$$

The measures  $AM_2^{var}$  and  $AM_3^{var}$  are expected to be correlated. Using the definition of the cumulative impulse response function, the asymmetry measure  $AM_2^{var}$  can be presented as

$$AM_{2,\tau}^{var} = CIRF_{S,var,\tau}^+ - CIRF_{S,var,\tau}^-, \quad \tau = N, N+1, \dots, T \quad (7)$$

The asymmetry measure in (7) is simply the difference in the cumulative adjustment functions in the final period  $S$ . The asymmetry measure in (6) equals the maximum difference in the cumulative impulse response function which may be close to the difference in the cumulative adjustment functions in the final period  $S$ .

The asymmetry of gasoline prices may be derived based on the cumulative adjustment functions estimated from the partial adjustment models introduced by Borenstein *et al.* (1997). For each period  $\tau = N, N+1, \dots, T$ , I estimate the following model:

$$\begin{aligned}\Delta R_t &= \sum_{i=0}^n (\beta_i^+ \Delta C_{t-i}^+ + \beta_i^- \Delta C_{t-i}^-) + \sum_{i=1}^n (\gamma_i^+ \Delta R_{t-i}^+ + \gamma_i^- \Delta R_{t-i}^-) \\ &+ \theta_1 [EC_{t-1}^+] + \theta_2 [EC_{t-1}^-] + u_t, \quad t = \tau_0, \dots, \tau\end{aligned}\quad (8)$$

where  $EC$  is the error correction term,  $EC_t^+ = \max\{EC_t, 0\}$ ,  $EC_t^- = \min\{EC_t, 0\}$ . The variables  $\Delta R_t$ ,  $\Delta R_t^+$  and  $\Delta R_t^-$  are defined in the same way as  $\Delta C_t$ ,  $\Delta C_t^+$  and  $\Delta C_t^-$ . The error term  $u_t$  is assumed to be a white noise process. The error correction term  $EC_t$  is computed based on the following long-run equilibrium relationship between retail gasoline prices and the crude oil prices:

$$R_t = \phi_0 + \phi_1 C_t + \phi_2 TIME + \epsilon_t, \quad t = \tau_0, \dots, \tau \quad (9)$$

where  $\epsilon_t$  is a white noise process. The error correction term in (8) is then defined as  $EC_t = R_t - \hat{\phi}_0 - \hat{\phi}_1 C_t - \hat{\phi}_2 TIME$ . Borenstein *et al.* (1997) show how one can construct the cumulative adjustment functions for the response of gasoline prices to oil price increases and oil price decreases.<sup>15</sup>

Based on the estimated parameters of model (8), one may construct the asymmetry of gasoline price measures by taking the largest difference between the cumulative adjustment function for the oil price decreases and increases. Let  $\{CAF_{j,pam,\tau}^+\}_{j=1}^S$  and  $\{CAF_{j,pam,\tau}^-\}_{j=1}^S$  be the cumulative adjustment functions that shows the response of gasoline prices to oil price increases and decreases, respectively, for  $S$  periods after the oil price change for the PAM estimated at period  $\tau$ . The PAM measure of the gasoline price asymmetry is defined:

$$AM_{4,\tau}^{pam} = \max\{CAF_{j,pam,\tau}^+ - CAF_{j,pam,\tau}^-\}_{j=1}^S$$

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<sup>15</sup>See Borenstein *et al.* (1997) or Johnson (2002) for details.

The measures  $AM_1^{var}$ ,  $AM_2^{var}$ ,  $AM_3^{var}$ , and  $AM_4^{pam}$  are expected to be different for several reasons. First, the cumulative response functions from the PAM models show the response of gasoline prices to a combination of anticipated and unanticipated oil price changes, while the impulse response functions from the VAR models show the response to unanticipated oil price changes only.<sup>16</sup> Second, the partial adjustment model (8) allows for the asymmetric effect of the error correction term. The VAR models in equation (3) do not have error correction terms and this leads to different gasoline price responses to oil price increases and decreases.

The constructed measures of oil price volatility and the gasoline price asymmetry are used to estimate model (1). Having analyzed the relationship between oil price volatility and gasoline asymmetry, I divide the sample into two subsamples with a low and high oil price volatility and check how the gasoline responses to oil price increases and decreases change across the two samples. This is done to distinguish the oligopolistic coordination theory and the search theory with Bayesian updating.

## 4 Data and VAR Results

Data on retail gasoline and crude oil prices have been obtained from US Department of Energy.<sup>17</sup> I use weekly data in the analysis, but the data sets include daily and weekly observations on regular gasoline prices, West Texas Intermediate crude oil prices for the time period from March 1991 to February 2003, the time period for which weekly data are available from the US Department of Energy. The Department's US average weekly retail gasoline prices are for Monday of each week. Data have been deseasonalized by running a regression on weekly dummy observations.

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<sup>16</sup>See Radchenko (2004) for more details.

<sup>17</sup>The data can be accessed on Internet via the link <http://www.eia.doe.gov/neic/historic/hpetroleum2.htm#Gasoline>.

Retail prices include taxes which potentially may raise a problem if there were any significant gasoline tax fluctuations over the time period of the analysis. While there were no significant movements in state average taxes,<sup>18</sup> federal tax rates on gasoline increased from 14.1 cents per gallon to 18.4 cents per gallon on October 1, 1993.<sup>19</sup> To check whether this increase has any significant effect on the parameter estimates, I have included a dummy variable in the regression model. The dummy variable takes on a value of zero before October 1, 1993 and a value of one otherwise. The empirical results are robust to the inclusion of the tax dummy variable and, because it turned out to be insignificant, I omit it from the model estimation.

Another potential problem is inflation. The time period in estimation is relatively short, March 1991 - August 2002, and the inflation rate for the period was quite low, ranging from 1.54 % to 3.58 % on an annual basis. The analysis is restricted to changes in the log levels of oil and gasoline prices rather than the log levels of prices so that inflation biases do not at least accumulate and should not be severe.

Based on the AIC criteria for the full sample, I set the number of lags  $n$  equal to two in estimating models (8) for  $\tau = N, N + 1, \dots, T$ . The number of lags is set equal to nine in estimation of the VAR models (3). Ideally, I would like to vary the optimal lag length for the models as I vary the time period  $\tau$  for which I estimate the gasoline asymmetry measures. Because of the large number of models that I estimate, this approach seems impractical and I use the same lag length for all the models in construction of gasoline asymmetry proxies.

The rolling standard deviation approach and the GARCH based method produce very similar measures of oil price volatility. The correlation matrix of oil price volatility measures

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<sup>18</sup>One may check state motor-fuel tax rates at the following webpage <http://www.fhwa.dot.gov/ohim/hs00/mf205.htm>.

<sup>19</sup>One may check federal tax rates on motor fuels at the following webpage <http://www.fhwa.dot.gov/ohim/hs00/fe101a.htm>.

is presented in Table 1. The correlation between these two measures is equal to 0.89 if twenty six observations are used in the estimation and is equal to 0.92 if thirteen observations are used. In Figure 3, I present the estimated rolling standard deviation (using 26 observations) measure and the GARCH oil price volatility measure. The two measures are close since the end of 1995, but there is some difference in the beginning of the sample.

I investigate how the estimated gasoline price asymmetry proxies are intercorrelated in Tables 2 - 4. In total, twelve asymmetry measures are constructed. I estimate four asymmetry measures using the fixed 150 estimation window, the four asymmetry measures are constructed using the fixed 200 estimation window, and the remaining four measures are computed using the recursively updated estimation windows. There is high correlation between asymmetry measures  $AM_2^{var}$  and  $AM_3^{var}$ . For all estimation windows, the correlation between these two measures is above 0.95. The correlation of these two measures with the measure  $AM_1^{var}$  depends on the estimation window used. The correlation exceeds 0.7 when the recursive window is used in construction of the gasoline price asymmetry measures (Table 4). The correlation between  $AM_2^{var}$ ,  $AM_3^{var}$  and  $AM_1^{var}$  drops to 0.2–0.3 if the fixed windows,  $N = 150$  and  $N = 200$ , are used in estimation (Tables 2 - 3).

The PAM model produces a pattern of the gasoline price asymmetry completely different from the VAR method. The reason is that the PAM measure  $AM_4^{pam}$  is mostly negatively correlated with the three asymmetry measures from the VAR model.

Based on results in Tables 2 - 4, I conclude that the the construction of asymmetry measure influences the estimates of the gasoline price asymmetry. Nevertheless, the difference in the gasoline price asymmetry estimates is the benefit of this paper because it allows one to check the robustness of results.

Next, I show that asymmetry measures are influenced by the estimation windows in construction of the gasoline price asymmetry proxies. This can be seen from Tables 5 - 8 which show the correlation of the gasoline price asymmetry measures across the different kinds

of estimation windows. The asymmetry measures  $AM_2^{var}$ ,  $AM_3^{var}$ , and  $AM_4^{pam}$  constructed using the fixed 150 and 200 observations are highly correlated with the correlation coefficient exceeding 0.63 (Tables 6 - 8). The asymmetry measure between the fixed 200 estimation window and the recursive estimation window are correlated for  $AM_1^{var}$ ,  $AM_2^{var}$  and  $AM_3^{var}$  with the correlation coefficient reaching 0.601

The correlation between asymmetry measures using the fixed 150 window and the recursive sample is low. The reason for this is that the recursive scheme uses a very long sample for estimation resulting in low variability of the parameter estimates and the asymmetry measures. The construction of the gasoline price asymmetry measures using 150 observations leads to a higher variability in the asymmetry measures.

I present the asymmetry measures using the fixed 200 observations estimation window and the recursive window in Figures 4 - 5. The asymmetry measures fluctuate a lot for the fixed estimation window. For the recursive estimation window, there seems to be variability in the beginning of the sample, but, as expected, it seems to become stable and less variable in the second half of the sample. The standard deviation of the asymmetry measures in recursive window is 0.18, while the standard deviations of the asymmetry measures using the fixed 200 observations estimation window is 0.26. Based on these results, I have decided not to use the asymmetry measures constructed using the recursive estimation window.

Having constructed the measures of oil price volatility and the gasoline price asymmetry, I estimate 16 VAR models, numbered M1 - M16, consisting of oil price volatility and the gasoline price asymmetry variables. Because of the high correlation between oil price volatility measures constructed using rolling standard deviations with 26 and 13 observations in the estimation window, I use only the former measure in the estimation of the VAR models. The impulse response functions of gasoline price asymmetry measure to a shock in oil price volatility are presented in Figures 6 - 7. The bold line on graphs represents the estimate of

the impulse response function, while the dashed lines are the estimated standard errors.<sup>20</sup>

Overall, the results consistently show that an increase in oil price volatility causes a decline in the degree of gasoline price asymmetry. In the long-run, there is a statistically significant decline in the degree of gasoline price asymmetry in 11 out of the 16 models estimated. In models *M8* and *M16* the gasoline price asymmetry declines in the short-run, but the effect is insignificant in the long-run. There is no statistically significant effect of an oil price volatility shock on asymmetry in models *M14* and *M15*. The evidence for the negative effect of oil price volatility on the gasoline price asymmetry is the strongest for the fixed 200 observations estimation window.

The documented results from the VAR analysis contradict the standard search theory explanation of the asymmetry in the gasoline price response. This theory predicts that the degree of gasoline asymmetry should increase as the oil price volatility increases. Nevertheless, two models (oligopolistic coordination theory and the search theory with Bayesian updating) are consistent with the observed decline in the gasoline price asymmetry as oil volatility increases.

To test which of these two models is more appropriate in explaining the asymmetry, I estimate the gasoline responses for oil price increases and decreases for both a period of low volatility and a period of high volatility.

## **5 Gasoline asymmetry decline: a faster (slower) response to an oil price decrease (increase)**

I estimate the gasoline price responses using the entire sample and using two subsamples: (i) 01/21/91 - 09/25/95 and (ii) 10/02/95 - 02/21/03. The date for dividing the sample into two

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<sup>20</sup>The approach of Killian (1998) is used to construct the standard errors for the impulse response functions.

periods was chosen based on the estimated structural break in oil price volatility using the Quandt Likelihood Ratio test. I look at oil price variance across the two subsamples. The oil price variance equals 25.4 in the first period, while it equals 194.6 in the second period, more than 7 times higher than in the first period.<sup>21</sup> Based on the findings in the previous section, I expect that the degree of the gasoline price asymmetry is higher in the first period. In the second period the asymmetry is expected to decline because of a higher oil volatility. Based on Figure 2, there are two possible reasons for the decline in the asymmetry: (i) a faster response to an oil price decline predicted by the oligopolistic coordination theory and (ii) a slower response to an oil price increase predicted by the search theory with Bayesian updating. I check how gasoline price responses change across the two periods and make conclusions about the validity of two competing theories.

Using the partial adjustment model, I estimate the responses of gasoline prices to oil price increases and decreases and present them in Figure 8. The solid line shows the response of gasoline prices to an oil price increase, while the dashed line shows the gasoline response to an oil price reduction.

Comparing the graphs of gasoline price response for the first and second periods, one can notice that the first period has evidence of asymmetric response. The gasoline price adjusts faster to oil price increases than to oil price decreases. The second period indicates a symmetric response of gasoline prices. There is no difference in the gasoline response to oil price increases and decreases. One may also notice that the decline in the asymmetry in the second period is the consequence of the faster adjustment of gasoline prices to an oil price reduction. This is consistent with the prediction of the oligopolistic coordination theory and is not consistent with the prediction of search model with Bayesian updating proposed by Johnson (2002).

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<sup>21</sup>The oil price is expressed in cents per gallon of oil.



## 6 Conclusions

In this paper, I study the relationship between oil price volatility and the degree of gasoline price asymmetry. I construct three measures of oil price volatility and twelve measures of gasoline price asymmetry and examine the impulse response functions of gasoline price asymmetry to a shock in oil price volatility. I find that there is a robust negative relation between oil price volatility and the asymmetry of gasoline price.

The results are used to check three possible explanations of the asymmetric response of gasoline prices: the oligopolistic coordination theory, the search theory with Bayesian updating, and the standard search theory. The results from VAR analysis support the search theory with Bayesian updating and the oligopolistic coordination theory.

To distinguish between the two competing models, I divide the entire sample into two subsamples with high and low oil price volatility and find that the decline in the asymmetry is attributed to a faster response of gasoline prices to oil price decreases when oil price volatility increases. This result points to an oligopolistic coordination theory as the most likely model to explain asymmetry among the three models considered.

## References

- [1] Bacon, R. W., 1991. Rockets and feathers: the asymmetric speed of adjustment of UK retail gasoline prices to cost changes. *Energy Economics* 13, 211-218.
- [2] Balke, N. S., Brown, S. P. A., and M. K. Yücel, 2002. Oil price shocks and the U.S. economy: where does the asymmetry originate? *The Energy Journal* 23(3), 27 - 52.
- [3] Balke, N. S., Brown, S. P. A., and M. K. Yücel, 1998. Crude oil and gasoline prices: an asymmetric relationship? *Federal Reserve Bank of Dallas Economic Review*, First Quarter, 2-11.
- [4] Bachmeier, L. J., and James. M. Griffin, 2003. New evidence on asymmetric gasoline price responses. *Review of Economics and Statistics* 85(3), 772-76.
- [5] Benabou, R., and R. Getner, 1993. Search with learning from prices: does increased inflationary uncertainty lead to higher markups? *Review of Economic Studies* 60, 69-94.
- [6] Bettendorf, L., van der Geest, S. A., and M. Varkevisser, 2003. Price asymmetry in the Dutch retail gasoline market. *Energy Economics* 25, 669-689.
- [7] Brown, S. P. A., and M. K. Yücel, 2000. Gasoline and crude oil prices: why asymmetry? *Federal Reserve Bank of Dallas Economic and Financial Review*, Third Quarter, 23-29.
- [8] Borenstein, S., and A. Shepard, 2002. Sticky prices, inventories, and market power in wholesale gasoline markets. *Rand Journal of Economics* 33, 116-139.

- [9] Borenstein, S., Cameron A. C., and R. Gilbert, 1997. Do gasoline prices respond asymmetrically to crude oil price changes? *The Quarterly Journal of Economics* 112, 305-339.
- [10] Borenstein, S., and A. Shepard, 1994. Dynamic pricing in retail gasoline markets. *Rand Journal of Economics* 27(3): 429-451.
- [11] Campbell, J. Y., Malkiel B., Lettau M., and Y. Xu, 2001. Have individual stocks become more volatile? An empirical exploration of idiosyncratic risk. *Journal of Finance* 56, 1-43.
- [12] Engle, R., 2001. GARCH 101: the use of ARCH/GARCH models in applied econometrics. *Journal of Economic Perspectives* 15(4), 157-168.
- [13] Galeotti, M., Lanza A., and M. Manera, 2003. Rockets and feathers revisited: an international comparison on European gasoline markets. *Energy Economics* 25, 175 - 190.
- [14] Godby, R., Lintner A. M., Stengos T., and B. Wandschneider, 2000. Testing for asymmetric pricing in the Canadian retail gasoline market. *Energy Economics* 22, 349-368.
- [15] Green, E. J., and R. H. Porter, 1984. Noncooperative collusion under imperfect price information. *Econometrica* 52(1), 87-100.
- [16] Hansen, P. R., and A. Lunde, 2001. A comparison of volatility models: does anything beat a GARCH(1,1) model? Brown University working paper.
- [17] Johnson, R. N., 2002. Search Costs, Lags and Prices at the Pump. *Review of Industrial Organization* 20, 33-50.

- [18] Kaufmann, R. K., and C. Laskowski, 2004. Causes for an asymmetric relation between the price of crude oil and refined petroleum products. *Energy Policy*, forthcoming.
- [19] Kilian, L., 1998. Small-sample confidence intervals for impulse response functions. *The Review of Economics and Statistics* 80, 218-230.
- [20] Lee, K., Ni, S., Ratti, R. A., 1995. Oil shocks and the macroeconomy: the role of price variability. *Energy Journal* 16(4), 39-56.
- [21] Peltzman, S., 2000. Prices rise faster than they fall. *Journal of Political Economy* 108, 466 - 502.
- [22] Pindyck, R. S., 2004a. Volatility and commodity price dynamics. *The Journal of Futures Markets*, forthcoming.
- [23] Pindyck, R. S., 2004b. Volatility in natural gas and oil markets. Massachusetts Institute of Technology working paper.
- [24] Radchenko, S., 2004. Anticipated and unanticipated effects of crude oil price and oil inventory changes on gasoline prices. UNCC mimeo.
- [25] Reilly B., and R. Witt, 1998. Petrol price asymmetries revisited. *Energy Economics* 20, 297-308.
- [26] Sadorsky, P., 1999. Oil price shocks and stock market activity. *Energy Economics* 21, 449 - 469.
- [27] Swanson, N. R., 1998. Money and output viewed through a rolling window. *Journal of Monetary Economics* 41, 455-473.
- [28] Thoma, M. A., 1994. Subsample instability and asymmetries in money-income causality. *Journal of Econometrics* 64, 279-306.

Table 1: The correlation matrix of oil price volatility measures

	<i>Std.Dev, N = 26</i>	<i>Std.Dev, N = 13</i>	<i>GARCH(1, 1)</i>
<i>Std.Dev, N = 26</i>	1	-	-
<i>Std.Dev, N = 13</i>	0.871	1	-
<i>GARCH(1, 1)</i>	0.898	0.920	1

Table 2: The correlation matrix of gasoline asymmetry measures, the estimation window N=150

	$AM_1^{var}$	$AM_2^{var}$	$AM_3^{var}$	$AM_4^{pam}$
$AM_1^{var}$	1	-	-	-
$AM_2^{var}$	0.323	1	-	-
$AM_3^{var}$	0.382	0.957	1	-
$AM_4^{pam}$	0.169	-0.477	-0.424	1

Table 3: The correlation matrix of gasoline asymmetry measures, the estimation window N=200

	$AM_1^{var}$	$AM_2^{var}$	$AM_3^{var}$	$AM_4^{pam}$
$AM_1^{var}$	1	-	-	-
$AM_2^{var}$	0.206	1	-	-
$AM_3^{var}$	0.243	0.986	1	-
$AM_4^{pam}$	0.078	-0.570	-0.560	1

Table 4: The correlation matrix of gasoline asymmetry measures, the recursive estimation window

	$AM_1^{var}$	$AM_2^{var}$	$AM_3^{var}$	$AM_4^{pam}$
$AM_1^{var}$	1	-	-	-
$AM_2^{var}$	0.710	1	-	-
$AM_3^{var}$	0.718	0.962	1	-
$AM_4^{pam}$	-0.573	-0.726	-0.680	1

Table 5: The correlation matrix of the asymmetry measure across models,  $AM_1^{var}$

	$VAR, N = 150$	$VAR, N = 200$	$VAR, recursive$
$VAR, N = 150$	1	-	-
$VAR, N = 200$	0.368	1	-
$VAR, recursive$	0.289	0.594	1

Table 6: The correlation matrix of the asymmetry measure across models,  $AM_2^{var}$

	$VAR, N = 150$	$VAR, N = 200$	$VAR, recursive$
$VAR, N = 150$	1	-	-
$VAR, N = 200$	0.648	1	-
$VAR, recursive$	0.241	0.546	1

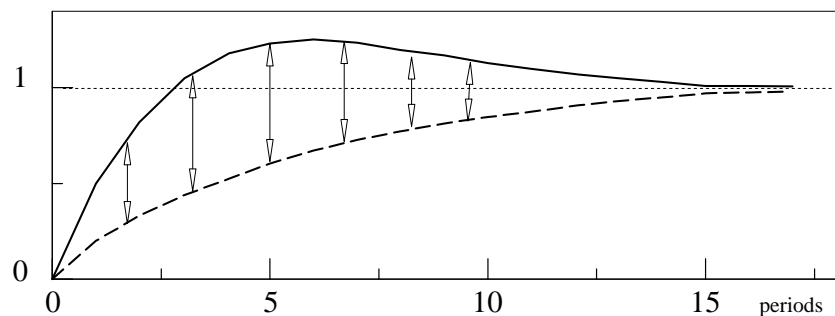
Table 7: The correlation matrix of the asymmetry measure across models,  $AM_3^{var}$

	$VAR, N = 150$	$VAR, N = 200$	$VAR, recursive$
$VAR, N = 150$	1	-	-
$VAR, N = 200$	0.632	1	-
$VAR, recursive$	0.270	0.601	1

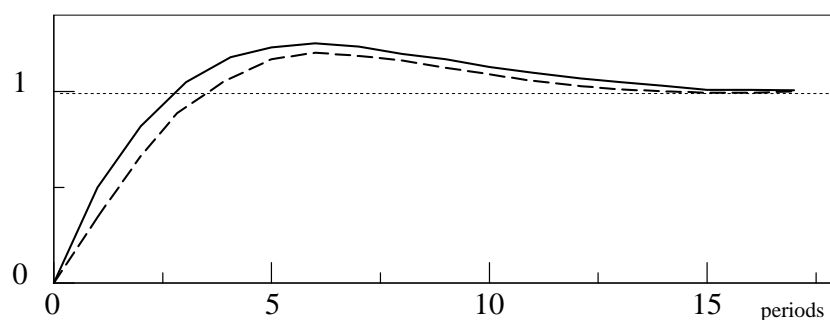
Table 8: The correlation matrix of the asymmetry measure across models,  $AM_4^{pam}$

	$PAM, N = 150$	$PAM, N = 200$	$PAM, recursive$
$PAM, N = 150$	1	-	-
$PAM, N = 200$	0.696	1	-
$PAM, recursive$	-0.098	0.246	1

a) Asymmetry in response



b) No asymmetry in response: a faster response to an oil price decrease



c) No asymmetry in response: a slower response to an oil price increase

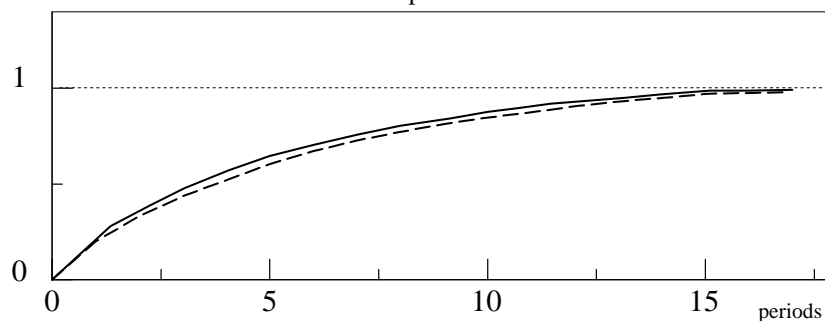


Figure 1: A bold line is the response of gasoline prices to an oil price increase, while a dashed line is the response to an oil price decrease. A decline in the degree of asymmetry in the response of gasoline price may be a result of either a faster response of gasoline prices to an oil price decrease (panel b) or a slower response to an oil price increase (panel c).



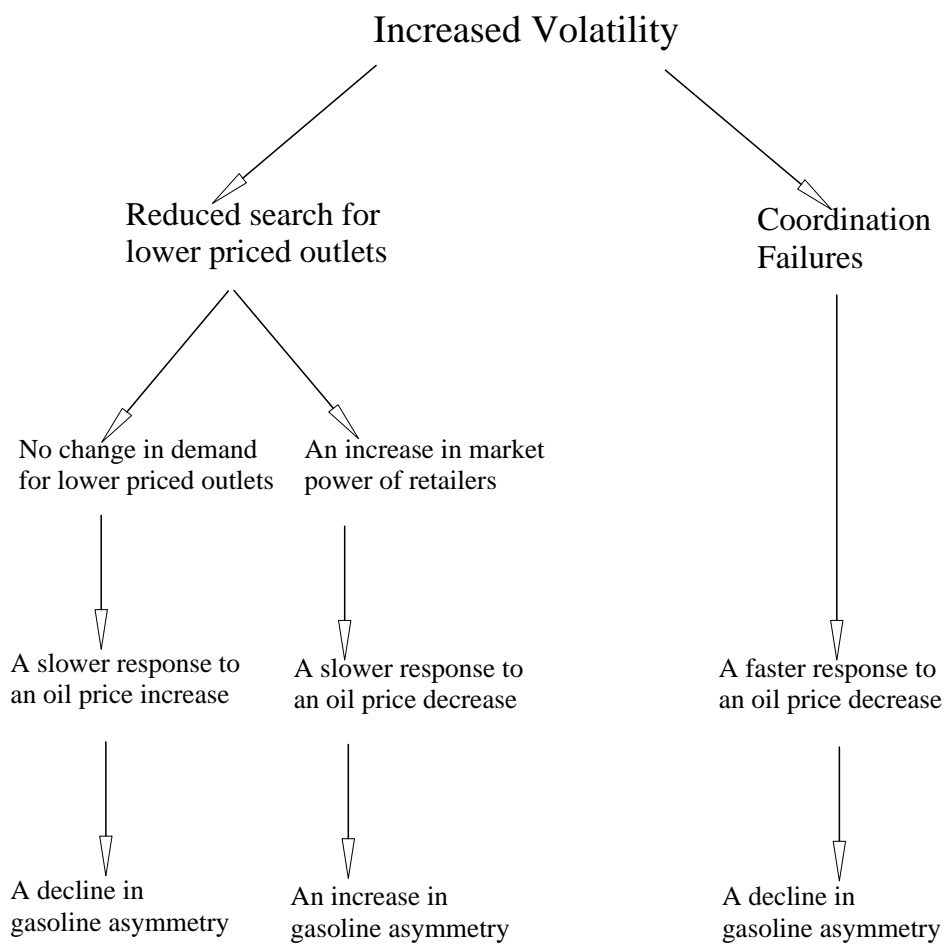


Figure 2: The transmission mechanisms of increased oil price volatility on the degree of gasoline price asymmetry.

## Volatility Measures

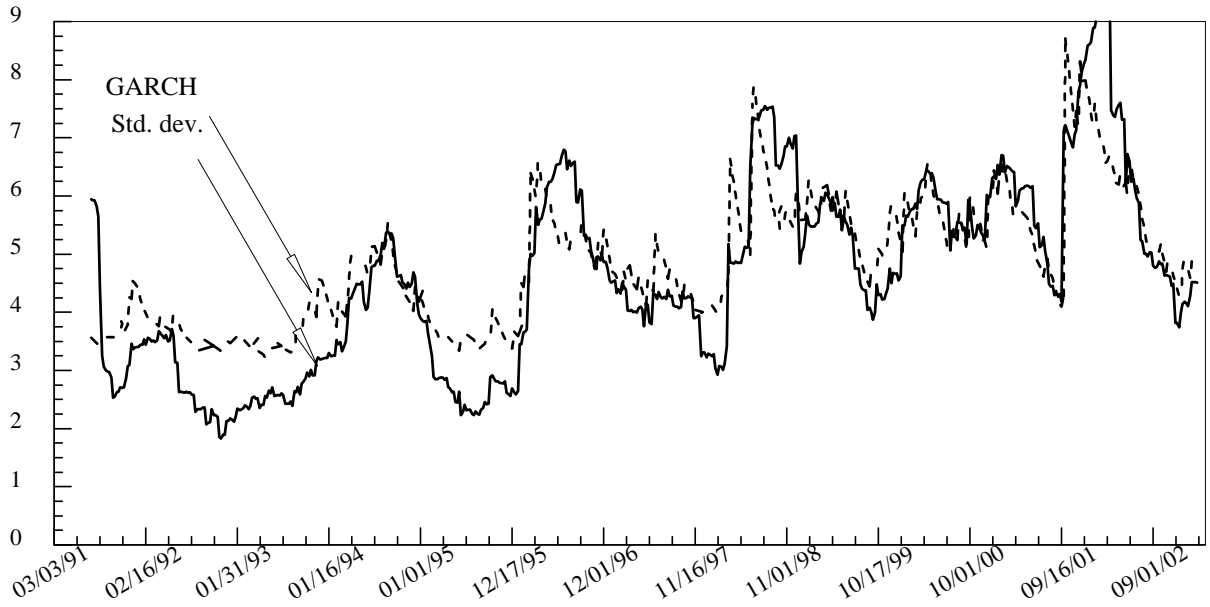
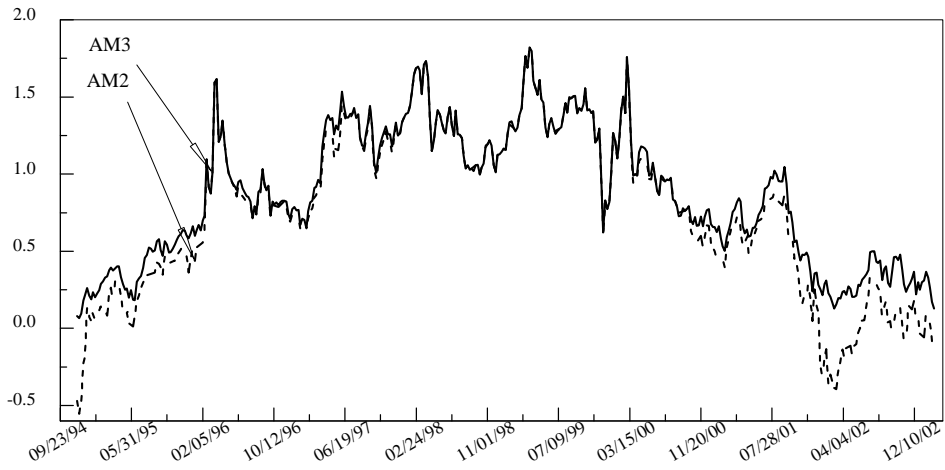


Figure 3: The oil price volatility measures.

Aymmetry Measures, N=200



Aymmetry Measures, N=200

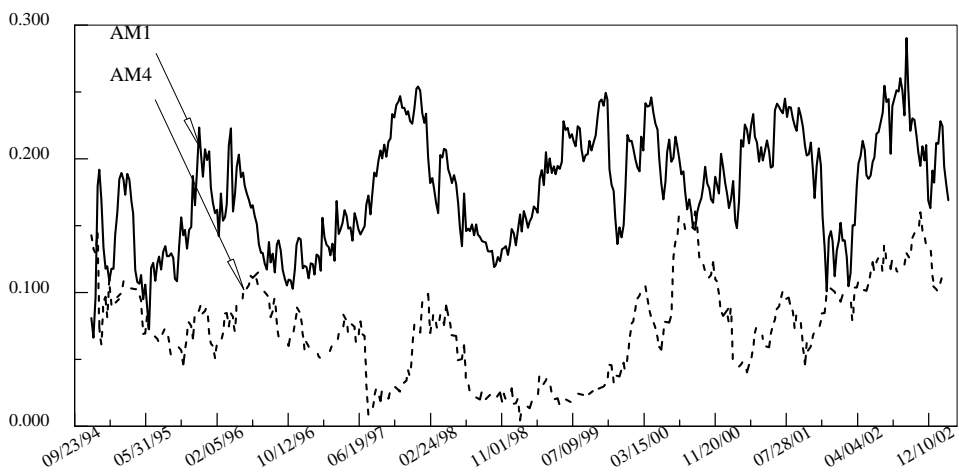
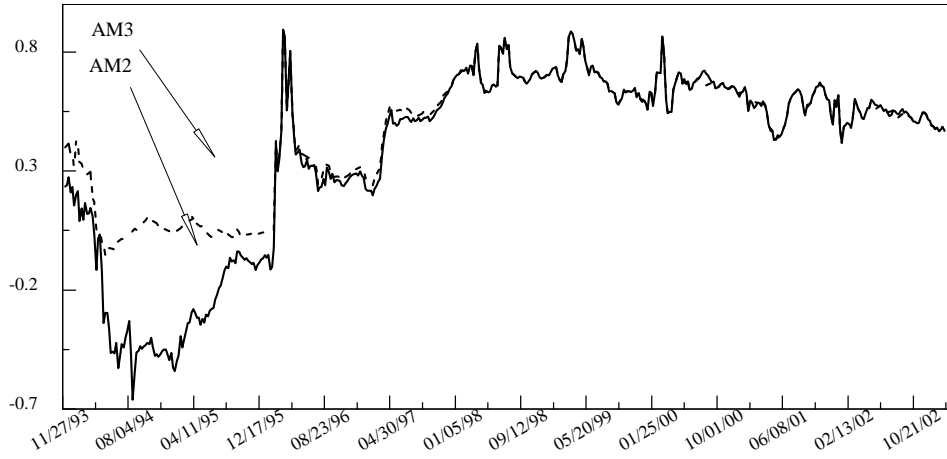


Figure 4: The gasoline price asymmetry measures.

Aymmetry Measures, recursive window



Aymmetry Measures, recursive window

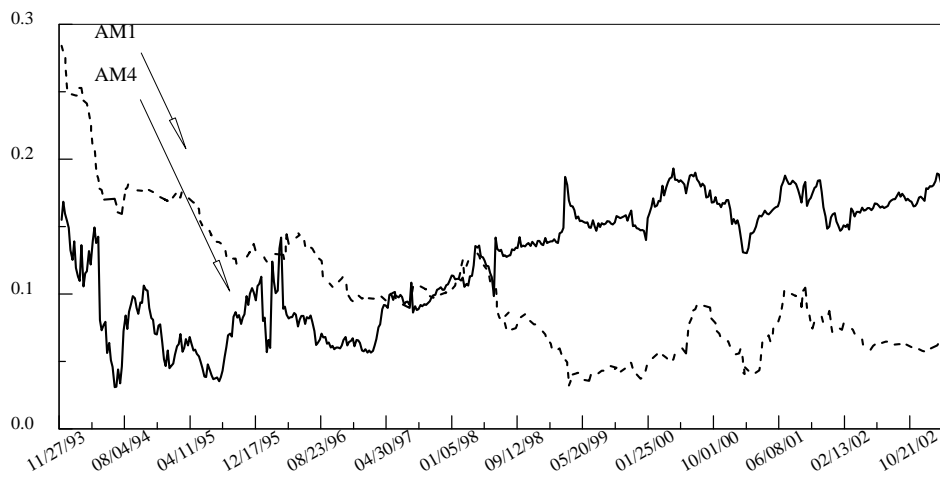


Figure 5: The gasoline price asymmetry measures.

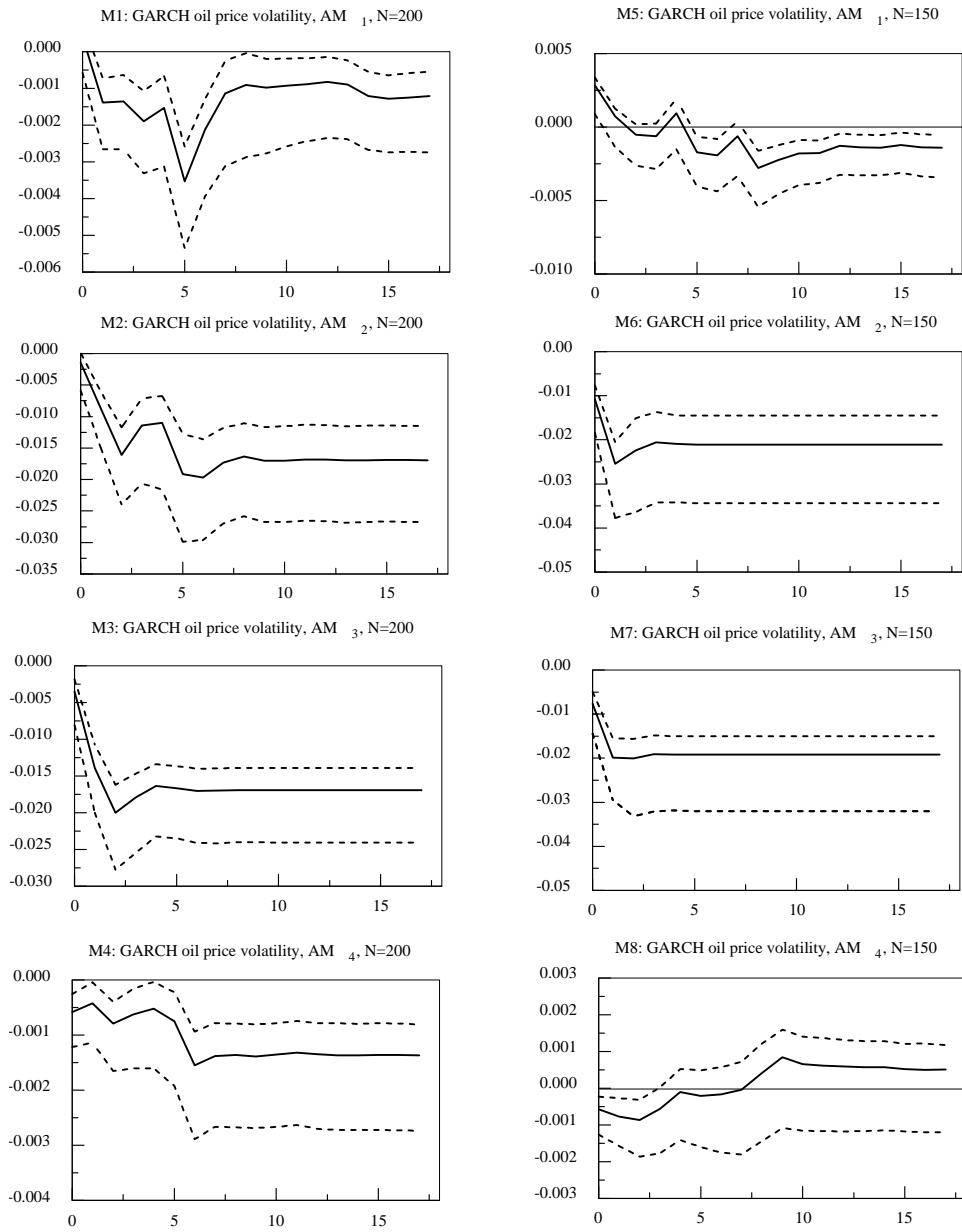


Figure 6: The response of gasoline asymmetry measures to changes in oil price volatility.

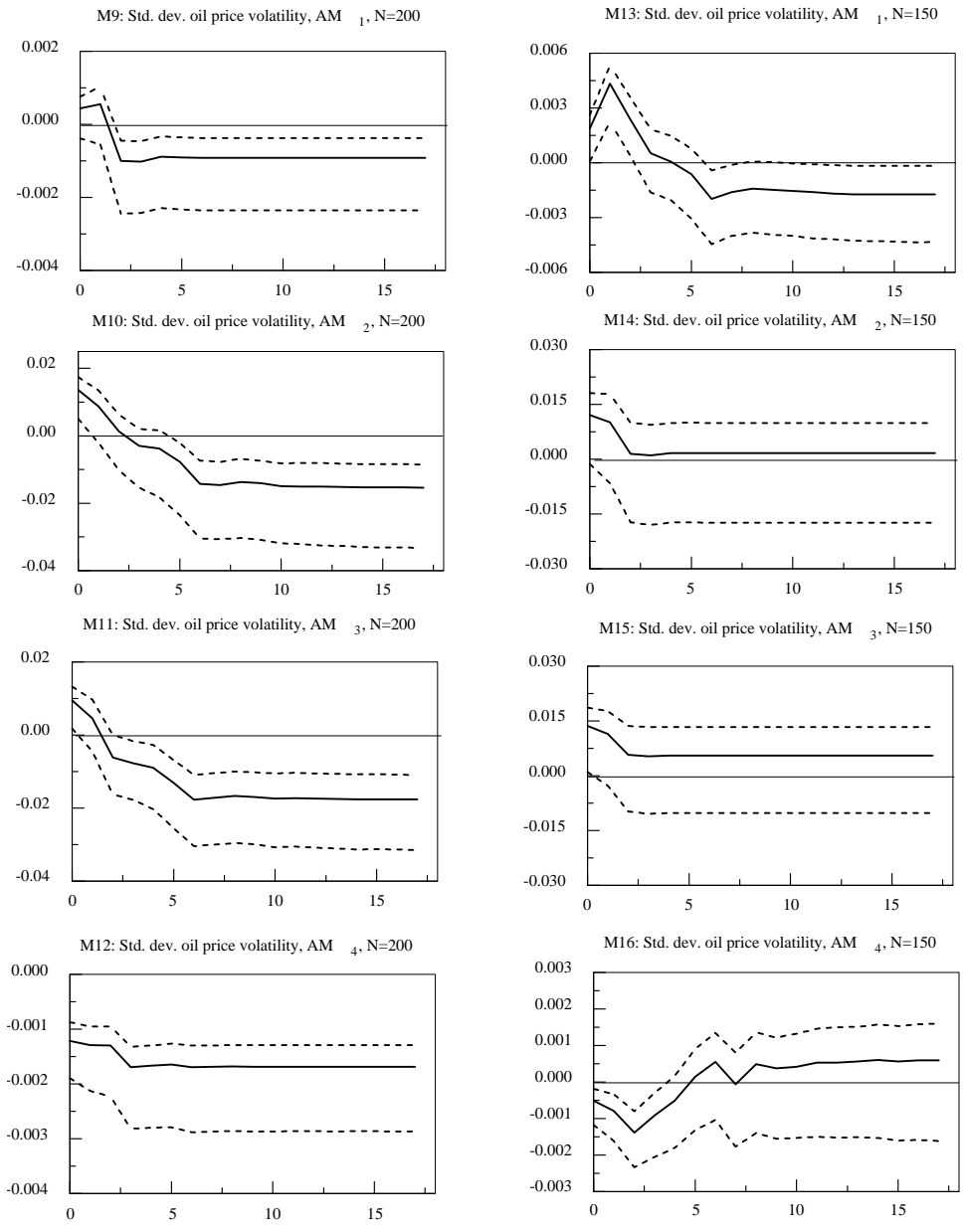


Figure 7: The response of gasoline asymmetry measures to changes in oil price volatility.

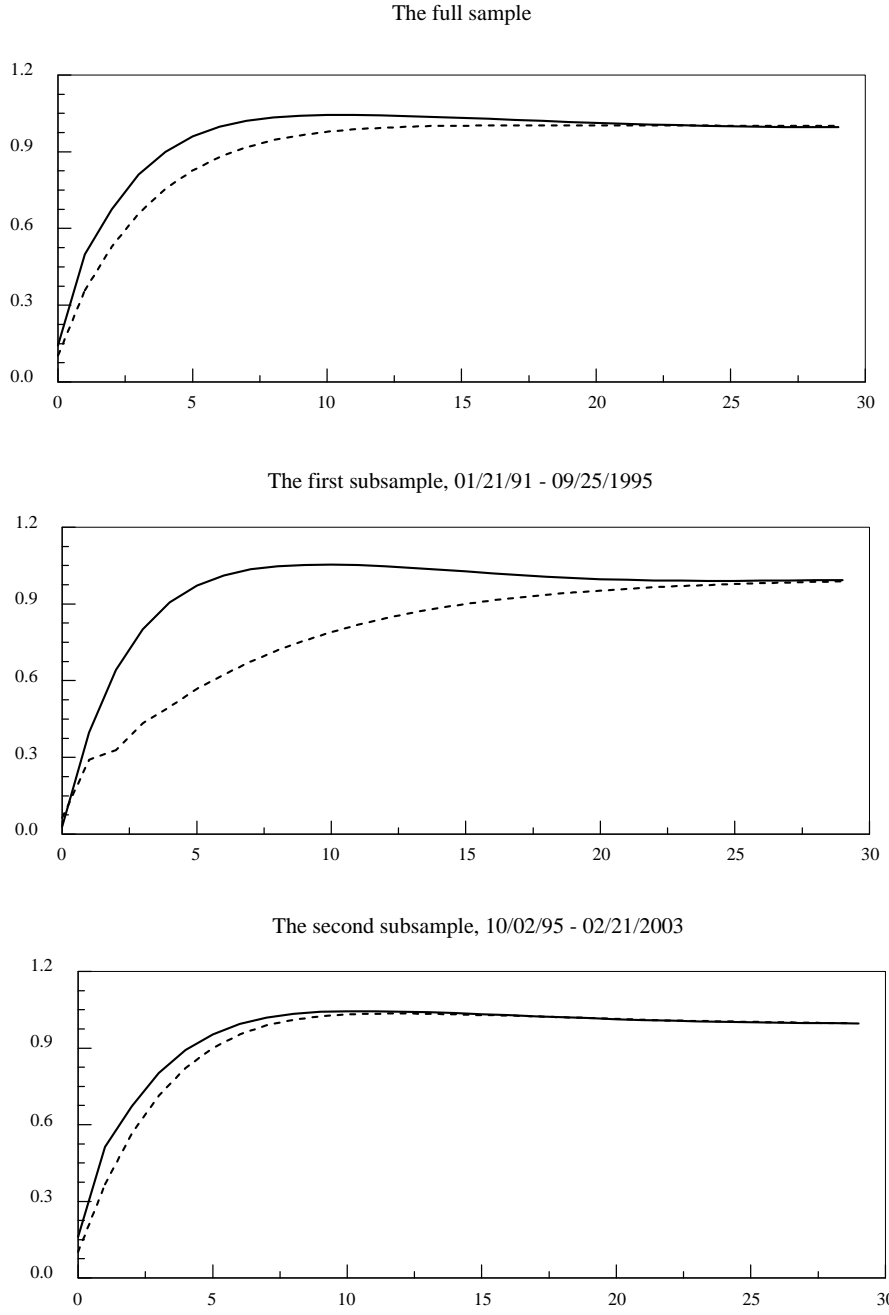


Figure 8: The gasoline price response to changes in crude oil prices.