

# Anticipated and unanticipated effects of crude oil prices and oil inventory changes on gasoline prices

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Abstract

This paper proposes a method of distinguishing between the effect of anticipated and unanticipated changes in oil prices and oil inventories on the US gasoline prices. I show that gasoline price adjustments are faster and stronger for anticipated changes in oil prices and inventory levels than for unanticipated changes. The dynamics of the gasoline price response depends on the relative importance of anticipated and unanticipated changes in oil prices and oil inventories in the model. In all versions of the adjustment model, the response of gasoline prices to unanticipated oil price changes is lagged and incomplete. In versions of the model where anticipated oil price changes are relatively important, the response of gasoline prices to anticipated changes in oil prices is immediate and large. As anticipated oil price changes become less important, the response of gasoline prices to anticipated oil price changes becomes muted and delayed.

Keywords: *gasoline price response, anticipated price changes, oil inventory*

# 1 Introduction

The question of lags in the response of gasoline prices to oil price changes has received considerable attention from researchers. Since the study by Borenstein et al. (1997) which illustrates that gasoline prices adjust slowly to changes in crude oil prices, several explanations of the observed phenomena have been suggested and tested. Borenstein and Shepard (2002) argue that the slow response of gasoline prices is due to the high cost of adjustment of production and inventory<sup>1</sup>. Johnson (2002) argues that a search cost may lead to long lags in the response of gasoline prices. Godby et al. (2000) explore the behavior of gasoline and oil prices and suggest that only oil price changes that are bigger than some threshold level lead to revision of gasoline prices. Similar results were obtained by Radchenko (2004) who points to possible nonlinearities in retail gasoline prices and the role that different types of oil price changes play in the gasoline price response. Nevertheless, none of the papers have analyzed the difference in the response of gasoline price to anticipated and unanticipated oil price changes. In this paper, I add new evidence to the literature on lags in the response of gasoline prices to changes in crude oil prices by analyzing the response of gasoline prices to anticipated and unanticipated oil price fluctuations.

I propose a methodology to distinguish between the effect of anticipated and unanticipated oil price on the adjustment of retail gasoline prices and apply it to analyze the lags in the response of gasoline prices. Instead of developing a structural model that embodies gasoline prices and anticipated and unanticipated oil price changes, I use a reduced form approach in the analysis. I show that empirical responses of gasoline prices to changes in

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<sup>1</sup>Consideration of the inventory adjustment cost along with the production adjustment cost is important since it is known that many commodities do not exhibit statistically significant cost of adjusting production. See Pindyck (1994) who presents evidence of insignificant cost of adjustment for copper, heating oil, and lumber.

oil market conditions (oil prices and oil inventory) depend crucially on the assumption of whether changes in oil prices and inventory are anticipated or unanticipated. The reported evidence is used to check the cost of adjustment explanation of gasoline price lags advocated by Borenstein and Shepard (2002). I estimate models with different weights of anticipated/unanticipated oil price movements to demonstrate how the measures of gasoline price adjustment vary as one assumes different relative weights of anticipated and unanticipated oil price changes.

In addition, anticipated and unanticipated oil inventory changes are added to the analysis to explain the observed hump-shaped form of the gasoline price response to changes in crude oil prices. It is generally agreed that producers must determine output prices, production levels and inventory levels jointly with the expected inventory drawdowns and buildups. Pindyck (1994, 2001) presents models that explain how prices, rates of production and inventory are determined. Borenstein and Shepard (2002) argue that inventory dynamics are important in understanding gasoline price dynamics.

The findings of the paper may be summarized as follows. Gasoline prices respond much faster to anticipated changes in oil prices than to unanticipated oil price changes giving further support to the cost of adjustment explanation of the gasoline price lags. While there is a lag in the response of gasoline prices to unanticipated oil price changes, there is no lag in the gasoline price response to anticipated oil price changes. The gasoline price response depends on the relative importance (frequency) of anticipated changes in the model. As the relative importance of anticipated changes in oil prices decreases, the response of gasoline prices to anticipated oil price changes becomes weaker and looks more similar to the response of gasoline prices to unanticipated oil price changes.

Consideration of the oil inventory in the analysis is important in understanding the hump-shaped form and the incomplete adjustment of gasoline prices to changes in oil prices. The changes in oil prices, anticipated and unanticipated, induce changes not only in gasoline

prices but also in oil inventory which reverses changes in gasoline prices caused by a change in the oil price. In addition, the response of oil inventory to changes in gasoline prices suggests that most of the variation in gasoline price is the result of variation in oil supply rather than oil demand. When gasoline prices increase, the level of oil inventory declines slightly initially, but increases in the long-run. An increase in oil prices raised the level of oil inventory in the short-run, but the effect is insignificant in the long-run.

The structure of the paper is as follows. I present motivation for the anticipated/unanticipated model of oil price changes in Section 2. In Section 3, I present the econometric approach that I use to derive gasoline price responses to anticipated and unanticipated movements in oil prices and inventory. In Section 4, I describe the data and results. Concluding remarks are in Section 5.

## **2 Motivation of the anticipated/unanticipated oil price changes**

The question of how anticipated and unanticipated oil price changes influence the response of gasoline prices is of a practical interest for several reasons. The first reason is that it seems reasonable to assume that fluctuations in oil prices may be anticipated and unanticipated, but one needs to test the validity of this assumption. Arguably, the changes in oil prices may be anticipated correctly by refineries because of a systematic component attributed to seasonal fluctuations, to OPEC policy, or to both<sup>2</sup>. As well, oil price shocks can be caused by a unanticipated variation in demand and/or non-OPEC related supply shocks. For example, refineries may anticipate correctly changes in the oil price when the crude oil price approaches

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<sup>2</sup>OPEC officially announced its goal to keep oil prices in the price band of \$22-28 a barrel for OPEC's Reference Basket. The official Press releases can be found at <http://www.opec.org>.

the bounds of the announced price band or when OPEC has its regular meetings to decide on the current state of the market and production quotas. Based on the expectations of OPEC meeting outcomes, refineries may start the necessary production and inventory adjustment earlier<sup>3</sup> so that by the time OPEC makes its announcement on production quotas refineries are better positioned to implement gasoline price adjustments immediately and fully<sup>4</sup>. When a change in oil price is unanticipated refineries may not be able to undertake an immediate and full price adjustment because of high production and inventory costs of adjustment. Therefore, one can make a case that anticipated and unanticipated oil price changes may lead to different gasoline price adjustments. It is reasonable to conjecture that gasoline prices respond faster to anticipated oil price changes than to unanticipated oil price changes, and I test this conjecture in the paper.

The second reason for separating the impact of anticipated and unanticipated oil price shocks is that a clarification of the effects may modify the interpretation of empirical evidence on the source of lags in the response of gasoline prices. The common aspect of many papers empirically exploring the relationship between oil prices and gasoline prices is that the authors compute the measures of adjustment of gasoline prices to changes in oil prices without explaining whether this measure is the response of gasoline prices to *anticipated* oil price changes, to *unanticipated* oil price changes, or to a combination of anticipated and unanticipated price changes. This leads to differences in the reported empirical results from various empirical models.

The proposed anticipated/unanticipated model explains the difference in results from the

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<sup>3</sup>Borenstein and Shepard (2002) note that refineries optimize their production using a complex algorithm and it is costly for them to make supply adjustments immediately.

<sup>4</sup>Wirl and Kujundzic (2004) analyze the possible impact of OPEC Conference outcomes. They suggest that sufficient information about the possible OPEC Conference outcome is leaked prior to a meeting, while Hammoudeh and Madan (1995) argue that under "normal conditions" the oil market participants form expectations and may even cause a turnaround in the market in anticipation of OPEC's intervention.

partial adjustment model (PAM) and the vector autoregressive model (VAR). Borenstein and Shepard (2002) estimate measures of gasoline price adjustment from the VAR model and the PAM model and note that the outcomes from the two models are different without giving many details as to why differences may arise. I argue that the measures of the gasoline price adjustment from the VAR and PAM models describe different phenomena. The measure of adjustment of gasoline prices from a VAR model captures the response of gasoline prices only to *unanticipated* oil price changes; the measure of gasoline price adjustment from a PAM type model captures the response of gasoline prices to a combination of *both* anticipated and unanticipated oil price changes by assuming that both types of price changes have the same effect on gasoline prices.

Both models are unrealistic; it is unlikely that anticipated and unanticipated oil price changes have the same effect on the gasoline price, as in PAM, or that only unanticipated oil price changes influence the gasoline price, as in VAR. I develop a model that allows both kinds of oil price changes to have a different impact on gasoline prices and show how one may recover the measures of gasoline price adjustment to different kinds of oil price movements.

The last reason for the analysis of anticipated/unanticipated oil price changes is that it provides evidence on the validity of the cost of adjustment explanation of gasoline price lags advocated by Borenstein and Shepard (2002). This hypothesis is supported by empirical evidence if it is shown that unanticipated changes in oil prices lead to lags in the response of gasoline prices and gasoline prices respond without substantial lags to anticipated changes in oil prices. The explanation is not supported if the gasoline price adjustment occurs with a substantial delay for anticipated oil price movements. The reason is that for unanticipated oil price variation the rapid adjustment of production and inventory is costly and that is why the cost of adjustment theory predicts lags in the response of gasoline prices. An anticipated oil price movement should give refineries time to adjust production and inventory levels without substantial cost when the oil price changes, which should lead to a faster adjustment

of gasoline prices.

### 3 The model of the anticipated/unanticipated oil price changes

This section describes the approach underlying the estimation. I modify the approach of Cochrane (1998) to investigate the response of gasoline prices to oil price and inventory changes when refineries react to both anticipated and unanticipated oil price fluctuations<sup>5</sup>.

It is generally agreed that retail gasoline prices respond to oil price movements asymmetrically, that is gasoline prices adjust faster to oil price increases than to oil price decreases<sup>6</sup>. I present the econometric model for the symmetric case first, in which gasoline prices respond in the same manner to oil price increases and decreases, and then show how it can be modified to allow asymmetry in the gasoline price response. Next, I show how oil inventory can be introduced in the analysis of oil and gasoline prices. The model with gasoline and oil prices and oil inventory is presented at the end of the section.

The basis for the analysis of the relation between oil and gasoline prices is the following model:

$$\Delta g_t = a^*(L)[\lambda \Delta o_t + (1 - \lambda)(\Delta o_t - E_{t-1} \Delta o_t)] + b^*(L) \Delta g_{t-1} + e_t \quad (1)$$

where  $\Delta g_t = g_t - g_{t-1}$  and  $g_t$  is the retail gasoline price,  $\Delta o_t = o_t - o_{t-1}$  and  $o_t$  is the crude oil price,  $a^*(L)$  and  $b^*(L)$  are lag polynomials, in particular  $a^*(L) = a_0^* + \sum_{i=1}^q a_i^* L^i$ , and  $b^*(L)$  is defined in a similar way, the term  $E_{t-1} \Delta o_t$  denotes the expectation of oil price at

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<sup>5</sup>Cochrane (1998) investigates how the VAR-based measures of the effect of money on output change as one varies the relative effects of anticipated/unanticipated money.

<sup>6</sup>See Borenstein et al. (1997), Godby et al. (2000) or Brown and Yucel (2000).

period  $t$  given the information up to the period  $t - 1$ , the term  $(\Delta o_t - E_t \Delta o_{t-1})$  captures the effect of unanticipated oil price changes. The term  $\Delta o_t$  does not discriminate whether a change in oil price is anticipated or unanticipated.

In this model,  $\lambda$  is a prespecified parameter that determines the relative importance of anticipated and unanticipated oil price changes and varies between 0 and 1. As  $\lambda \rightarrow 1$ , the anticipated and unanticipated shocks are restricted to have the same effect on gasoline prices and model (1) reduces to the partial adjustment model (PAM):

$$\Delta g_t = a^*(L)\Delta o_t + b^*(L)\Delta g_{t-1} + e_t \quad (2)$$

The response function of gasoline prices to a combination of anticipated and unanticipated changes in crude oil prices is measured by the structural parameters in  $a^*(L)$ . As  $\lambda \rightarrow 0$ , the model specifies that gasoline prices respond only to unanticipated oil price changes and becomes:

$$\Delta g_t = a^*(L)(\Delta o_t - E_{t-1}\Delta o_{t-1}) + b^*(L)\Delta g_{t-1} + e_t \quad (3)$$

The parameters of polynomial  $a^*(L)$  can be used to construct the response of gasoline prices to unanticipated changes in crude oil prices. Empirically, the analysis of model (3) is conducted using the VAR framework because autoregressive polynomial may be represented as a moving average (MA) polynomial which allows one to estimate the response of variables of interest to the unanticipated changes in other variables. The analysis of gasoline markets in the VAR framework (3) was conducted by Borenstein and Shepard (2002).

Model (2) has proved to be a popular choice for the analysis of gasoline markets. Borenstein et al. (1997) employ the partial adjustment framework to analyze the fluctuations in gasoline and oil prices. Johnson (2002) use a variant of the PAM to analyze the search cost explanation for the long lags in the response of gasoline prices to oil prices. The same

approach was followed by Radchenko (2004) who introduced Markov switching in the polynomial  $a^*(L)$ . Godby et al. (2000) use the error correction threshold autoregressive model, which is similar to the PAM, to investigate the Canadian retail gasoline market. Galeotti et al. (2003) employ an error-correction model to analyze the European gasoline markets. The structural parameters  $a^*(L)$  are used to construct the cumulative response function of gasoline prices to changes in crude oil prices<sup>7</sup>.

It has been reported that PAM and VAR models produce different responses of gasoline prices. Borenstein and Shepard (2002) use both the PAM and the VAR models to estimate the adjustment of gasoline prices to crude oil prices. They show that estimated gasoline price responses from the VAR model indicate a faster adjustment to oil price changes than those responses from the PAM<sup>8</sup>. The authors indicate that the difference in the results may be due to the fact that the PAM model constrains price adjustments to be of equal proportions in all adjustment periods, while the VAR model does not impose this restriction<sup>9</sup>. I offer an alternative explanation for this difference later in the paper.

I estimate model (1) because it nests the VAR model and the PAM model as special cases for  $\lambda = \{0, 1\}$  and allows the researcher a more flexible approach for the analysis of gasoline responses in the presence of anticipated/unanticipated price changes by varying the values of  $\lambda$  between zero and one. I consider how the estimated gasoline responses shift for  $\lambda = \{0.0, 0.25, 0.50, 0.75, 1.0\}$ . As  $\lambda$  increases from 0 to 1, it is interpreted that the unanticipated oil price changes become less frequent and their relative importance (effect on the gasoline price) increases and the relative importance of anticipated changes decreases. Therefore, the

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<sup>7</sup>See Borenstein et al. (1997) and Johnson (2002) for the details of how to recover the gasoline response to oil prices based on the parameters  $a^*(L)$ .

<sup>8</sup>Incidentally, the VAR model produces gasoline responses that show a stronger evidence of asymmetry between the responses of gasoline prices to oil price increases and decreases than the PAM.

<sup>9</sup>Balke et al. (1998) consider several model specifications for the asymmetry analysis of gasoline prices. The authors find that results are puzzling since the models produce different conclusions.

higher values of  $\lambda$  are associated with the lower relative importance of anticipated oil price changes.

I adopt Cochrane (1998) identification scheme to recover the structural parameters of  $a^*(L)$  polynomial based on the estimates of the reduced VAR model. To construct orthogonalized impulse responses using Cholesky decomposition, I estimate the VAR model with oil and gasoline prices and obtain the following MA representation:

$$\begin{bmatrix} \Delta o_t \\ \Delta g_t \end{bmatrix} = \begin{bmatrix} c_{oo}(L) & c_{og}(L) \\ c_{go}(L) & c_{gg}(L) \end{bmatrix} \begin{bmatrix} e_{ot} \\ e_{gt} \end{bmatrix}; \quad E \left( \begin{bmatrix} e_{ot} \\ e_{gt} \end{bmatrix} \begin{bmatrix} e_{ot} & e_{gt} \end{bmatrix} \right) = I \quad (4)$$

where the polynomial  $c_{og}(L)$  represents the response of oil prices to the normalized shock in gasoline prices,  $c_{og}(L) = c_{og,0} + c_{og,1}L + c_{og,2}L^2 + \dots$ , and other polynomials are defined similarly. By ordering the oil price first in the VAR model, I make the assumption that gasoline prices respond contemporaneously to changes in oil prices while oil prices respond to gasoline prices with a lag. In order to identify the parameters of the polynomial  $a^*(L)$ , one needs to substitute the moving average representation for  $\Delta g_t$  into model (1) and equate the coefficients on  $e_{ot}$ :

$$\begin{aligned} c_{go}(L) &= a^*(L)(\lambda c_{oo}(L) + (1 - \lambda)c_{oo}(0)) \\ c_{go,0} + c_{go,1}L + c_{go,2}L^2 + \dots &= (a_0^* + a_1^*L + a_2^*L^2 + \dots)(c_{oo,0} + \lambda c_{oo,1}L + \lambda c_{oo,2}L^2 + \dots) \end{aligned} \quad (5)$$

To obtain equation (5), note that the VAR response of  $\Delta g_t$  to the unanticipated oil price change is  $\Delta g_t = c_{go}(L)e_{ot}$ , the VAR response of  $\Delta o_t$  to the unanticipated oil price change is  $\Delta o_t = c_{oo}(L)e_{ot}$  and  $\Delta o_t - E_{t-1}o_{t-1} = c_{oo}(L)e_{ot} - E_{t-1}[c_{oo}(L)e_{ot}] = c_{oo}(0)$ . One may match powers of  $L$  in equation (5) to recover the  $\{a_j^*\}$  from  $\{c_{go,j}\}$  and  $\{c_{oo,j}\}$ :

$$a_0^* = \frac{c_{go,0}}{c_{oo,0}}; \quad a_j^* = \frac{c_{go,j} - \lambda \sum_{k=0}^{j-1} a_k^* c_{oo,j-k}}{c_{oo,0}} \quad j > 0 \quad (6)$$

The recovered structural parameters  $a^*(L)$  measure the effect of unanticipated oil price changes on gasoline prices in a model where both anticipated and unanticipated oil price movements are present. If there is no distinction in the effect of anticipated and unanticipated oil prices changes on gasoline prices ( $\lambda = 1$ ), equation (5) simplifies to

$$a^*(L) = \frac{c_{go}(L)}{c_{oo}(L)} \quad (7)$$

which is the response of gasoline prices to crude oil price changes recovered from estimation of the PAM. If one assumes that only unanticipated oil price changes matter ( $\lambda = 0$ ) one recovers the response of gasoline prices to the oil price innovation  $e_{ot}$

$$a^*(L) = \frac{c_{go}(L)}{c_{oo}} \quad (8)$$

which is the response of gasoline prices to crude oil prices recovered from a standard VAR model<sup>10</sup>.

Next, I explain the difference in results obtained by Borenstein and Shepard (2002) for the PAM and VAR models. They report a faster response of gasoline prices for VAR model. Comparing the measures of gasoline prices responses in equations (7) - (8) it becomes clear that the PAM models and VAR models should produce different results because these models estimate the response of gasoline prices to different types of oil price changes. While the VAR model measures the responses of gasoline prices only to *unanticipated* oil price changes (the so-called oil price shocks) the PAM measures the responses of gasoline prices to some kind of weighted average of both anticipated and unanticipated oil price changes restricting both kinds of oil price movements to have the same effect on oil prices.

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<sup>10</sup>See Cochrane (1998) for more details.

The faster response of gasoline prices in the VAR model, obtained by Borenstein and Shepard (2002), may seem counterintuitive at first because one expects that refineries respond faster to anticipated oil price changes rather than unanticipated oil price changes. Hence, PAM responses should be at least as fast as the responses from VAR because some changes in the PAM are anticipated. The estimated response of gasoline prices in the VAR model takes into account historical developments in the oil market after unanticipated oil price changes. Based on the history, market participants may expect that an unanticipated increase in the oil price is more often followed by further increases in oil prices while an unanticipated decrease is followed by further decreases in oil prices. As a result, the impulse response from the VAR model measures not only the response of gasoline prices to unanticipated oil price changes in period  $t$ , but also the response of gasoline prices to conventional (and may be anticipated) behaviour of oil prices once the unanticipated oil price change at period  $t$  is realized.

The interesting question is how gasoline prices respond to changes in crude oil prices that are *anticipated* in the model in which both anticipated and unanticipated oil price changes matter and are not restricted to have the same effect on gasoline prices. If a change in oil prices is anticipated, then equation (5) becomes

$$c_{go}(L) = \tilde{a}^*(L)\lambda c_{oo}(L) \quad (9)$$

One may match powers of  $L$  in equation (9) to recover the  $\{\tilde{a}_j^*\}$  from  $\{c_{go,j}\}$  and  $\{c_{oo,j}\}$ :

$$\tilde{a}_0^* = \frac{c_{go,0}}{\lambda c_{oo,0}}; \quad \tilde{a}_j^* = \frac{c_{go,j} - \lambda \sum_{k=0}^{j-1} \tilde{a}_k^* c_{oo,j-k}}{\lambda c_{oo,0}} \quad j > 0 \quad (10)$$

Note from equation (10) that the response of gasoline prices to anticipated oil price changes is not defined for the model  $\lambda = 0$ , the model with only unanticipated oil price changes. From equation (10) one may notice that the response of gasoline prices to unanticipated

oil prices changes depends on the coefficient  $\lambda$ , the coefficient of relative importance of anticipated/unanticipated oil price changes.

It is straightforward to modify the model in (1) to allow the asymmetric effect of oil price increases and oil price decreases. Model (1) becomes

$$\begin{aligned} \Delta g_t = & a^*(L)[\lambda\Delta o_t^+ + (1 - \lambda)(\Delta o_t^+ - E_{t-1}\Delta o_{t-1}^+)] + d^*(L)[\lambda\Delta o_t^- \\ & + (1 - \lambda)(\Delta o_t^- - E_{t-1}\Delta o_{t-1}^-)] + b^*(L)\Delta g_{t-1} + e_t \end{aligned} \quad (11)$$

where  $\Delta o_t^+ = \max\{\Delta o_t, 0\}$ ,  $\Delta o_t^- = \min\{\Delta o_t, 0\}$ , the polynomials  $a^*(L)$  and  $d^*(L)$  determine the effect of oil price increases and decreases on gasoline prices, respectively. I use the same coefficient  $\lambda$  for the relative importance of anticipated/unanticipated oil price increases and decreases.

This model can be estimated using a three variable VAR model to obtain the following MA representation:

$$\begin{bmatrix} \Delta o_t^+ \\ \Delta o_t^- \\ \Delta g_t \end{bmatrix} = \begin{bmatrix} c_{o^+o^+}(L) & c_{o^+o^-}(L) & c_{o^+g}(L) \\ c_{o^-o^+}(L) & c_{o^-o^-}(L) & c_{o^-g}(L) \\ c_{go^+}(L) & c_{go^-}(L) & c_{gg}(L) \end{bmatrix} \begin{bmatrix} e_{o^+t} \\ e_{o^-t} \\ e_{gt} \end{bmatrix}; \quad E \left( \begin{bmatrix} e_{o^+t} \\ e_{o^-t} \\ e_{gt} \end{bmatrix} \begin{bmatrix} e_{o^+t} & e_{o^-t} & e_{gt} \end{bmatrix} \right) = I \quad (12)$$

where the polynomials are defined similarly to (4). From the MA representation (12) one can recover the structural parameters  $a^*(L)$  and  $d^*(L)$  to measure the gasoline price adjustment to anticipated and unanticipated oil price increases and decreases with the obvious change in notation.

To investigate the role of oil inventory, I formulate the following three variable VAR model:

$$\begin{bmatrix} \Delta J_t \\ \Delta o_t \\ \Delta g_t \end{bmatrix} = \begin{bmatrix} c_{jj}(L) & c_{jo}(L) & c_{jg}(L) \\ c_{oj}(L) & c_{oo}(L) & c_{og}(L) \\ c_{gj}(L) & c_{go}(L) & c_{gg}(L) \end{bmatrix} \begin{bmatrix} e_{jt} \\ e_{ot} \\ e_{gt} \end{bmatrix}; \quad E \left( \begin{bmatrix} e_{jt} \\ e_{ot} \\ e_{gt} \end{bmatrix} \begin{bmatrix} e_{jt} & e_{ot} & e_{gt} \end{bmatrix} \right) = I \quad (13)$$

where  $\Delta J_t$  denotes a change in oil inventory.

The ordering of the variables implies that oil and gasoline prices respond contemporaneously to the inventory dynamics. In order to avoid confusion in the discussion of results, I refer to the model in equation (12) as the *asymmetric oil price model* and to the model in equation (13) as the *oil inventory model*. I do not split the changes in oil prices into oil price increases and decreases because the results from the asymmetric oil model suggest that the difference in impact of oil price increases and decreases is not significant.

## 4 Data and Results

Data on gasoline inventory, spot and retail gasoline prices and crude oil price have been obtained from US Department of Energy<sup>11</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, while the average weekly gasoline inventory level is for Thursday of each week. Data have been deseasonalized by running a regression on weekly dummy observations.

Retail prices include taxes which may raise a problem if there were any significant gasoline tax fluctuations over time considered. While there were no significant movements in state

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<sup>11</sup>The data can be accessed at <http://www.eia.doe.gov/neic/historic/hpetroleum2.htm#Gasoline>.

average taxes<sup>12</sup>, federal tax rates on gasoline increased from 14.1 cents per gallon to 18.4 cents per gallon on October 1, 1993<sup>13</sup>. To check for the effect of this increase on the parameter estimates, I have included a dummy variable into the regression model. The dummy variable takes on a value zero before October 1, 1993 and a value one otherwise. The empirical results are robust to the inclusion of tax dummy variable. Given that it is insignificant, I omit it from the model estimation that is presented.

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 accumulate, and the biases should not be severe.

The model estimation was performed using log-differenced data in the VAR model estimation, implying a simple percent mark-up rule for margins. This, in turn, implies that crude-gasoline margins increase with the price of crude oil. To test the robustness of the estimates to a change in a functional form of the data<sup>14</sup>, I have estimated the model using changes in the levels of variables in the VAR model and have found the results to be similar across the two specifications. Therefore, I report the empirical results only for the log-differenced specification of the model.

The ordering of the variables may be an important issue in the VAR methodology. I order variables as follows  $\Delta o_t^+$ ,  $\Delta o_t^-$ ,  $\Delta g_t$  for the asymmetric oil price models and  $\Delta J_t$ ,  $\Delta o_t$ ,  $\Delta g_t$  for the oil inventory models. For the inventory models, I assume that oil inventory

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<sup>12</sup>One may check state motor-fuel tax rates at the following webpage:  
<http://www.fhwa.dot.gov/ohim/hs00/mf205.htm>.

<sup>13</sup>One may check federal tax rates on motor fuels at the following webpage:  
<http://www.fhwa.dot.gov/ohim/hs00/fe101a.htm>.

<sup>14</sup>Borenstein, Cameron and Gilbert (1997) and Johnson (2002) argue that a use of data in levels in estimation of the long-run equilibrium relationship between crude oil and gasoline price is more appropriate.

dynamics has a contemporaneous effect on both oil and gasoline prices while oil prices have a contemporaneous effect on gasoline prices and gasoline prices effect oil prices and inventory with a lag.

I estimate five asymmetric oil price models ( $\lambda = \{0.0, 0.25, 0.50, 0.75, 1.0\}$ ) and three oil inventory models ( $\lambda = \{0.25, 0.50, 0.75\}$ ).

### Asymmetric Oil Price Models

When the asymmetry models, with the number of lags set to nine<sup>15</sup> and  $\lambda$  set at 0 and 1, are estimated over the full sample period, results imply the pattern of gasoline price responses displayed in Figures 1 - 2. The two solid lines on each graph in Figure 1 - 2 are the estimated responses of gasoline prices to oil price increases and decreases with the upper solid line always representing the gasoline price response to an oil price increase. The dashed lines define a 95 percent confidence interval for the responses<sup>16</sup>. Graphs labeled with anticipated blip show the response of gasoline prices to an anticipated change in oil prices. Likewise, graphs labeled with unanticipated blip show the adjustment to a unanticipated shock in oil prices. Looking across the graphs for anticipated and unanticipated oil price movements, the shape of the gasoline responses is similar within those groups, though there is a considerable difference in the size of response between the two groups. One should note that the scale of the responses is different among the unanticipated and anticipated graphs for all figures except Figure 1.

To analyze the adjustment of gasoline prices to the long-run equilibrium, the gasoline response functions were normalized by coefficient  $\phi_1$  from the following long-run equilibrium relation between gasoline and oil prices:

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<sup>15</sup>The number of lags was set based on the AIC criteria.

<sup>16</sup>The confidence intervals for the impulse response functions were constructed using the approach of Killian (1998).

$$\ln g_t = \phi_0 + \phi_1 \ln o_t + \phi_2 TIME + \epsilon_t \quad (14)$$

where the variable *TIME* represents the time trend and  $\epsilon_t$  is a white noise process<sup>17</sup>. The passthrough rate,  $\phi_1$ , is estimated to be 0.42<sup>18</sup>. Because of the normalization, if the gasoline prices adjust to the long-run equilibrium completely then gasoline response functions should converge to unity on the graph.

For  $\lambda = 1$ , the response of gasoline prices to anticipated and unanticipated oil price fluctuations, presented in Figure 1, are identical. This is because in this model there is no difference between the effect of those price changes and they are assumed (restricted) to have the same effect by construction. The response of gasoline prices seems to have a hump-shaped form, the initial increase in gasoline prices is followed by a decline in the price level. The size of the gasoline price decline depends on whether oil prices increase or decrease. The gasoline price response to an oil price increase declines from 1.1% after four weeks to 0.9% after thirty weeks from the oil price change. The decline in the gasoline price response to an oil price decrease is from 0.8% to 0.4%. The gasoline prices adjust completely to the long-run equilibrium during the first four weeks in response to a oil price increase. This is a much faster speed of adjustment than the one reported by Borenstein et al. (1997) who report the adjustment in ten weeks. The adjustment of gasoline prices to an oil price decrease is not complete, and reaches its peak of around 0.8 after five weeks.

The dynamics of gasoline prices in the model with  $\lambda = 0$  are slightly different. For the model with  $\lambda = 0$ , the gasoline prices, presented in Figure 1, react only to unanticipated oil price changes and remain unchanged if an oil price change is anticipated. Similar to the

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<sup>17</sup>The long-run relation of this form is standard in the literature and was used, for example, by Borenstein et al. (1997) and Johnson (2002).

<sup>18</sup>When the long-run equilibrium relation is estimated using levels of oil and gasoline prices instead of logs, the estimated passthrough rate is 1.04 which is close to the previously reported estimates.

model with  $\lambda = 1$ , the gasoline price adjusts to the long-run equilibrium after the oil price increase during the first four weeks after the oil price change. The adjustment to the oil price decrease is incomplete reaching 0.8% in six weeks after which the gasoline price declines. The decline in the model with  $\lambda = 0$  is not as big as in the model with  $\lambda = 1.0$ . Gasoline prices decline proportionally from 1.1% to 1% for the oil price increase and from 0.8% to 0.5% for the oil price decrease.

Figure 1 calls for two remarks. First, this figure demonstrates the difference between the response of gasoline prices from the VAR model in equation (8), the response of gasoline prices to unanticipated oil price shock with  $\lambda = 0$ , and from the PAM model in equation (7), the response of gasoline prices to a anticipated (unanticipated) oil price shock with  $\lambda = 1$ . Unlike the results previously reported by Borenstein and Shepard (2002), the adjustment of gasoline prices in the VAR type model and in the PAM model seem to be similar with a slightly stronger response of gasoline prices in the PAM. This matches the prior expectations of a stronger gasoline price response for anticipated oil price changes rather than unanticipated oil price changes. Second, judging by the estimates of the gasoline price response to oil price increases and decreases, there seems to be asymmetry in the gasoline price response. However, this asymmetry is not statistically significant as there are overlaps in the confidence intervals for the responses of the gasoline price to oil price increases and decreases.

Next, I vary the values of  $\lambda$  between 0 and 1. That is, I look at models in which both anticipated and unanticipated oil price changes influence the gasoline price and they are permitted to have different effects on gasoline prices depending on the relative importance of anticipated/unanticipated oil price changes  $\lambda$ .

For the model with  $\lambda = 0.25$ , the model with a relatively high importance of anticipated oil price changes, we observe a fast and big response of gasoline prices to both anticipated and unanticipated oil price changes during the first month. However, the response of gasoline prices to anticipated oil price changes is much stronger than to unanticipated variation

in oil prices. Gasoline prices change proportionally by 3-4.5%, depending on whether oil prices increase or decrease, to anticipated 1% change in oil prices during the first four weeks and by 1-2% during the first week only. That is, the complete adjustment to the long-run equilibrium is achieved within the first week (no lags) when an oil price change is anticipated. In contrast, the response of gasoline price to 1% unanticipated oil price change is slower and is equal proportionally to 0.75-0.9% in four weeks. The complete adjustment for unanticipated changes occurs only for oil price increases and with a lag of five weeks. The dynamics of gasoline price adjustments in this model confirms the prior expectation that the response of gasoline prices to anticipated oil price changes should be without substantial lags, while the response of gasoline prices to unanticipated oil price changes is delayed. As reported for the models with  $\lambda = \{0, 1\}$ , gasoline prices have a hump-shaped response and tend to decline during the next 6-8 weeks after reaching their peak. The response of gasoline prices to unanticipated oil price changes is declining more gradually during the weeks 6-14, while the response of gasoline prices to anticipated oil price changes is decreasing during weeks 6-16 and is much stronger.

For models with  $\lambda = 0.50$  and  $\lambda = 0.75$ , the relative importance of anticipated oil price changes is smaller compared to the model with  $\lambda = 0.25$  because more oil price changes are treated as anticipated when  $\lambda$  is higher. One may observe a considerable shift in the dynamics of gasoline prices when oil price movements are anticipated. As I increase  $\lambda$  and decrease the relative importance of anticipated oil price changes, the response of gasoline prices to anticipated oil price changes start to look more like the adjustment of gasoline prices to unanticipated oil price changes. Gasoline prices respond only 1.5-2% (compared to 3-4.5% for the model with  $\lambda = 0.25$ ) to 1% anticipated oil price increases and decreases for the model with  $\lambda = 0.50$ . The response is even smaller, 1-1.5%, for the model with  $\lambda = 0.75$ .

The gasoline price response to unanticipated oil price changes seems to be only slightly affected by the relative importance of anticipated and unanticipated price changes in the

model. The response of gasoline prices to a unanticipated oil price change is almost the same for the model with different values of  $\lambda$  during the first 4-6 weeks and differs only in the long run. The adjustment of gasoline prices to unanticipated oil price changes is slightly stronger in the long run for the model with  $\lambda = 0.25$  than for the model with  $\lambda = 0.75$ .

Because the empirical results confirm prior expectations about the effect of anticipated and unanticipated oil price changes on gasoline prices, I conclude that an assumption of both anticipated and unanticipated changes in oil prices is empirically plausible and it may be an explanation for the reported evidence of long lags in the response of gasoline prices. Lags in the response of gasoline price occur if the oil price changes are unanticipated and there are no lags in the response of gasoline prices for anticipated oil price changes. However, the estimated responses of gasoline prices to anticipated oil price fluctuations depend on their relative importance in the model. To further investigate the role of anticipated and unanticipated oil price changes, a structural model that consists of both types of price changes needs to be developed and estimated.

### **Oil Inventory Models**

To investigate the sources of the observed hump-shaped response of gasoline prices, I consider oil inventory models. My conjecture is that when oil prices rise or decline, they affect not only gasoline prices, but also the level of oil inventory which has a feedback effect on oil and gasoline prices. For example, an oil price increase should lead to an increase in the gasoline price, but it may also lead to an increase in oil inventory in the long run if, responding to higher oil prices, oil production does not decline as much as the quantity of oil demanded. The production surplus then leads to an increase in oil inventory, but because of inventory capacity constraints the increase in oil inventory may force oil producers to decrease oil prices which, in turn, causes gasoline prices to decline as well. As a result, the observed hump-shaped response of gasoline prices may be attributed to the positive effect of

oil price movements in the short run and the negative effect of oil inventory fluctuations in the long-run. This hypothesis is tested by estimating a three variable VAR model. In this model I do not split oil price changes into oil price increases and decreases because I lack statistical evidence of an asymmetric response in the oil asymmetry model.

When inventory models, with the number of lags set to seven<sup>19</sup> and  $\lambda = \{0.25, 0.5, 0.75\}$ , are estimated over the full sample period, results imply the pattern of gasoline responses displayed in Figures 3 - 10. The impulse response functions on these graphs are not normalized by the estimated long-run equilibrium relations<sup>20</sup>. Therefore, the direct comparison of graphs with gasoline price response to oil price changes in the inventory model and graphs with the gasoline price response from the asymmetric oil price model analyzed before is not appropriate. I expect the gasoline response to converge to the estimated long-run rate in response to an oil price change,  $\phi_1 = 0.42$ , which corresponds to a value of 1 in Figures 1 - 2.

Results from the inventory model confirm prior expectations about the effect of oil inventory and oil prices on gasoline prices. In Figures 3 - 4, one may notice a considerable and statistically significant decline in gasoline prices for both the anticipated and unanticipated oil inventory changes and a statistically significant rise in the gasoline prices for anticipated and unanticipated oil price changes. The results on the effect of anticipated and unanticipated oil price and oil inventory changes on gasoline prices suggest that anticipated fluctuations in oil inventory have a stronger effect on fluctuations of gasoline prices than fluctuations in oil prices.

The response of gasoline prices to unanticipated oil inventory changes, presented in Figure 3, is only slightly affected by different values of  $\lambda$ . Gasoline prices decline approximately 1.1-

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<sup>19</sup>The number of lags was set based on the AIC criteria.

<sup>20</sup>The reason I do not normalize the response functions for this model is that I also present the response of gasoline prices to oil inventory changes and there is no accepted long-run equilibrium model for the relation between gasoline prices and oil inventory.

1.2% in response to 1% unanticipated change in oil inventory in the short run and 0.8-0.9% in the long-run. Interestingly, the estimated long run passthrough coefficient  $\eta_1$  between the oil inventory and the gasoline price in the model  $\ln g_t = \eta_0 + \eta_1 \ln J_t + \eta_2 TREN D + \epsilon_t$  is  $-0.756$ , which is close to the estimated response of gasoline prices to unanticipated oil inventory change in the long run in Figure 3. The effect of a change in oil inventory is much stronger if it is anticipated. In the oil inventory model with  $\lambda = 0.25$ , gasoline prices decline approximately 4% in both the short run and the long run as a result of 1% anticipated oil inventory change. As I increase the value of  $\lambda$  and decrease the relative importance of anticipated inventory changes in the model, the response of the gasoline prices to anticipated oil inventory changes decreases. Gasoline prices decrease 2.5% to a anticipated 1% increase in the oil inventory for the model with  $\lambda = 0.50$  and 2% for the model with  $\lambda = 0.75$ .

Figure 4 shows the response of gasoline prices to anticipated and unanticipated oil price changes. It seems that gasoline response functions adjust incompletely and converge to the value 0.25 (instead of 0.42) in response to an unanticipated oil price change. As previously reported, the response of gasoline prices to anticipated oil price changes is much stronger and depends heavily on the assumption about the relative importance of anticipated price changes in the model. When  $\lambda = 0.25$ , gasoline prices respond 1.3% to a 1% in change in oil prices. The gasoline price response to anticipated oil price movement for the model with  $\lambda = 0.75$ , is approximately 0.45% which is close to the estimated passthrough rate between oil and gasoline prices (0.42). It is not possible to estimate the value of  $\lambda$  empirically in this framework. If one believes that the response of gasoline prices to unanticipated and anticipated oil price changes should be close to the long-run rate, then it seems that the approximate value of  $\lambda$  is close to 0.75, indicating a relatively small role for the anticipated oil price changes in the model.

Having established that changes in oil inventory have a significant negative effect on gasoline prices, I look at the response of oil inventory to a change in oil price. By construction,

oil inventory responds to oil prices with at least a one period lag, but, in Figure 5, one may notice that there is no change in oil inventory for the first five weeks after the oil price change, but then oil inventory increases sharply from week five to six and continues to increase until week twelve. Based on confidence intervals for the inventory response, there is considerable uncertainty about the change of oil inventory because the change in oil inventory is not statistically significant in the long run and in the first eight weeks. However, the effect of oil price changes on oil inventory is significant for weeks 8-16 suggesting a considerable lag in the response of oil inventory to oil price movements. This increase in oil inventory coincides in timing with the observed decline in the response of gasoline prices to oil price changes in both the asymmetric oil price models and oil inventory models. Based on this evidence, I conclude that the hump-shaped form of gasoline prices is explained by the following chain of events depicted in Figure 6. A change in oil prices, whether anticipated or unanticipated, leads to a gradual adjustment of gasoline prices during the first five weeks after an oil price change without changing the oil inventory. Then, the level of oil inventory starts to adjust to a change in oil prices and it leads to a gradual decline in the response of gasoline prices.

I present the effect of gasoline prices on oil prices and oil inventory in Figures 7 - 9 and the effect of oil inventory on oil prices in Figure 10. The most interesting is the response of oil inventory to an increase in gasoline price depicted in Figure 7. An increase in gasoline price may be a result of an increase in demand or decrease in supply or a combination of these two factors. I expect that when gasoline prices increase because of increase in gasoline demand, refineries should increase the quantity of gasoline supplied which may lead to a decline in oil inventory as refineries increase gasoline production. Looking at the graph, the oil inventory does decline during the first week since the gasoline price increase. However, it starts accumulating rapidly after the second period and the overall effect of the gasoline price increase on oil inventory is positive in the long run. This is the behavior of oil inventory that I expect from an increase in gasoline prices resulting from a decrease in supply of gasoline

rather than in increase in gasoline demand. Figure 8 presents the effect of a gasoline supply decrease and a gasoline demand increase on gasoline prices and oil inventory. When the gasoline demand stays constant, a decrease in the supply of gasoline may lead to higher gasoline prices and oil inventory levels. To increase gasoline prices, refineries decrease the production of gasoline and refining of oil which leads to a higher oil inventory level. In contrast, an increase in demand should lead to a higher gasoline price and a lower level of oil inventory. Therefore, the estimated effect of gasoline prices on oil inventory suggests that most of the variation in gasoline prices are a consequence of the variation in oil supply rather than variation in oil demand. This conclusion is similar to the conclusion of Balke et al. (1998) that most of the price volatility originates in market for crude oil rather than in final consumer market.

The response of oil price to changes in oil inventory in Figure 10 confirms prior expectations. The oil inventory has a big negative effect on oil price which is very similar in the magnitude to the effect of oil inventory on the gasoline price in Figure 4.

Investigation of Figure 4 and Figure 10 reveals that oil prices adjust much faster than gasoline prices to a change in oil inventories. The decline in the oil price peaks four weeks after the oil inventory change, but the decline in the gasoline price peaks eight weeks after the oil inventory change. This sheds more light on the documented big effect of anticipated changes in oil inventory on gasoline price in Figure 3. This effect is actually a result of an oil inventory change and an oil price change that follows it and further reinforces a decline in the gasoline price.

Figure 9 exhibits the response of oil price to an increase in gasoline price. Based on this figure, I conclude that gasoline prices have a very short-lived effect on oil prices which is significant only for the second week.

## 5 Conclusions

This paper illustrates that the responses of gasoline prices are different to anticipated and unanticipated changes in oil prices and oil inventory. The response of gasoline prices to an anticipated change in oil prices is fast and completed within a week after the oil price change; the gasoline price response to unanticipated oil price changes is slow and incomplete. I develop an adjustment model that allows anticipated and unanticipated oil price movements have different effects on gasoline prices. In this framework, the gasoline price response depends on the relative importance of anticipated/unanticipated oil price fluctuations. The response of gasoline prices to anticipated changes in oil prices is the strongest and fastest for the versions of the model where anticipated oil price changes are relatively important. As anticipated oil price changes become less important, the response of gasoline prices to anticipated oil price changes becomes muted and delayed.

The obtained results support claims in the literature that the cost of adjustment of production and inventory are responsible for the long lags observed in the response of gasoline prices. A reported hump-shaped response of gasoline prices to changes in crude oil prices is explained by the effect of oil prices on oil inventory and its feedback effect on the gasoline price. Gasoline prices increase during the first six weeks after an oil price change and decline during the weeks 6-14 before stabilizing to a new level of gasoline prices. The gasoline price decline is attributed to a delayed, approximately six weeks, and statistically significant effect of an oil price change on oil inventory which has a big and statistically significant effect on gasoline prices. In addition, the results on the response of oil inventory to gasoline price movements suggest that most of the changes in gasoline prices are the result of oil supply fluctuations rather than demand fluctuations.

In sum, the obtained results present new evidence about the role of anticipated and unanticipated oil prices and oil inventory changes on gasoline price, using a reduced form

approach. The assumed relative importance of anticipated oil price changes determines the influence on gasoline prices. Future work should use a structural approach to analyze this question further. The structural approach should allow to estimate the relative importance of anticipated price changes rather than vary it as in the reduced form approach.

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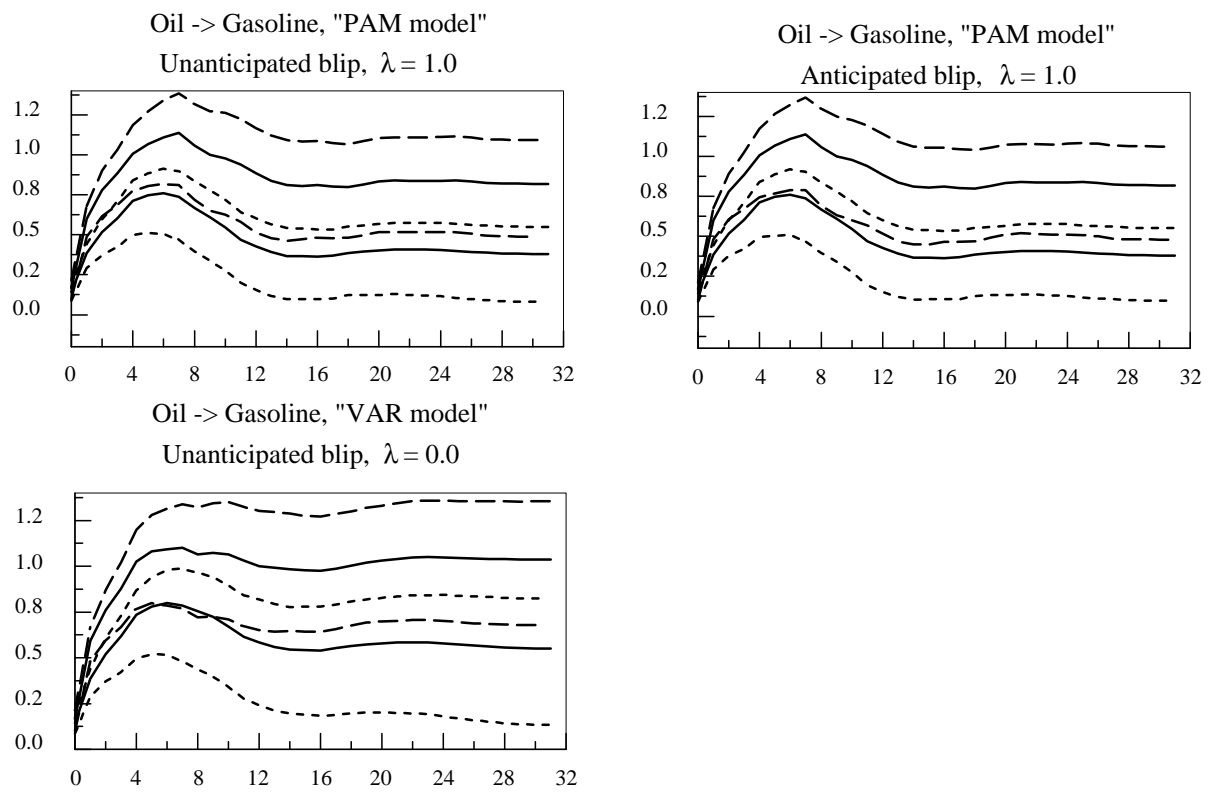


Figure 1: The response of gasoline prices to changes in oil prices.

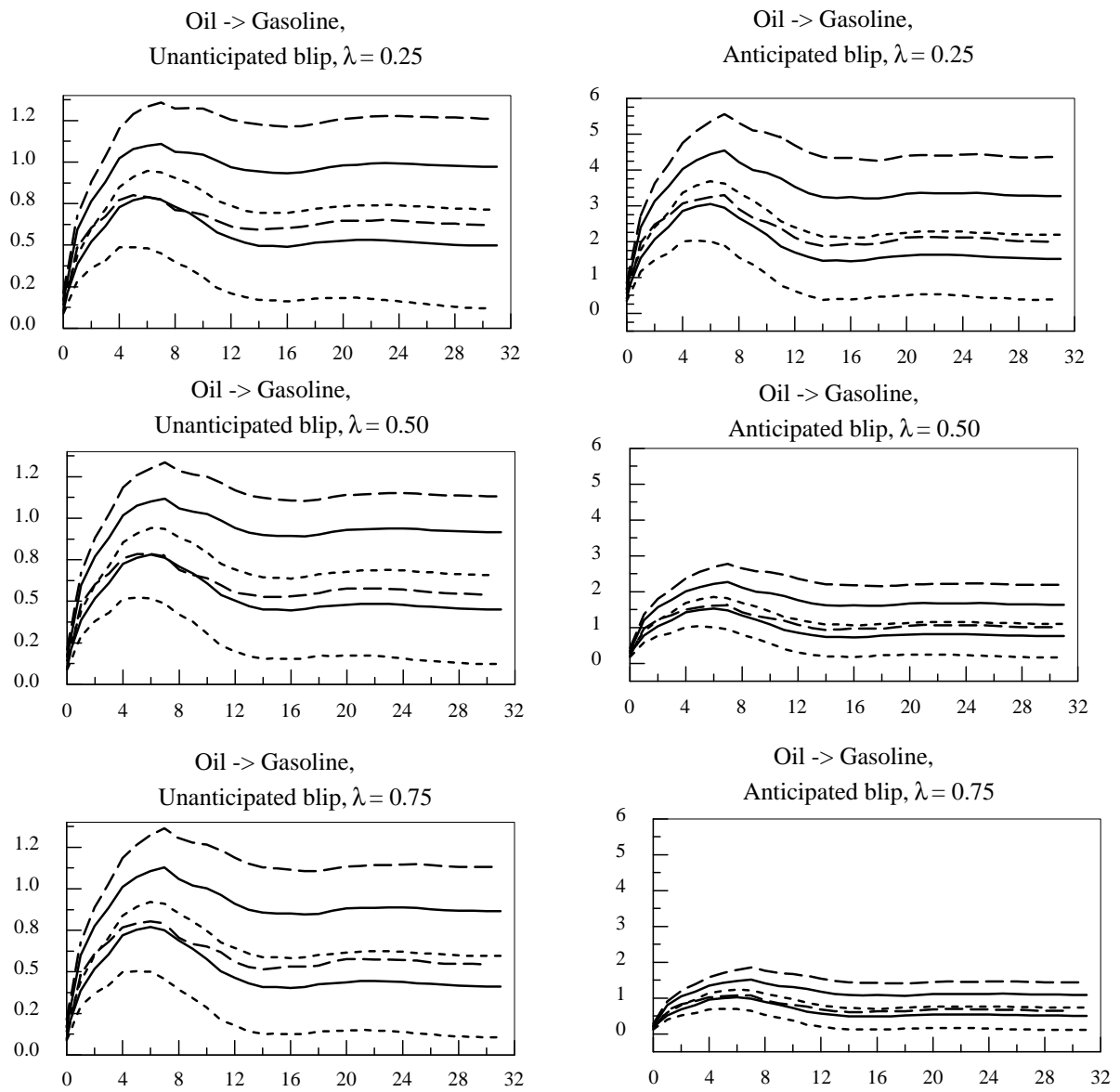


Figure 2: The response of gasoline prices to changes in oil prices.

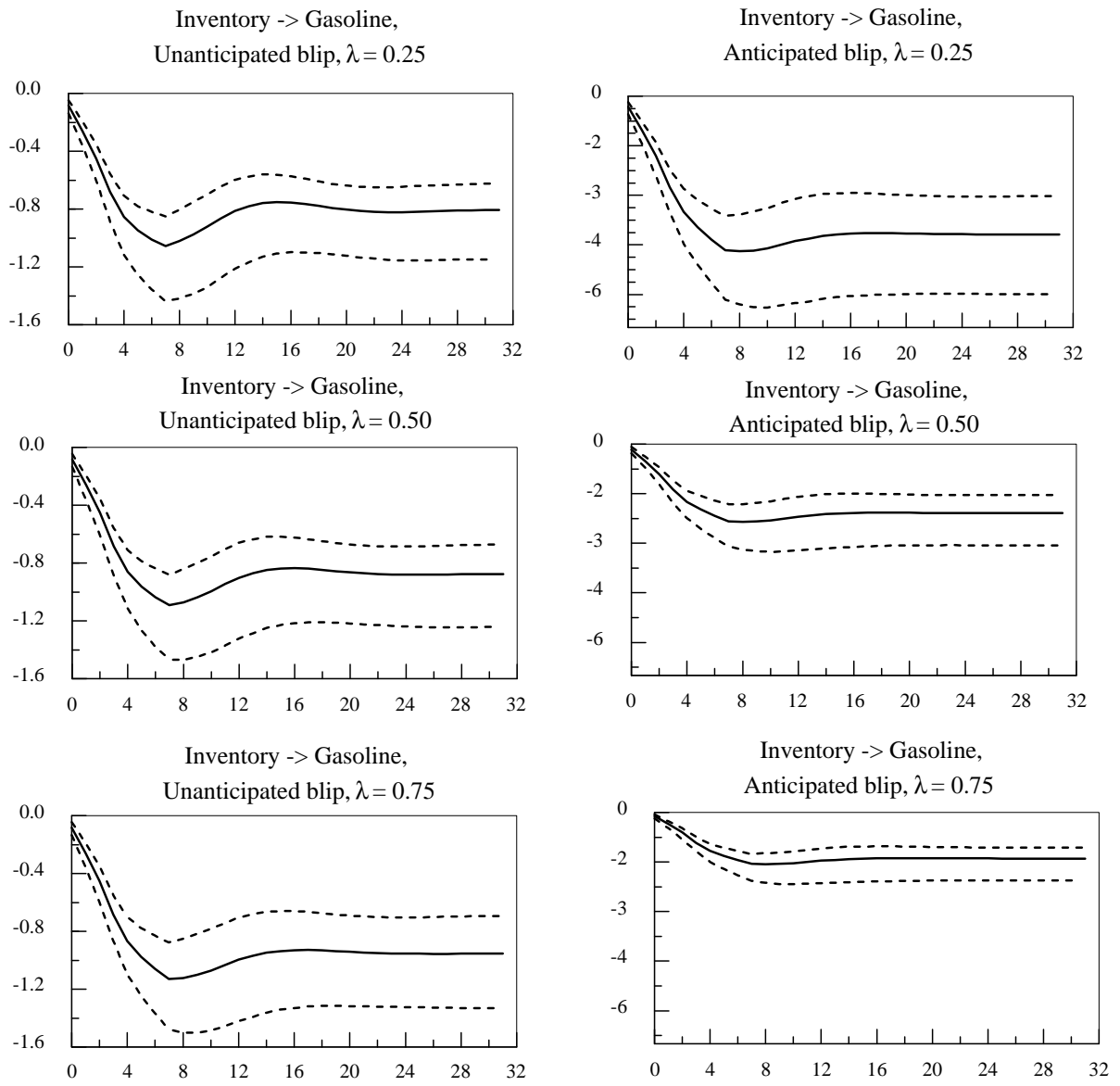


Figure 3: The response of gasoline prices to changes in inventories.

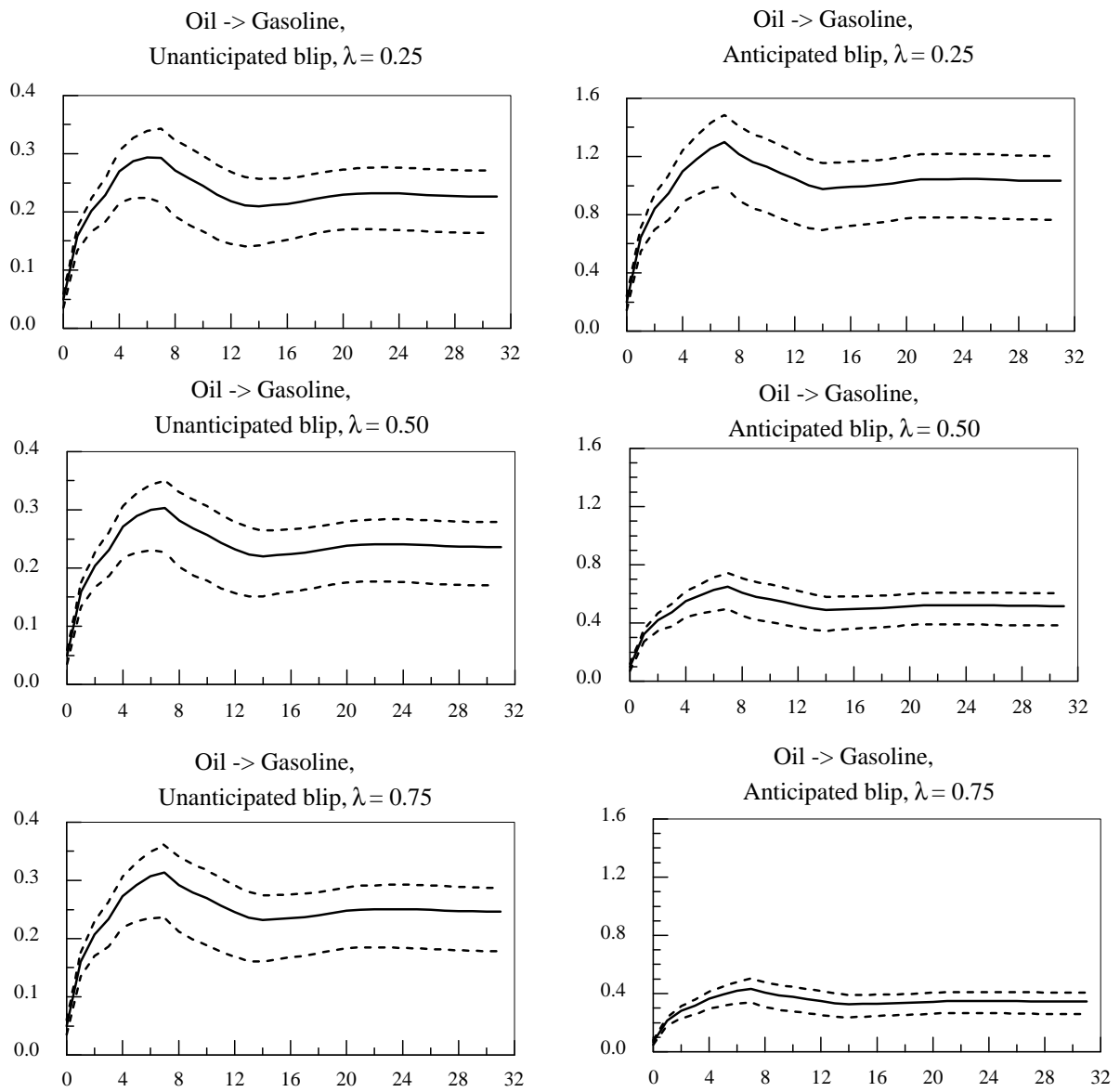


Figure 4: The response of gasoline prices to changes in oil prices.

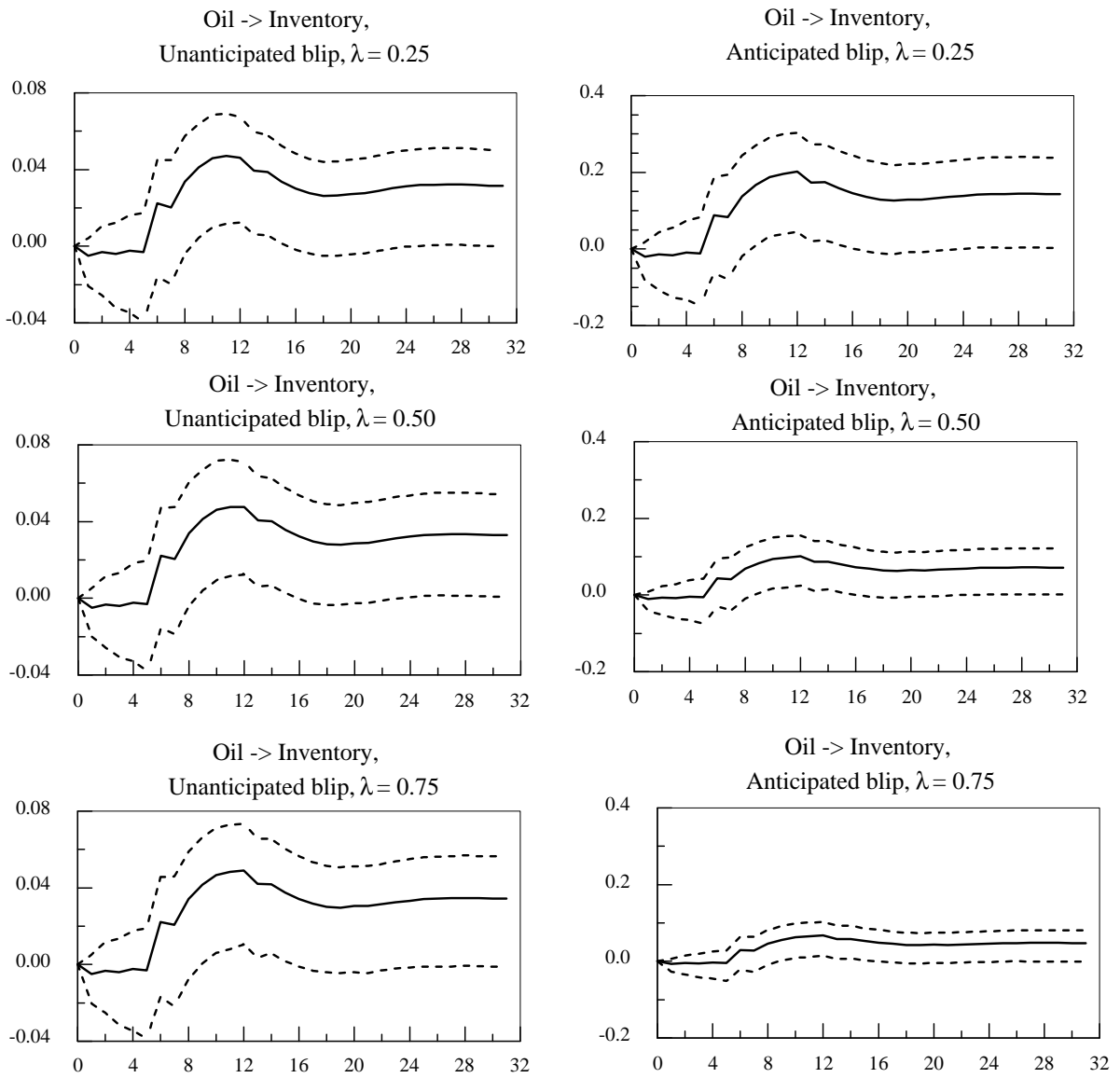


Figure 5: The response of oil inventory to changes in oil prices.

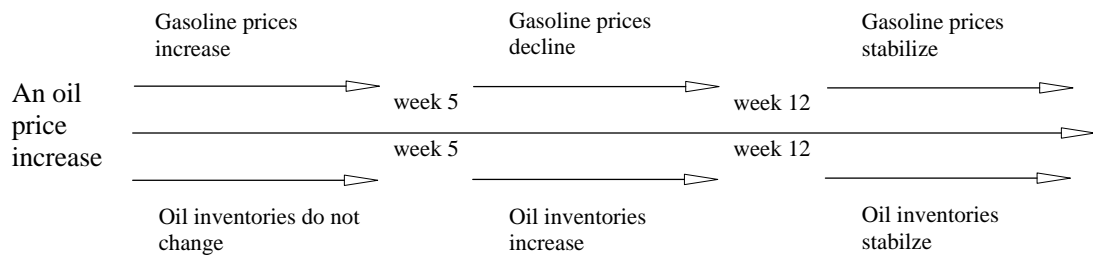


Figure 6: The effect of an oil price increase on the gasoline price and oil inventory. An oil price reduction has the opposite effect.

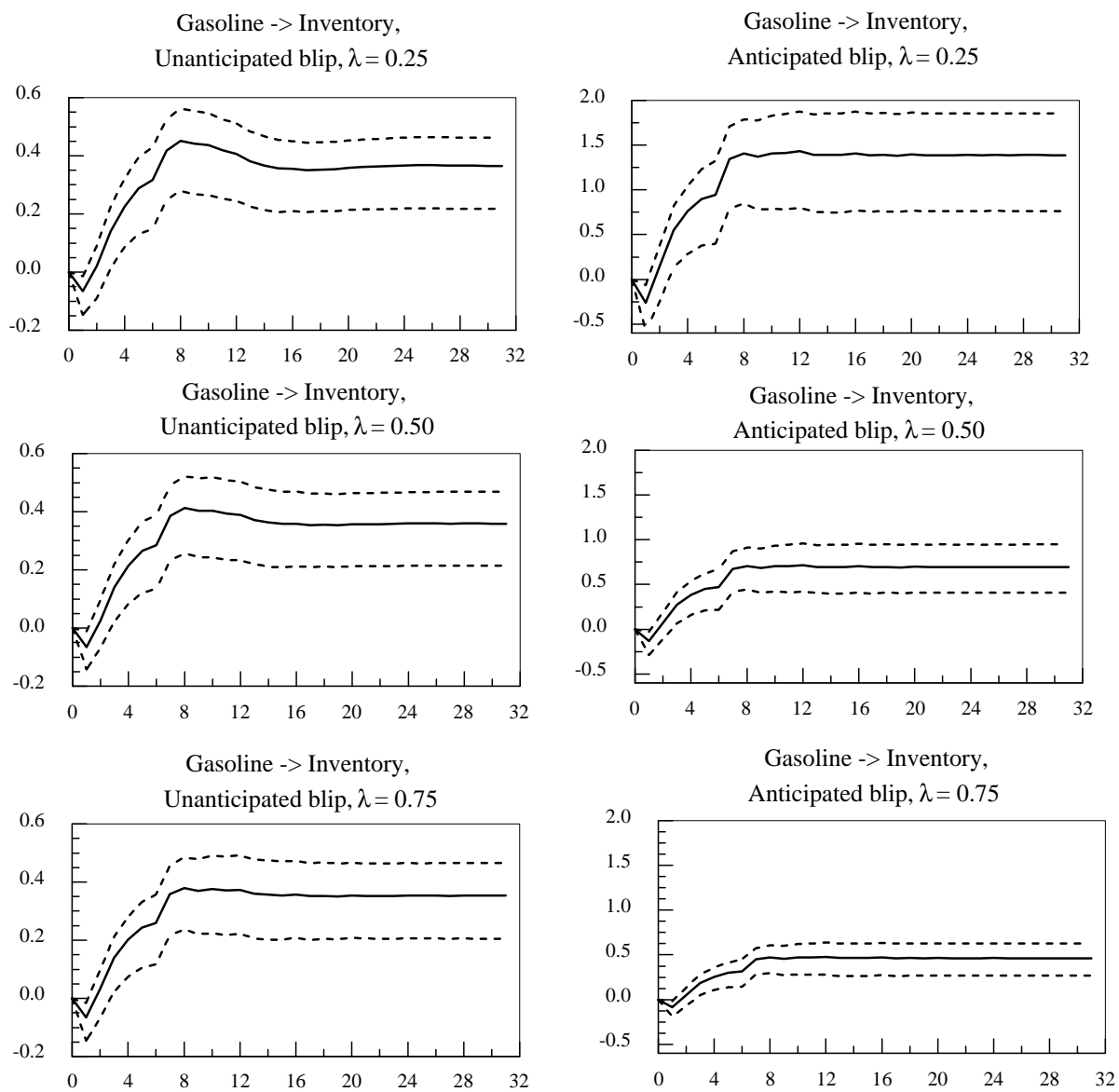


Figure 7: The response of oil inventory to changes in gasoline prices.

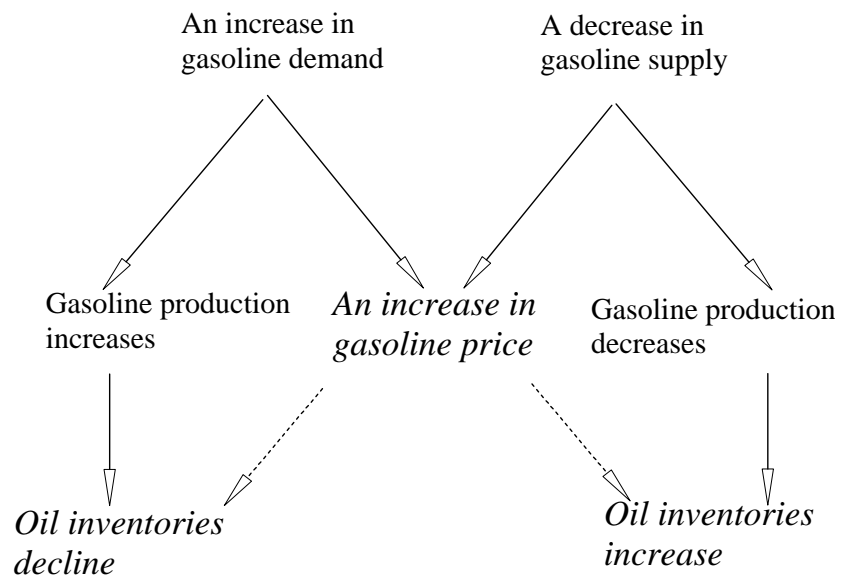


Figure 8: The possible links between a gasoline price increase and oil inventories.

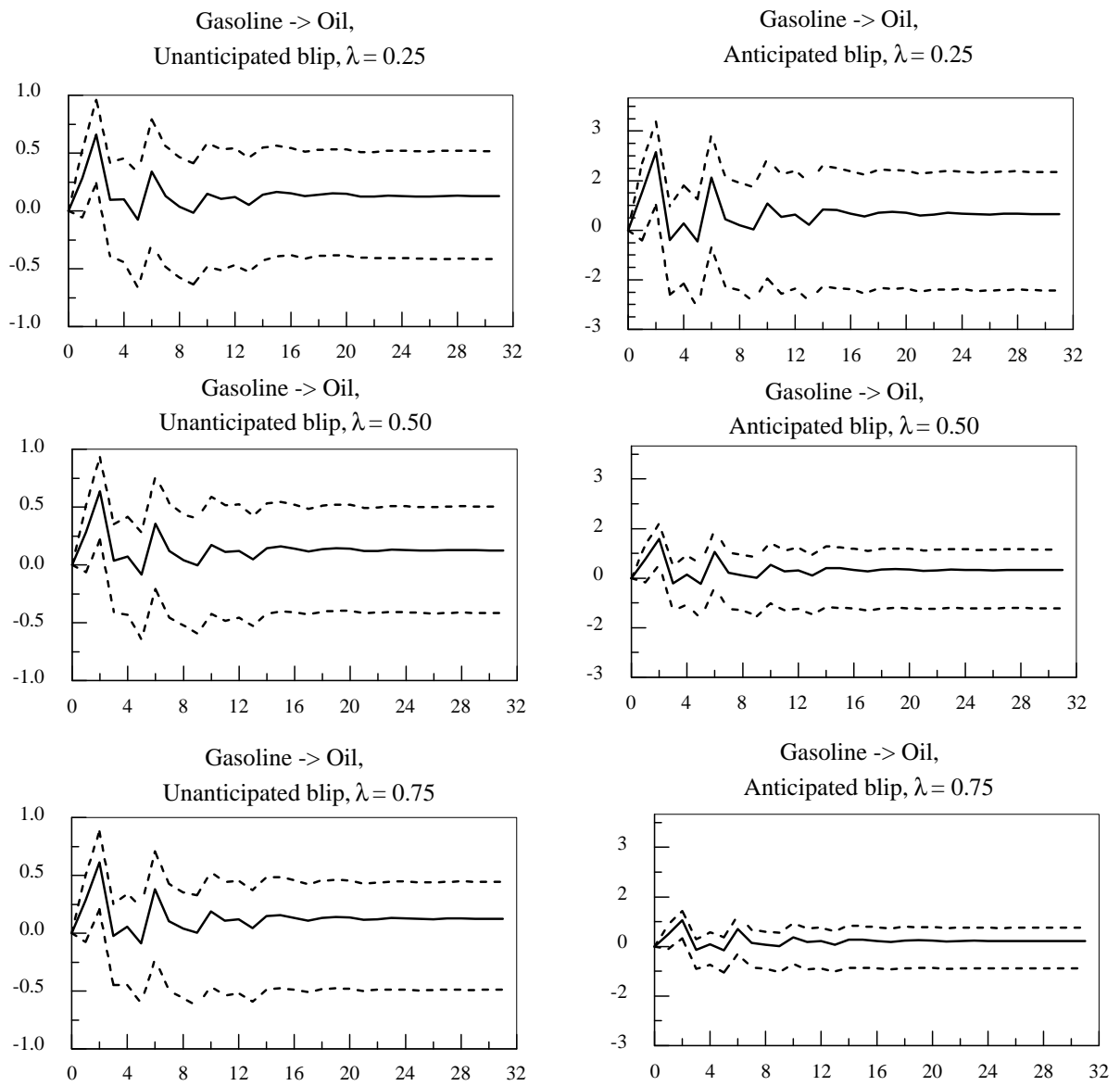


Figure 9: The response of oil prices to changes in gasoline prices.

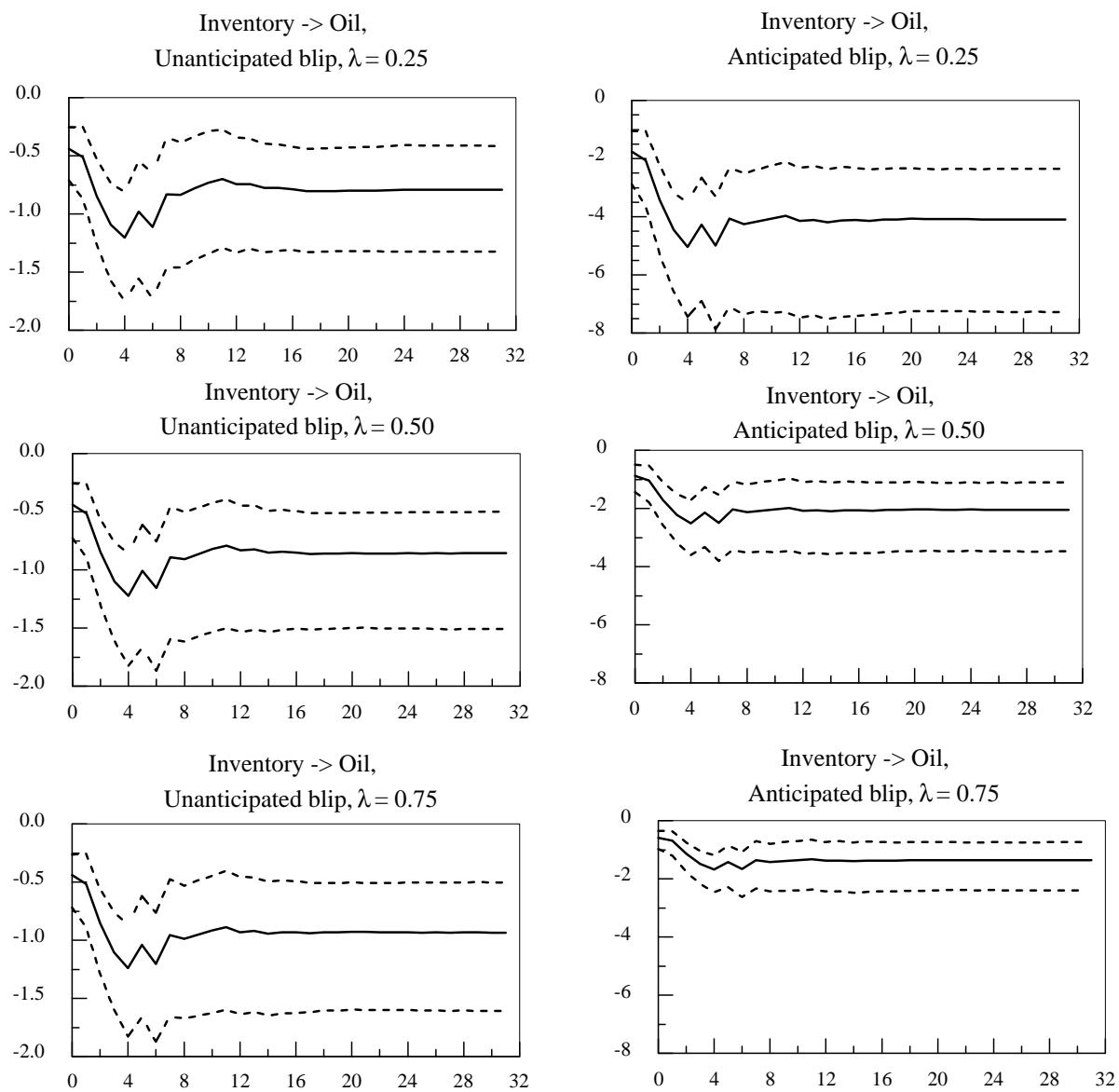


Figure 10: The response of oil prices to changes in oil inventory.