Consumer gasoline prices: an empirical investigation

A structural vector autoregression model indicates that price changes for consumer gasoline have been driven by changes in supply rather than changes in demand

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According to the BLS Consumer Expenditure Survey, the average consumer spent approximately $1,300 on gasoline and motor oil in 2000, an increase of 22.4 percent over the 1999 figure. Over the same period, the average price of gasoline increased 36.3 percent,[1] indicating that price changes within the gasoline market can substantially affect consumers' expenses. Conventional reasoning suggests that the high level of volatility for gasoline prices is the result of supply forces, as the price of crude petroleum changes rapidly due to production decisions of the Organization of Petroleum Exporting Countries (OPEC) nations. However, shifts in demand also can cause variations in gasoline prices. The purpose of this article is to examine the nature of price changes for consumer gasoline, using econometric techniques as well as historical evidence.

The second section of the article analyzes the impact of crude-oil supply shocks on prices at various stages of gasoline production by visually examining those price changes for crude oil, producer gasoline, and consumer gasoline which occurred subsequent to interruptions in the supply of crude petroleum. The major supply shocks considered are the Yom Kippur War, the Iranian Revolution, the Iran-Iraq War, the Persian Gulf War, and a 1999 OPEC production cut.

The article's third section constructs a structural simultaneous-equations model of the market for consumer gasoline to determine the effects of changes in supply and demand on the price of gasoline. The model developed is a five-variable structural vector autoregression constructed from the Producer Price Indexes (PPI's) for crude petroleum and gasoline, the Consumer Price Index (CPI) for gasoline, the quantity of gasoline consumed domestically, and the industrial production index. The final section of the article presents its conclusion.

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Historical evidence

The impact of supply shocks on prices at various stages of processing within the gasoline market can be analyzed by visually examining historical price movements for crude petroleum, producer gasoline, and consumer gasoline. The actions of the OPEC cartel enable petroleum-based supply shocks to be easily identified and their effects on prices throughout the gasoline market to be examined. The analysis begins with a historical overview of OPEC.

OPEC's history. OPEC was established in September 1960 at the Baghdad Conference. Initially, the cartel included Iran, Iraq, Kuwait, Saudi Arabia, and Venezuela. By the end of 1971, Qatar, Indonesia, Libya, the United Arab Emirates, and Nigeria had joined the organization. From OPEC's inception until the early 1970s, the cartel was unable to exert any significant control over crude-petroleum prices. Prices for crude petroleum remained relatively stable in nominal terms at around $3.00 per barrel from 1958 to 1970 and fell in real terms over the same period.[2]

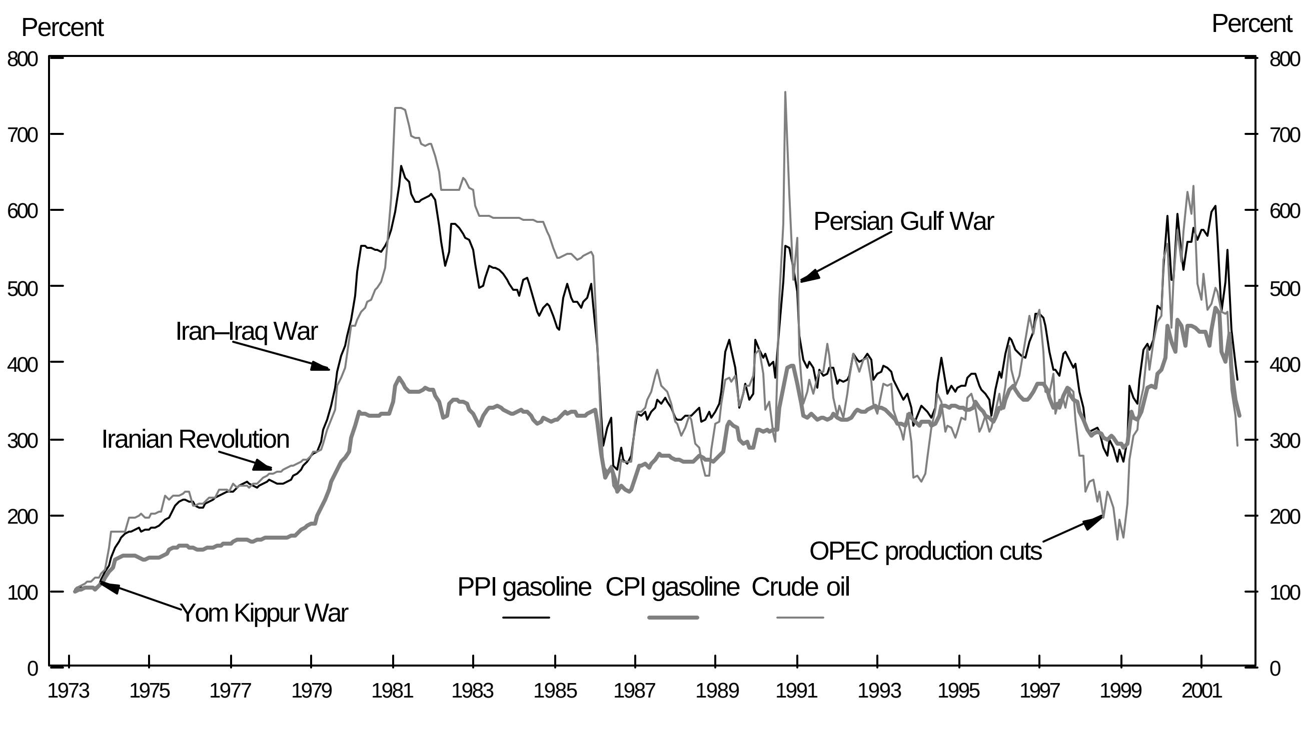
During the 1970s, OPEC's ability to influence crude-petroleum prices increased substantially due to rising demand for petroleum products[3] and the strength the organization gained from the addition of new members. OPEC's increasing power in the petroleum market becomes apparent from the effects its supply decisions have had on petroleum prices since the 1970s.

OPEC supply shocks. Chart 1 displays the PPI's for crude petroleum and gasoline and the CPI for gasoline. For a simplified comparison, the three indexes were rebased to March 1973 = 100. The first major interruption in OPEC's petroleum supply resulted from an oil embargo launched in connection with the Yom Kippur War. As a result, U.S. imports of crude petroleum fell by approximately 30 percent while the embargo was in place.[4] The drastic reduction in the supply of crude petroleum caused domestic prices to rise 67 percent from October 1973 to the end of 1974. Over the same period, domestic prices for wholesale and consumer gasoline increased 67 and 32 percent, respectively, indicating a strong pass-through relationship between crude-petroleum prices and gasoline prices. (See chart 1.)

The second crude-petroleum supply shock took place at the time of the Iranian revolution, in conjunction with the Iran-Iraq War. The shock began as a result of panic in the world oil market caused by the revolution. The situation worsened when Iran prohibited oil exports to U.S. firms after the U.S. administration froze Iranian assets in the United States.[5] The war between Iran and Iraq exacerbated the crisis, and Iran's oil production declined 3.9 million barrels a day from 1978 to 1981. Furthermore, the war caused other Persian Gulf countries to reduce their oil production. By 1981, OPEC's oil production fell 7 million barrels per day, decreasing world oil production by 11.6 percent from its 1978 average.[6] From November 1978 to October 1981, the price of crude petroleum rose 172 percent. Increasing prices were passed forward through the chain of production, with prices for wholesale and consumer gasoline rising 150 and 103 percent, respectively, over the same period. (See chart 1.)

The third crude-oil interruption occurred in 1990 as tensions between Iraq and Kuwait rose. On July 17, 1990, Iraq accused Kuwait of overproducing oil and of stealing oil from the Iraqi Rumaila oil fields. Iraq invaded Kuwait on August 2, 1990, and the ensuing Gulf War resulted in a reduction of about 4.3 million barrels of oil per day from Iraq and Kuwait. This decrease in the oil supply caused world production to decline by approximately 7.2 percent from its average 1989 level. However, non-OPEC countries in Central America, Western Europe, and the Far East, as well as the United States, supplemented OPEC production to offset some of the losses.[7] Chart 1 shows that crude-petroleum prices rose 155 percent between July 1990 and October 1990. Over

Chart 1. Historical price movements and supply shocks, 1973–2001



NOTE: All year labels are for January.

the same period, domestic prices of gasoline at the wholesale and consumer levels increased by 45 percent and 26 percent, respectively, to reflect skyrocketing input costs.

The fourth significant crude-petroleum supply shock took place in 1999, after OPEC reduced its production of oil by 1.7 million barrels per day, representing a 2.5-percent decline in world oil production.[8] In addition, U.S oil production decreased approximately 6 percent from 1998 to 1999.[9] Crude-petroleum prices soared 277 percent from February 1999 to November 2000 in response to drastically reduced supplies. Gasoline prices at the wholesale and consumer levels rose 114 and 55 percent, respectively, due to increasing crude-petroleum input prices.

An examination of historical price movements for crude petroleum, wholesale gasoline, and consumer gasoline indicates that the production decisions of OPEC nations have considerable effects on prices within the gasoline market at all stages of production. The historical price trends also suggest that price volatility resulting from supply shocks diminishes at progressively more advanced stages of processing. In three out of four instances, supply shocks increased prices for crude petroleum more than they did wholesale gasoline prices, and in all four instances crude-petroleum prices rose more than consumer gasoline prices.

Model of gasoline price movements

To examine the source of variations in consumer gasoline prices more rigorously, a five-variable structural vector autoregression model of supply and demand within the gasoline market is presented. Vector autoregressions are an econometric tool used to study systems of interrelated time series in which all variables in a system are expressed as a linear function of the lagged values of every variable in the system.[10] A structural vector autoregression model is developed by imposing theoretically plausible contemporaneous restrictions on the error terms of the unrestricted vector autoregression.

Unrestricted vector autoregression. A five-variable unrestricted vector autoregression model was constructed with 1974–2001 monthly data of the PPI's for crude petroleum and gasoline, the CPI for gasoline, the quantity of domestically consumed gasoline, and the industrial production index. The PPI's for crude petroleum and gasoline were included in the model as supply variables, because both are major inputs into the production of consumer gasoline. To account for shifts in demand, the industrial production index, a major determinant of gasoline demand, was included in the model.

All data are seasonally adjusted and were transformed into percentage growth form by taking the first differences of the natural logarithms of the data. Converting data to percentage growth form usually induces *stationarity*, indicating that the mean, variance, and covariance of the time series are independent of time. Estimation of vector autoregressions with nonstationary data is problematic, because tests used to estimate the significance of the regressions' coefficients will not be valid.[11] Accordingly, to test for stationarity, the augmented Dickey-Fuller test was applied to the variables in percentage growth form; this is a one-tailed test of the null hypothesis that the time series is not stationary. A large negative test statistic rejects the null hypothesis and implies that the time series is stationary.[12] As the following tabulation shows, the tests suggested that, at the significance level of $p = 0.01$, all five time series were stationary when they were expressed in percentage growth form:

Variable	*Augmented Dickey-Fuller statistic*
Crude petroleum	–8.87
PPI for gasoline	–5.02
CPI for gasoline	–5.22
Quantity of gasoline	–4.71
Industrial production	–5.97

The Akaike, Schwarz, and Hannan-Quinn information criteria were implemented to compare the performance of the vector autoregression model with various lag length specifications. The Schwarz and Hannan-Quinn criteria indicated that a vector autoregression whose equations have two lags is optimal, while the Akaike criterion suggested a three-lag regression. The two-lag specification suggested by the Schwarz and Hannan-Quinn criterion was chosen, and the unrestricted vector autoregression was estimated by using ordinary least squares.

Structural vector autoregression. Innovations within a vector autoregression are generally contemporaneously correlated with each other: a random innovation to one variable often occurs simultaneously with innovations to other variables in the system.[13] To recover the contemporaneous relationships among the vector autoregression's innovations, allowing for economically meaningful conclusions, it is necessary to orthogonalize the residuals from the unrestricted vector autoregression. The conventional method of orthogonalization is based on the Cholesky decomposition, which assumes that the residuals have a recursive structure.[14] However, this approach is often not supported by economic theory and leads to a series of orthogonal shocks that have no particular meaning. Alternatively, the structural impulses can be obtained by imposing theoretically plausible restrictions on the vector autoregression's residuals.[15] The latter of these two approaches is taken in this article.

The estimated variance-covariance matrix of the unrestricted vector autoregression's residuals contains $n(n + 1)/2$ distinct elements. Recovering the structural disturbances requires the estimation of an $n \times n$ matrix of parameters. Therefore, $n^2 - n(n + 1)/2 = n(n - 1)/2$ additional restrictions are required to recover the structural disturbances. These additional restrictions can be obtained by letting the coefficients of the structural parameters vanish. Consequently, in the case of the five-variable vector autoregression model that was constructed, identification of the structural disturbances requires at least 10 restrictions.

The following structural specification of the contemporaneous interactions among the vector autoregression's innovations was estimated:

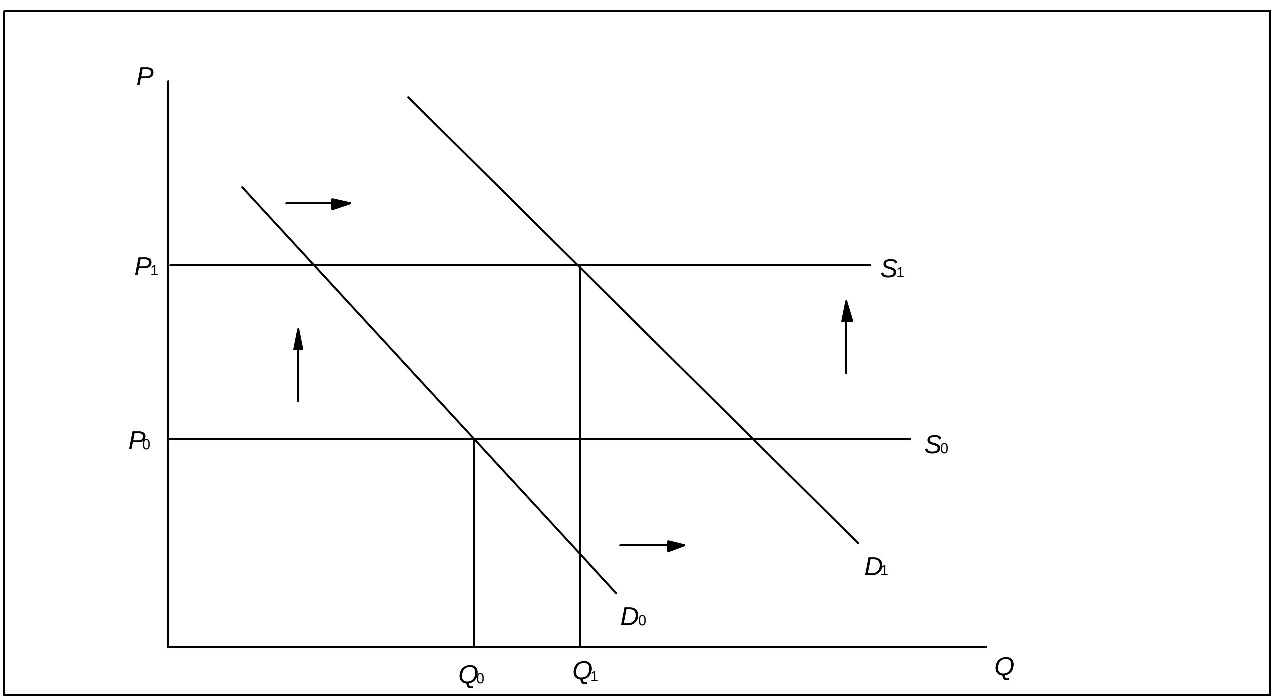
(1) PCP = $ß_1$QIP + u_1;
(2) PPG = $ß_2$PCP + u_2;
(3) PCG = $ß_3$PCP + $ß_4$PPG + u_3;
(4) PCG = $-ß_5$QCG + $ß_6$QIP + u_4;
(5) QIP = u_5.

In the preceding equations, PCP, PPG, PCG, QCG, and QIP refer to the innovations in, respectively, the PPI for crude petroleum, the PPI for gasoline, the CPI for gasoline, the quantity of gasoline consumed, and the quantity of industrial production, as estimated by the unrestricted vector autoregression. The *u*'s are uncorrelated error terms. For symmetry purposes, the fourth equation is normalized to the price of consumer gasoline.

In all of the equations, all of the coefficients are positive, with the exception of the coefficient of QCG . The structure of the contemporaneous relationships in the system is derived by assuming a horizontal supply curve and a downward-sloping demand curve in the market for consumer gasoline. Under this framework, shifts in the supply curve affect price and quantity, whereas shifts in the demand curve change only quantity. The error terms u_1, u_2, and u_3 represent supply shocks, u_4 is a demand shock, and u_5 is a simultaneous shock to supply and demand. Given the assumptions about the slopes of the demand and supply curves, the following relationships hold: (1) crude-petroleum prices vary as a result of innovations in industrial production, reflecting shifts in demand due to changes in the level of production; (2) producer gasoline prices are affected by innovations to crude petroleum, which is a major material input to the production of producer gasoline; (3) consumer gasoline prices vary with innovations to crude petroleum and producer gasoline, both of which are inputs to the production of consumer gasoline; (4) consumer gasoline prices are affected by innovations to both the quantities of gasoline consumed and industrial production; and (5) the quantity of industrial production is exogenous to the system and is not affected by innovations to any variables.

To illustrate how shocks to demand and supply affect consumer gasoline market equilibrium, chart 2 shows the effects

Chart 2. Effects of an industrial production shock on the market for consumer gasoline



S = supply; *D* = demand; *P* = price; *Q* = quantity of a shock to u_5 (industrial production) on the equilibrium price and quantity of consumer gasoline. A shock to industrial production causes individuals to desire more gasoline and shifts the demand curve from D_0 to D_1. In turn, the supply curve shifts from S_0 to S_1, reflecting increased production costs as input prices are driven up by the change in industrial production. The effect on price is positive and results from the shifting supply curve. The effect on quantity is ambiguous and depends on the relative size of shifts in the demand and supply curves. In the chart, it is clearly seen that the positive effect on quantity resulting from the shift in demand outweighs the negative effect on quantity from the shift in supply.

The results of the estimation of the structural coefficients are as follows, where $^{(1)}$ indicates significance at the level of $p = 0.1$, $^{(2)}$ indicates significance at the level of $p = 0.05$, and $^{(3)}$ indicates significance at the level of $p = 0.0001$:

$$\begin{aligned}
&\mathrm{PCP} = 0.36\mathrm{QIP} + u_1;\\
&\mathrm{PPG} = 0.38\mathrm{PCP}^{(3)} + u_2;\\
&\mathrm{PCG} = 0.014\mathrm{PCP} + 0.42\mathrm{PPG}^{(3)} + u_3;\\
&\mathrm{PCG} = -12.5\mathrm{QCG}^{(2)} + 3.13\mathrm{QIP}^{(1)} + u_4;\\
&\mathrm{QIP} = u_5.
\end{aligned}$$

The signs of the estimated coefficients are as anticipated. Innovations to crude petroleum are positively affected by shocks to industrial production. Innovations to producer gasoline prices are positively correlated with crude-petroleum innovations. Shocks to the CPI for gasoline are positively affected by innovations to crude petroleum and to the PPI for gasoline. Innovations to the CPI for gasoline are negatively correlated with shocks to the quantity of consumer gasoline and are positively correlated with industrial production shocks.

The system of structural disturbances is overidentified, because estimation required only 10 restrictions, whereas 14 were provided. The overidentification of the system allowed the likelihood ratio (LR) test for overidentification to be applied. The LR test is a test of the validity of the system's restrictions, where the null hypothesis is that the identifying restrictions are valid. A p-value of 0.01 or 0.05 is required to reject the null hypothesis. The test's chi-square statistic and p-value were 4.24 and 0.37, respectively. Therefore, the null hypothesis was not rejected, and the restrictions were found to be valid.

Accumulated impulse response functions were constructed from the vector autoregression's coefficients with the use of the orthogonalized set of residuals. Impulse response functions measure the effect of a one-standard-deviation innovation of a variable on current and future values of the other variables in a system of equations.[16] Standard error bands demonstrating the statistical significance of the impulse response functions also were constructed, using analytical methods. The impulse response function is statistically significant when both standard error bands either are above zero or are below zero on the y-axis.

Chart 3 presents the accumulated impulse response functions. The first row of the chart indicates that, on the one hand, the PPI for crude petroleum is not significantly affected by unanticipated changes in the PPI for gasoline, the CPI for gasoline, or the quantity of consumer gasoline. On the other hand, shocks to the quantity of industrial pro-duction result in marginally significant changes in crude-petroleum prices. The second row suggests that innovations to crude-petroleum prices strongly affect producer gasoline prices and that unanticipated changes in the CPI for gasoline and the quantity of industrial production produce only marginal changes in the PPI for gasoline. By contrast, shocks to the quantity of gasoline consumed do not affect producer gasoline prices. The third row indicates that innovations in crude-petroleum prices and producer gasoline prices produce highly significant changes in the CPI for gasoline and that shocks to the quantity of industrial production affect consumer gasoline prices only marginally. Conversely, unanticipated changes in the quantity of gasoline consumed do not affect the CPI for gasoline. The fourth row of the chart shows that price shocks to crude petroleum, producer gasoline, and consumer gasoline tend to reduce the quantity of gasoline consumed, whereas innovations to the quantity of industrial production in-crease the quantity of gasoline consumed. The last row suggests that none of the variables in the system significantly affect the quantity of industrial production.

Variance decompositions were also constructed from the model. Variance decompositions show the percentage of forecast variance in one variable of the vector autoregression caused by innovations in the other variables.[17] The variance decompositions obtained from the analysis are presented in table 1.

The variance decomposition of the CPI for gasoline implies that the majority of the forecast error variance in consumer gasoline prices results from price shocks to production inputs. Innovations in crude petroleum and in the PPI for gasoline account for 73.74 percent of the forecast errors in the CPI for gasoline (40.14 percent from crude petroleum and 33.6 percent from producer gasoline). Conversely, shocks to the quantities of gasoline and industrial production account for only 0.11 and 1.82 percent, respectively, of the CPI's forecast error variance.

THIS ARTICLE HAS PRESENTED BOTH HISTORICAL AND EMPIRICAL EVIDENCE in examining the source of price variations within the gasoline market. The main finding of the article is that price changes for consumer gasoline have histori-cally been driven by changes in supply as opposed to demand.

The initial approach taken was to identify historical supply shocks within the crude-petroleum market and examine how

Chart 3. Accumulated impulse response functions

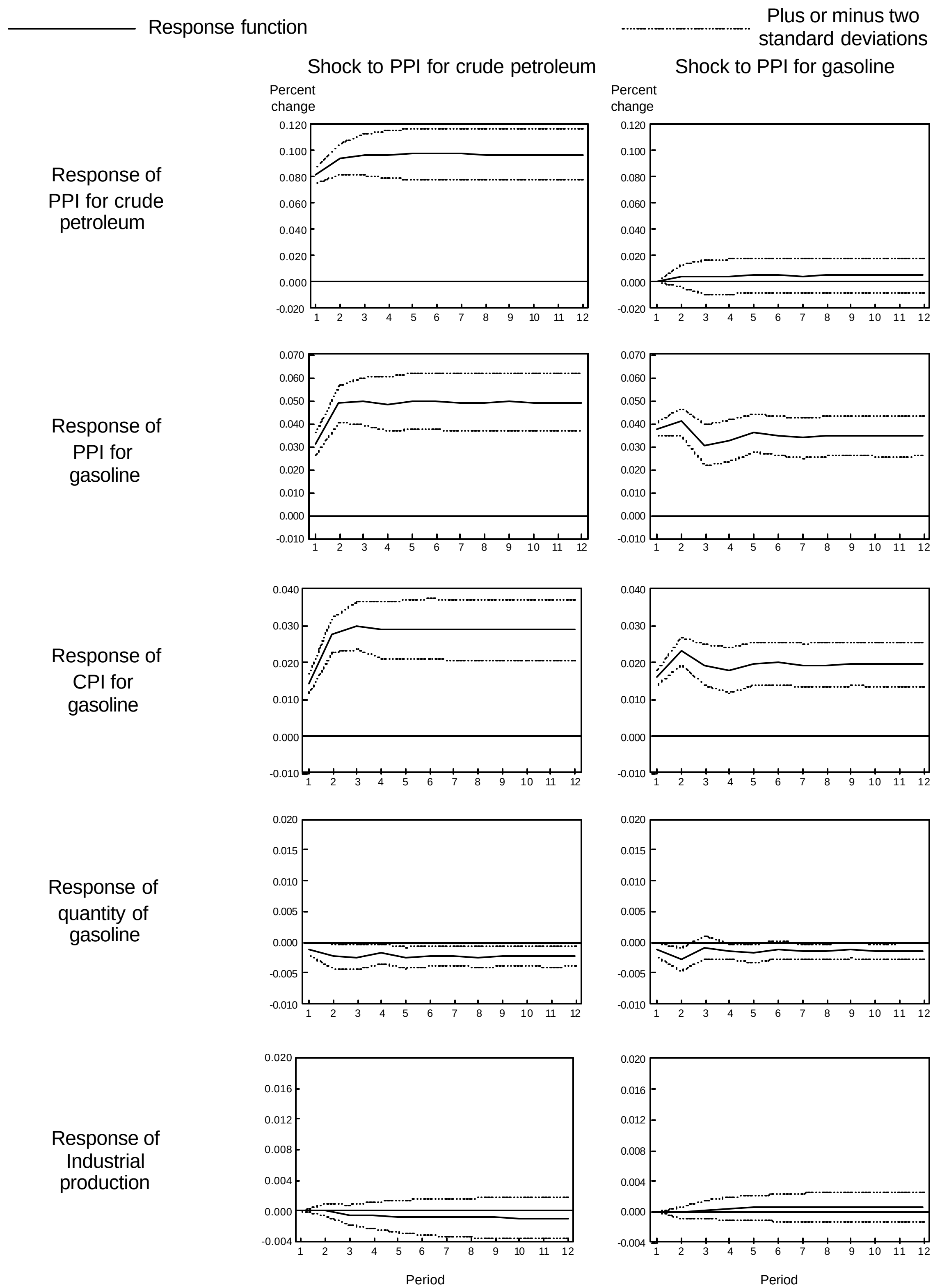


Chart 3. **Continued—Accumulated impulse response functions**

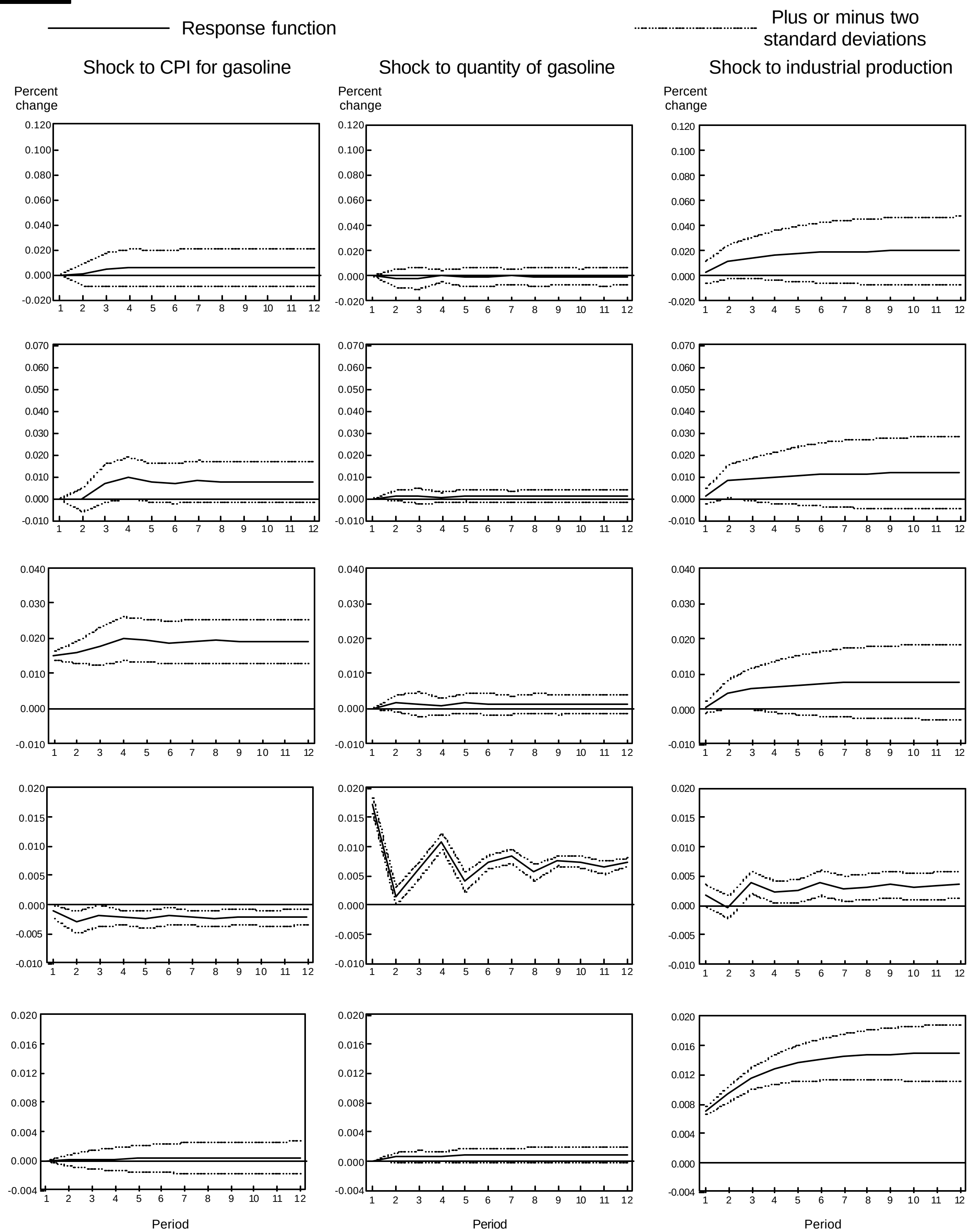


Table 1. Variance decompositions after 12 months

Decomposition variable	Percentage of forecast errors due to—				
	PPI for crude Petroleum	PPI for gasoline	CPI for gasoline	Quantity of gasoline	Industrial production
PPI for crude petroleum	97.82	0.31	.26	0.16	1.46
PPI for gasoline	43.08	52.57	2.42	.11	1.82
CPI for gasoline	40.14	33.60	23.97	.40	1.88
Quantity of gasoline	.49	1.28	.97	92.79	4.47
Industrial production	.71	.32	.05	.56	98.36

prices at various stages of processing responded to the shocks. In all cases examined, interruptions in the supply of crude petroleum resulted in significant increases in the prices of crude petroleum, wholesale gasoline, and consumer gasoline.

To analyze pricing relationships within the gasoline market more formally, a five-variable structural vector autoregression model of the gasoline market was developed, using the PPI's for crude petroleum and gasoline, the CPI for gasoline, the quantity of domestically consumed gasoline, and the industrial production index. Impulse response functions constructed from the model's coefficients imply that price changes of inputs to consumer gasoline (crude petroleum and PPI gasoline) significantly affect the CPI for gasoline, but that changes in demand (industrial production) affect gasoline prices only marginally. In addition, variance decompositions indicated that the majority of the forecast variance in consumer gasoline prices can be explained by price shocks to inputs, as opposed to shocks to demand. □

Notes

[1] The 36.3-percent figure represents the percent increase in the annual average of the Consumer Price Index for gasoline from 1999 to 2000.

[2] James L. Williams, *Energy Economics Newsletter*, on the Internet at **http://www.wtrg.com/prices.htm**.

[3] *Ibid.*

[4] *Petroleum Chronology of Events 1970–2000* (U.S. Department of Energy, 2002).

[5] Williams, *Energy Economics Newsletter*.

[6] *Petroleum Chronology of Events.*

[7] *Ibid.*

[8] *Oil Reserve Fact Sheet* (U.S. Department of Energy, 2000).

[9] Eleni Xenofondos and William F. Snyders, "Rising producer prices in 1999 dominated by energy goods," *Monthly Labor Review*, August 2000, pp. 15–25.

[10] William H. Greene, *Econometric Analysis* (Upper Saddle River, NJ, Prentice Hall, 1997); see especially pp. 815–16.

[11] Philip Hans Franses, *Time Series Models for Business and Economic Forecasting* (Cambridge, U.K., and New York, Cambridge University Press, 1998).

[12] Jack Johnston and John DiNardo, *Econometric Methods* (New York, McGraw-Hill, 1997); see especially pp. 224–25.

[13] *Ibid.*, p. 299.

[14] Christopher A. Sims, "Macroeconomics and Reality," *Econometrica*, January 1980, pp. 1–48.

[15] Ben Bernanke, "Alternative Explanations of the Money-Income Correlation," in Karl Brunner and Allan Meltzer (eds.), *Real Business Cycles, Real Exchange Rates, and Actual Policies*, Carnegie-Rochester Conference Series on Public Policy, Autumn 1986, pp. 49–99 (Amsterdam, North-Holland, 1986); see also Christopher A. Sims, "Are Forecasting Models Usable for Policy Analysis," *Federal Reserve Bank of Minneapolis Quarterly Review*, Winter 1986, pp. 2–16.

[16] Johnston and DiNardo, *Econometric Methods*, pp. 299–300.

[17] *Ibid.*, p. 301.