Price transmission: from crude petroleum to plastics products

A structural vector autoregression model is used to analyze the effects of crude-petroleum supply shocks on the market for organic chemicals and plastics products; the analysis demonstrates that changes in crude-petroleum prices are passed on to prices and quantities of organic chemicals and plastics products

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Crude petroleum is an important input used in the production of organic chemicals, which are in turn used as inputs into the production of more-processed goods, such as plastics products. Prices for plastics products compose a substantial portion of several aggregate producer price indexes (PPI's), and these indexes are often looked to as early indicators of consumer inflation. Price changes in crude petroleum, which are transmitted to prices for plastics products, would affect these aggregate PPI's. A thorough knowledge of the relationship between prices for crude petroleum and prices for plastics products, therefore, would help economists understand and explain movements of aggregate PPI's.

The main aggregate PPI's that include prices for plastics products are the indexes for All Commodities, Finished Goods, Finished Goods Excluding Foods and Energy, Intermediate Goods, and Intermediate Goods Excluding Foods and Energy. In December 2005, plastics products accounted for 2.5 percent of the All Commodities PPI. (PPI commodity weights are derived from the 1997 Census of Manufactures and are updated by changes in PPI commodity indexes.) In addition, plastics products accounted for 1.2 percent of the Finished Goods PPI, 2.0 percent of the PPI for Finished Goods Excluding Foods and Energy, 4.6 percent of the Intermediate Goods PPI, and 6.1 percent of the PPI for Intermediate Goods Excluding Foods and Energy. Two of these main aggregate PPI's exclude prices for energy, insulating them somewhat from energy price inflation; however, price changes in crude petroleum that are transmitted forward to organic chemicals and then to plastics products represent one way in which aggregate PPI's, which exclude energy prices, may still be affected by energy price shocks. In 2005, crude petroleum accounted for 16.8 percent of the Crude Goods PPI and organic chemicals accounted for 4.2 percent of the Intermediate Goods PPI.

The relationship between prices for crude petroleum and prices for plastics products has not been thoroughly examined, but price transmission within the gasoline market is well documented. Using January 1987–August 1996 weekly data on the spot price for West Texas intermediate crude oil, the New York Harbor spot price for unleaded regular motor gasoline, and the self-service pump price for unleaded regular motor gasoline, with and without taxes, Nathan Balke, Stephen Brown, and Mine Yucel estimated a series of bivariate vector autoregression and vector error correction models.[1] Their study indicates that crude petroleum price changes are passed forward to consumer gasoline prices, but that the response of gasoline prices to positive and negative crude petroleum price shocks may be asymmetric. In another study, Michael Burdette and John Zyren used Department of Energy spot

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and retail gasoline price data to estimate regression models.[2] Their results show that most of the movement in retail prices is determined by previous movements in spot prices. In an earlier *Monthly Labor Review* article, Jonathan Weinhagen used the PPI's for Crude Petroleum and Gasoline, the CPI for Gasoline, the quantity of domestically consumed gasoline, and the Federal Reserve's index of industrial production to estimate a structural vector autoregression model of the gasoline market.[3] His study reveals that crude petroleum supply shocks significantly affect prices for producer and consumer gasoline. Because the relationship between prices for crude petroleum and prices for plastics products is an area that has seen little research, the analysis that follows attempts to fill the gap by empirically examining price transmission from crude petroleum to plastics products. Toward that end, a structural vector autoregression (VAR) approach is used to examine the effects of crude petroleum price shocks on the market for plastics products from 1974 through 2003.

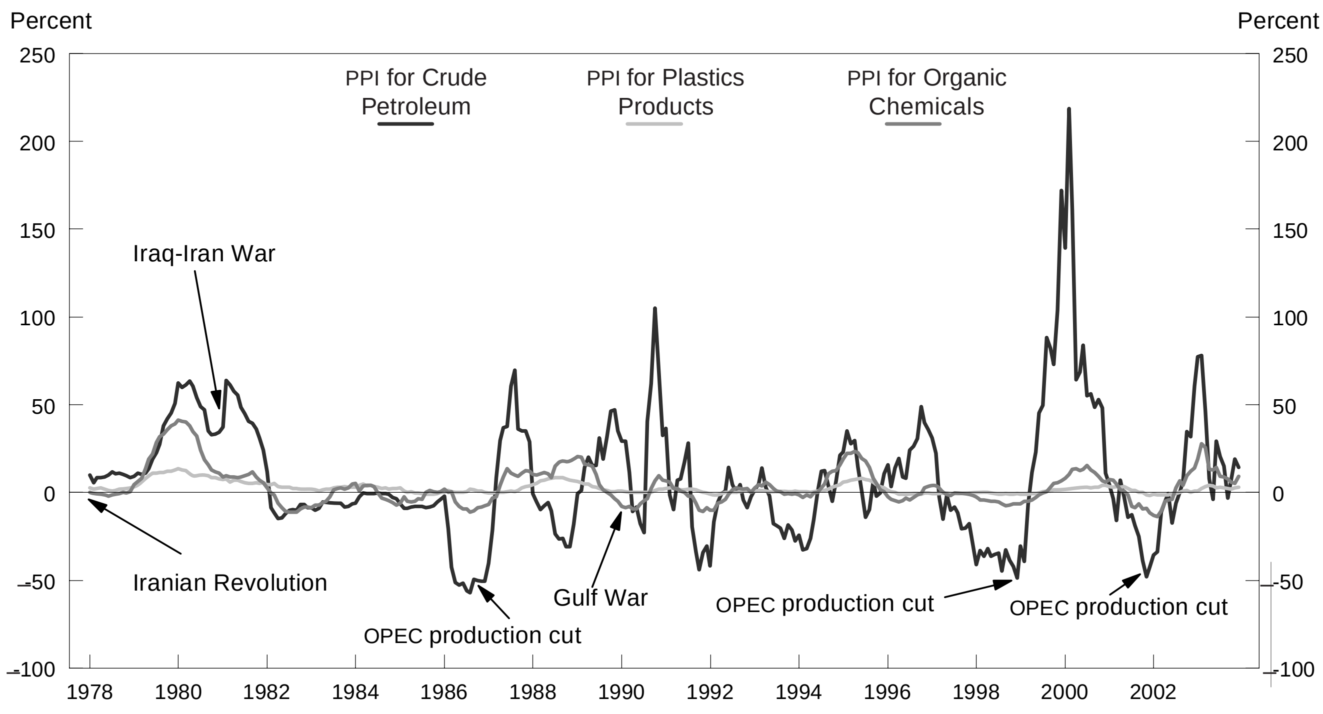
Price movements of three commodities

The analysis begins with an examination of historical price movements of the PPI's for Crude Petroleum, Organic Chemicals, and Plastics Products. In determining whether crude petroleum price changes are transmitted to prices for organic chemicals and plastics products, the relative timing of price changes for those three commodities in response to five crude-petroleum supply shocks is examined visually in the form of a chart. For each supply shock, the beginning of the acceleration, the peak, and the trough for the three time series presented are analyzed.

Chart 1 shows annual percentage changes in the PPI's for Crude Petroleum, Organic Chemicals, and Plastics Products on a monthly basis from 1978 through 2003. The mean annual percent changes in the PPI's for those commodities over the sample period are, respectively, 8.5, 3.7, and 2.5. The respective standard deviations are 36.2, 10.6, and 3.2 percent, indicating that both the standard deviations and the means of these three series decline as the degree of processing of the product increases.

The first crude-petroleum supply shock in the sample period occurred as a result of the Iranian Revolution in conjunction with the Iran-Iraq War.[4] In January 1978, Iranian students began protesting against the shah of Iran, and on January 16, 1979, the shah left Iran permanently. Then, on September 23, 1980, Iraq invaded Iran. By 1981, the Organization of Petroleum Exporting Countries' (OPEC's) production of oil decreased by 7 million barrels per day, reducing the world oil supply 11.6 percent from its 1978 average.

Chart 1. Annual percent changes in the January PPI's for Crude Petroleum, Organic Chemicals, and Plastics Products



The second crude-petroleum supply shock occurred in 1986 and can be traced to an OPEC agreement to reduce production. On August 4, 1986, reports surfaced of a probable decrease in OPEC production, and on December 19, 1986, OPEC agreed to reduce petroleum production by 7 percent in the first half of 1987.

The third supply interruption occurred when Iraq invaded Kuwait on August 2, 1990. In response to the Iraqi attack, the United States invaded Iraq on January 16, 1991. The Gulf War resulted in a production decline of approximately 4.3 million barrels of petroleum per day from Iraq and Kuwait combined, reducing world oil production approximately 7.2 percent from its 1989 average level.

The fourth supply shock followed on the heels of a March 1999 OPEC agreement to cut production by 1.7 million barrels per day, an amount that represented a 2.5-percent decline in world oil production from the 1998 average.

The final major petroleum supply shock during the period examined began at the end of 2001, when OPEC reduced production and fears of a greater reduction due to probable conflict in the Middle East drove prices higher. Average daily OPEC production of crude oil fell by approximately 2.2 percent from 2000 to 2001 and an additional 6.1 percent from 2001 to 2002.

For the three time series, the initial accleration, the peak, and the trough resulting from each of the five supply shocks were examined. The lone exception was the trough in the last supply shock, which had not yet occurred at the end of 2003. Exhibit 1 indicates the month in which each series began accelerating, peaked, and reached a trough in response to the five supply shocks.

In 9 out of 14 instances, the initial acceleration, the peak, or the trough in the PPI for Crude Petroleum occurred prior to the same event in the PPI for Organic Chemicals. In only 2 instances did the initial acceleration, peak, or trough in the PPI for Organic Chemicals precede the same event in the PPI for Crude Petroleum, and in 3 instances the initial accelerations, peaks, or troughs of the two series coincided. In 12 out of 14 instances, the initial acceleration, the peak, or the trough in crude-petroleum prices preceded that of plastics products prices. In only 1 instance did the initial acceleration, peak, or trough in the PPI for Plastics Products occur prior to the same event in the PPI for Crude Petroleum, and only once over the entire period studied did the initial accelerations, peaks, or troughs in the PPI's for Plastics Products and Crude Petroleum coincide.

In the majority of the cases examined in exhibit 1, price changes for crude petroleum *preceded* price changes for organic chemicals and plastics products. A visual analysis, therefore, suggests that petroleum price shocks are passed forward to prices for organic chemicals and plastics. In fewer cases, movements in the indexes for organic chemicals and plastics products *coincided* with or *preceded* changes in crude petroleum prices. The anticipation of crude-petroleum price changes may explain instances in which price changes for plastics or chemicals *preceded* changes in petroleum prices. For example, firms manufacturing organic chemicals may contract with plastics firms to sell chemicals at a fixed price over a given period. If petroleum prices are expected to increase, the contract may stipulate a higher price for chemicals currently, which in turn could lead to a current increase in plastics prices.

Empirical model of the plastics market

To examine price transmission from crude petroleum to organic chemicals and plastics more rigorously, a structural vector autoregression model of supply and demand within the plastics market is estimated. The model examines only cases in which price changes are passed forward through the stages of production. However, a vector autoregression model also can be used to examine the effect of expectations on variables in the model. For example, Takatoshi Ito used a VAR model to test the uncovered interest parity hypothesis, a hypothesis which asserts that the interest rate spread between two substitutable assets is equal to the difference between the expected future exchange rate and the current exchange rate.[5] Ito expresses the null hypothesis of the uncovered interest parity hypothesis in the form of nonlinear cross-equational restrictions on a VAR system and uses Wald tests to test these restrictions.

A VAR is a system of equations in which each variable is expressed as a linear function of lagged values of itself and all other variables in the system.[6] Sufficiently identifying restrictions on the covariances of the error terms of an unrestricted VAR allows the structural model to be estimated from the reduced-form model.[7]

Unrestricted vector autoregression

The unrestricted VAR was estimated with historical monthly data on the PPI's for Crude Petroleum, Organic Chemicals, and Plastics Products, and the Federal Reserve's indexes for Plastics Production and overall Industrial Production, for the period from January 1974 through December 2003. All time series were expressed in percentage growth form by taking first differences of the natural logarithms of the data. In addition, seasonally adjusted data were used when available. Seasonally adjusted data were not available for the PPI's for Crude Petroleum and Organic Chemicals, which the Bureau of Labor Statistics has determined exhibit no statistically significant seasonal patterns. To avoid redundancy between time series, the plastics components of the index for Overall Industrial Production was removed through the use of monthly relative importance values provided by the Federal Reserve.

Exhibit 1. Accelerations, peaks, and troughs, crude petroleum, organic chemicals, and plastics products, 1978–2003

Supply shock	Acceleration	Peak	Trough
Crude petroleum			
Iranian Revolution/ Iran-Iraq War	December 1978	January 1980	April 1982
OPEC production cut, 1986	September 1986	August 1987	October 1988
Gulf War	August 1990	October 1990	October 1991
OPEC production cut, 1999	March 1999	February 2000	November 2001
OPEC production cut, 2001	December 2001	February 2003	—
Organic chemicals			
Iranian Revolution/ Iran-Iraq War	July 1978	January 1980	September 1982
OPEC production cut, 1986	September 1986	January 1989	April 1990
Gulf War	June 1990	November 1990	November 1991
OPEC production cut, 1999	April 1999	July 2000	February 2002
OPEC production cut, 2001	March 2002	February 2003	—
Plastics products			
Iranian Revolution/ Iran-Iraq War	August 1978	January 1980	March 1983
OPEC production cut, 1986	March 1987	August 1988	April 1990
Gulf War	October 1990	February 1991	February 1992
OPEC production cut, 1999	April 1999	November 2000	March 2002
OPEC production cut, 2001	April 2002	April 2003	—

NOTE: Dash indicates trough not yet discernible.

A time series is considered stationary if the mean, variance, and covariance of the series exist and are independent of time. Estimation of a VAR with nonstationary data invalidates the tests used to determine the statistical significance of the model's coefficients and can indicate statistically significant correlations between unrelated variables within the model. These correlations are only the result of the underlying trends in the variables, not the result of a related generating mechanism.[8] To test for stationarity, augmented Dickey-Fuller tests were implemented.[9] The tests included a trend and an intercept, and the Schwarz criterion was used to select the optimal lag length.[10] The augmented Dickey-Fuller tests indicated that all of the time series are stationary in percentage growth form.

Information criteria can be used to select the appropriate lag length for a VAR. These criteria weigh the costs and benefits of including additional lags in a model by rewarding the increase in fit resulting from the additional lags, but penalizing the loss of degrees of freedom. The three most common information criteria used in econometric modeling are the Akaike, Schwarz, and Hannan-Quinn criteria. Of these, the Akaike criterion is the least strict in terms of penalizing loss of degrees of freedom, whereas the Schwarz criterion is strictest. The Hannan-Quinn information criterion was chosen to select the optimal length of the VAR, because it falls between the Akaike and Schwarz criteria in terms of strictness. Moreover, the Akaike criterion was not chosen, because it tends to asymptotically overstate the optimal lag length for models.[11] The Hannan-Quinn criterion suggested that a VAR whose equations have one lag is optimal; therefore, the one-lag specification was chosen, and the unrestricted VAR was estimated with ordinary least squares.

In addition to Dickey-Fuller tests, which determine whether individual time series are stationary, a VAR can be tested for stationarity by calculating the absolute eigenvalues from the matrix of the VAR's coefficients. A VAR is stationary when each of its absolute eigenvalues is less than unity.[12] The absolute eigenvalues from the one-lag VAR estimated here fall between 0.67 and 0.11, indicating that the VAR is stationary and reinforcing the earlier results from the Dickey-Fuller tests.

Structural vector autoregression

The residuals of a VAR are mutually contemporaneously correlated, so a random innovation to one variable is likely to occur simultaneously with innovations to other variables.

Therefore, to determine meaningful economic conclusions from the residuals, it is necessary to orthogonalize them.[13]

Orthogonalization is customarily achieved by a Cholesky decomposition.[14] This approach has been criticized because it is often not supported by economic theory, leading to a set of orthogonalized residuals that have no particular meaning.[15] Alternatively, orthogonalization of the residuals can be achieved by placing theoretically plausible contemporaneous restrictions on an unrestricted VAR's residuals, thereby allowing the structural disturbances to be estimated from the reduced-form VAR and meaningful economic conclusions to be drawn from the model.[16] This is the approach used here.

The estimated variance-covariance matrix of the unrestricted VAR's residuals contains $n(n + 1)/2$ distinct elements (where n is the number of variables included in the VAR). To obtain the structural disturbances from the reduced-form VAR requires estimating an $n \times n$ matrix of coefficients that relates the residuals to the orthogonal disturbances. Therefore, at least $n^2 - n(n + 1)/2 = n(n - 1)/2$ additional restrictions are required to estimate the structural disturbances. Imposing $n(n - 1)/2$ restrictions results in an exactly identified model, while imposing more than $n(n - 1)/2$ yields an overidentified model.

The following equations describe the system of contemporaneous interactions among the VAR's innovations that was estimated:

$$\text{PCP} = (\hat{a}_1 \times \text{QIP}) + u_{pcp}; \tag{1}$$

$$\text{POC} = (\hat{a}_2 \times \text{PCP}) + u_{poc}; \tag{2}$$

$$\text{PPP} = (\hat{a}_3 \times \text{QPP}) + (\hat{a}_4 \times \text{POC}) + u_{ppp}; \tag{3}$$

$$\text{QPP} = (-\hat{a}_5 \times \text{PPP}) + (\hat{a}_6 \times \text{QIP}) + u_{qpp}; \tag{4}$$

$$\text{QIP} = u_{qip}. \tag{5}$$

The estimated reduced-form VAR includes 5 variables, yielding a variance-covariance matrix with 15 distinct elements. As discussed earlier, at least $5^2 - 5(5 + 1)/2 = 10$ additional restrictions are required to estimate the 5-variable structural model. The model described in equations (1)–(5) provides 14 restrictions and thus is overidentified.

All of the $\hat{a}$ coefficients of the five equations are presumed to be positive, and PCP, POC, PPP, QPP, and QIP refer, respectively, to innovations in the PPI's for Crude Petroleum, Organic Chemicals, and Plastics Products and the Federal Reserve indexes of plastics production and industrial production. The *u's* are mutually and serially uncorrelated error terms.

The 14 restrictions in the system given by the model are derived by assuming an upward-sloping supply curve and a downward-sloping demand curve in the market for plastics products. Equation (1) imposes 3 restrictions, allowing only the quantity of industrial production to contemporaneously affect the price of crude petroleum. Equation (2) provides an additional 3 restrictions by assuming that the price of organic chemicals is affected in the current period by only the price of crude petroleum. Equation (3) imposes 2 more restrictions, permitting the price of plastics products to be contemporaneously affected by only the quantity of plastics and the price of organic chemicals. The positive sign of the coefficient $\hat{a}_3$ indicates an upward-sloping supply curve. Equation (4) allows the quantity of plastics to be affected in the current period by only the price of plastics products and the quantity of industrial production, resulting in 2 restrictions. The negative sign in $-\hat{a}_5$ indicates a downward-sloping demand curve. Finally, equation (5) imposes 4 additional restrictions by assuming that industrial production is contemporaneously exogenous. In this system of equations, u_{pcp}, u_{poc}, and u_{ppp} are supply shocks, u_{qpp} is a demand shock, and u_{qip} is a simultaneous shock to supply and demand.

The estimation results for the system of structural coefficients is shown in the following equations, where $^{(1)}$ indicates statistical significance at the level of $p = .0001$ and $^{(2)}$ indicates statistical significance at the level of $p = .05$:

$$\text{PCP} = (.23 \times \text{QIP}) + u_{pcp} \tag{6}$$

$$\text{POC} = (.05 \times \text{PCP}^{(1)}) + u_{poc} \tag{7}$$

$$\text{PPP} = (.10 \times \text{QPP}^{(2)}) + (.11 \times \text{POC}^{(1)}) + u_{ppp} \tag{8}$$

$$\text{QPP} = (-.29 \times \text{PPP}) + (.97 \times \text{QIP}^{(1)}) + u_{qpp} \tag{9}$$

$$\text{QIP} = u_{qip} \tag{10}$$

All of the signs of the structural coefficients are as anticipated. Equation (6) indicates that shocks to the quantity of industrial production affect crude petroleum price innovations positively. Equation (7) shows a weaker positive correlation between unanticipated changes in the price of crude petroleum and unanticipated changes in the price of organic chemicals. Equation (8) reflects the upward slope of the plastics supply curve and indicates that shocks to the price of organic chemicals also are positively related to innovations in plastics prices. Equation (9) shows the downward slope of the plastics demand curve and indicates that unanticipated changes in the quantity of industrial production are positively correlated with plastics quantity innovations.

The overidentification of the system allowed the likelihood ratio test for overidentification to be applied. This test is a test of the validity of the system's restrictions, where the null hypothesis asserts that the identifying restrictions are valid.[17] A *p*-value of less than 0.05 is required to reject the null hypothesis. The test's chi-square statistic and *p*-value were 3.8 and 0.43, respectively. The null hypothesis of the 14 overidentifying restrictions, therefore, was not rejected.

In addition to the system estimated, two alternative specifications were attempted. The first omitted the insignificant QIP variable from equation (6); however, this exclusion did not yield any changes to the structural coefficients as originally estimated, nor did it affect any of the subsequent analyses (the impulse response functions or variance decompositions). Because allowing a contemporaneous relationship between the price of crude petroleum and the quantity of industrial production seems more theoretically plausible than not allowing the relationship, and because both specifications yield identical estimates of equations (6) through (10), QIP was included in equation (6) of the final specification.

The second alternative specification excluded the insignificant PPP variable from equation (9). This specification only minimally altered the remaining structural coefficients, leading to no large change in the sign or significance of any structural coefficient. In the end, the PPP variable in equation (9) was included in the final model, for two reasons. First, assuming that the demand curve for plastics is downward sloping, as opposed to completely inelastic, seems theoretically more plausible. Second, the *p*-value of the coefficient for PPP in equation (9) is 0.12, indicating that the coefficient is close to being significant at the 10-percent level.

Impulse response functions

The orthogonalized set of residuals estimated in equations (6) through (10) and the coefficients from the unrestricted VAR were used to construct accumulated impulse response functions. Impulse response functions measure the dynamic effects of a one-standard-deviation shock to a variable in a system on the current and future values of all variables in the system.[18] In addition, standard error bands were constructed around the impulse response functions. An impulse response function is considered significant when its upper band and lower band are both above zero or both below zero. Chart 2 (pages 40 and 41) presents these impulse response functions.

Chart 2 illustrates the dynamic responses of all of the variables in the VAR to the structural disturbances. Recall that u_{pcp}, u_{poc}, and u_{ppp} are supply shocks, u_{qpp} is a demand shock, and u_{qip} is a simultaneous shock to supply and demand. The first column in the chart demonstrates that a shock to u_{pcp}, the price of crude petroleum, leads to increases in the prices of crude petroleum, organic chemicals, and plastics products; leads to a decrease in the quantity of plastics products; and does not affect the quantity of industrial production. The second column shows that a shock to u_{poc}, the price of organic chemicals, does not affect the price of crude petroleum, increases the prices of organic chemicals and plastics products, and decreases the quantities of plastics products and industrial production. The third column indicates that a shock to u_{ppp}, the price of plastic, does not affect the price of crude petroleum, increases the prices of organic chemicals and plastics products, and decreases the quantities of plastics products and industrial production. The fourth column demonstrates that a shock to u_{qpp}, the quantity of plastics, does not affect the prices of crude petroleum or organic chemicals and leads to increases in the price of plastics products, the quantity of plastics products, and the quantity of industrial production. Finally, the last column of the chart indicates that a shock to u_{qip}, industrial production, tends to increase the prices of crude petroleum, organic chemicals, and plastics products and to increase the quantities of plastics products and industrial production.

Variance decompositions

The orthogonalized set of residuals also was used to decompose variances. Variance decompositions show the percentage of variance in the forecast error in one variable of the vector autoregression caused by innovations in the other variables.[19] The variance decompositions after 24 months are presented in the following tabulation:

Decomposition variable	*Percent of forecast error due to—*				
	u_{pcp}	u_{poc}	u_{ppp}	u_{qpp}	u_{qip}
Price of crude petroleum	98.52	0.09	0.05	0.35	0.99
Price of organic chemicals	16.91	73.75	7.32	.18	1.84
Price of plastics	6.17	36.44	51.78	2.34	3.27
Quantity of plastics ...	.31	2.88	2.90	65.26	28.65
Quantity of industrial production	.57	1.67	1.71	9.28	86.77

The first row of the tabulation indicates that only shocks to crude-petroleum prices explain a significant portion of the variance in the forecast error for crude-petroleum prices. The second row shows that, although innovations to prices for organic chemicals are the most important factor in explaining the variance in the forecast error for prices of organic chemicals, shocks to the price of crude petroleum and to plastics prices account for approximately 17 percent and 7 percent, respectively, of the variance. The third row demonstrates that unanticipated changes in the price of crude petroleum, in the price of organic chemicals, and in plastics prices all explain a substantial amount of the variance in the

Chart 2. **Impulse response functions**

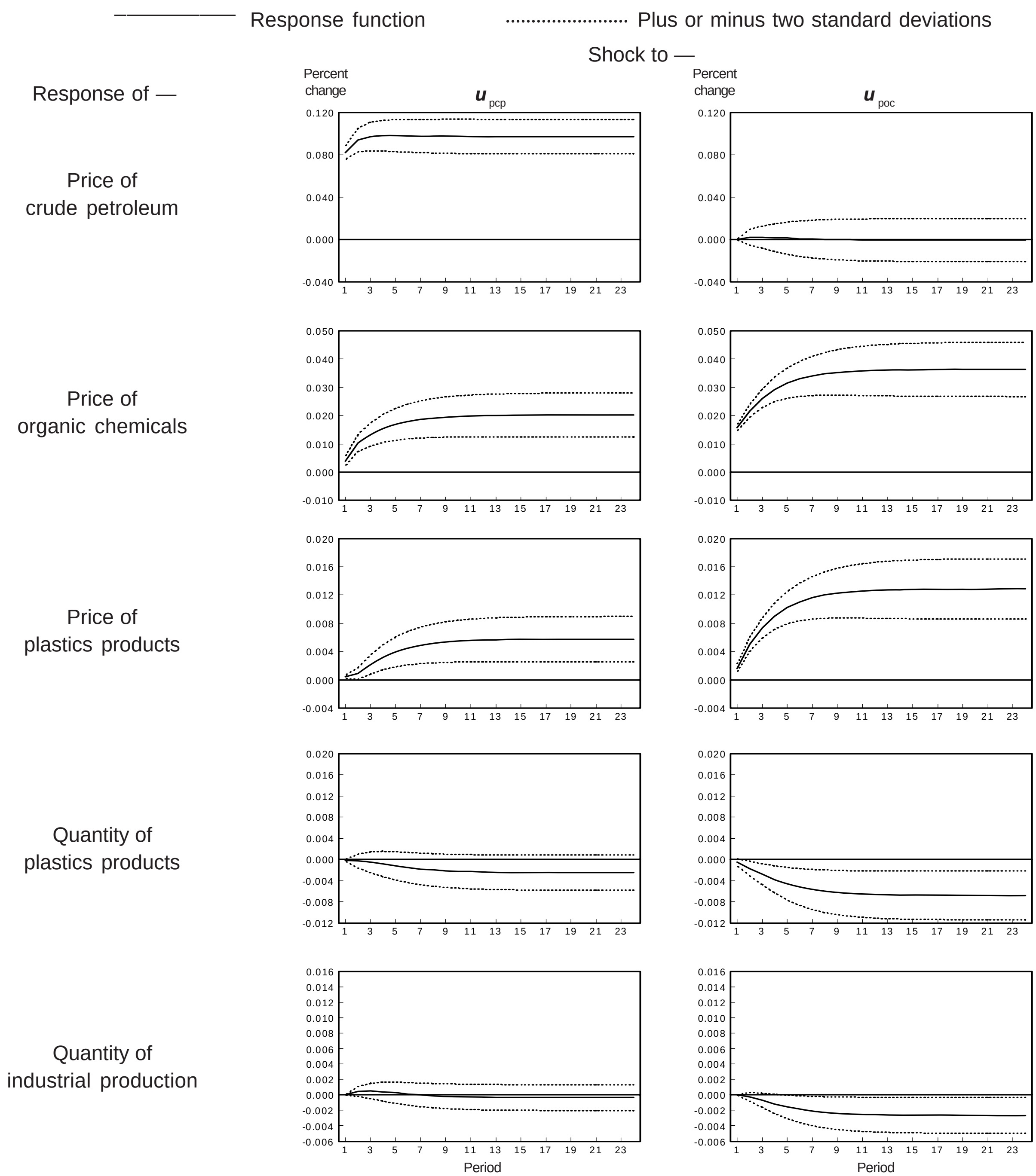
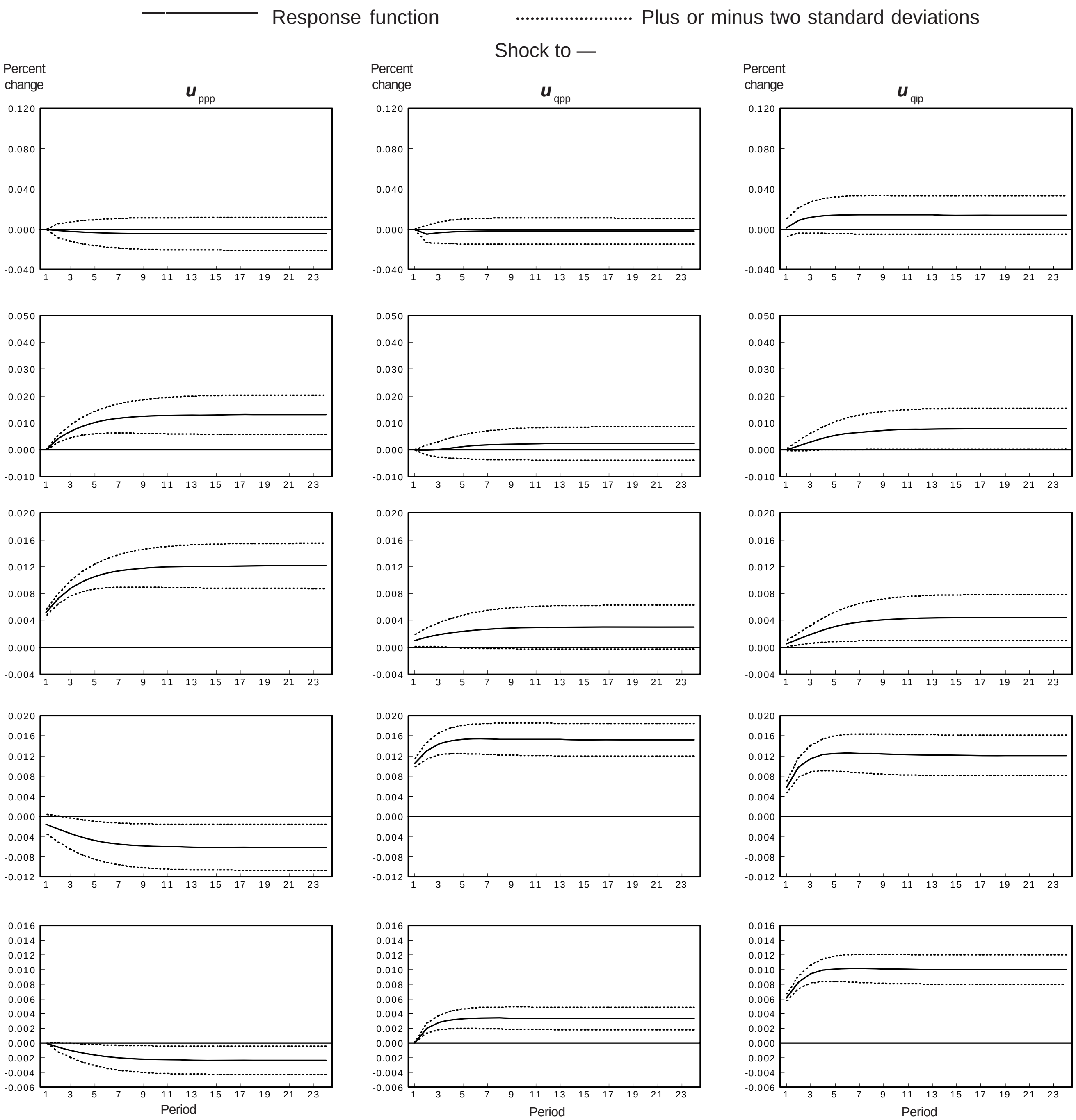


Chart 2. Continued—Impulse response functions



NOTE: See text, p. 38, for definitions of $\boldsymbol{u}_{pcp}$, $\boldsymbol{u}_{poc}$, $\boldsymbol{u}_{ppp}$, $\boldsymbol{u}_{qpp}$, and $\boldsymbol{u}_{qip}$.

forecast error for plastics prices, accounting for 6 percent, 36 percent, and 52 percent, respectively. Innovations to the quantity of plastics account for only 2 percent of the variance in the forecast error for plastics prices, while industrial production shocks explain only 3 percent of the variance. The fourth row shows that unanticipated changes in the quantity of plastics and in industrial production are the most important factors in explaining the variance in the forecast error for the quantity of plastics products. The former accounts for about 65 percent, the latter for approximately 29 percent, of the variance. Price innovations in plastics also explain a much smaller amount of the variance of the forecast error for the quantity of plastics.

Two scenarios

Crude-petroleum prices are often extremely volatile and can significantly affect the plastics market. Industrial production also deviates substantially from its trend during periods of economic downturn and upturn, and in these periods the plastics market can be affected. Given the importance of crude-petroleum prices and industrial production to the plastics market, the analysis next considers two scenarios in substantial detail.

Scenario 1: An unanticipated change in the price of crude petroleum. A one-standard-deviation shock to crude-petroleum prices is approximately 8.2 percent. A monthly percent change in crude petroleum prices of this magnitude is common, especially during periods of acceleration or deceleration in the price of crude petroleum. The Iranian Revolution, for example, caused oil prices to rise substantially from January 1978 through February 1979. During this period, monthly price increases ranged from 0.3 percent to 19.6 percent, and the average price increase was 4.4 percent.

A positive price shock to crude petroleum originates through the error term in equation (6). The crude-petroleum price shocks then lead to higher input costs for firms producing organic chemicals, causing the organic-chemicals market supply curve to shift upwards. This shift in the supply curve results in higher prices for organic chemicals, as is captured in equation (7). Increased prices for organic chemicals then cause plastics firms' input costs to rise and the plastics market supply curve, described in equation (8), to shift upwards. This upward shift in the plastics supply curve in turn leads to increased plastics prices and decreased quantities of plastics.

According to the estimated model, in the month of its occurrence a one-standard-deviation, 8.2 percent, positive crude-petroleum price shock increases the prices of organic chemicals and plastics products 0.4 percent and 0.04 percent, respectively, and decreases the quantity of plastics 0.01 percent. The effects of the crude-petroleum price shock, however, continue beyond that initial month, because, in the model, each variable is a function of lagged values of all variables in the system. The petroleum price shock affects organic-chemicals prices for approximately 14 months, eventually leading to a 2.02-percent price increase. The petroleum price shock increases plastics prices approximately 0.6 percent after 14 months and decreases the quantity of plastics products by about 0.2 percent after 11 months.

Scenario 2: An unanticipated change in industrial production. A one-standard-deviation shock to industrial production is approximately 0.6 percent. A monthly change of this magnitude is common during periods of considerable acceleration or deceleration in industrial production. From December 2000 to December 2001, for example, the index for industrial production fell significantly. Over this period, 1-month percent declines ranged from 0.2 percent to 0.9 percent, and the average price decline was 0.4 percent.

A positive shock to industrial production originates through the error term in equation (10). Equation (6) shows that the industrial production shock contemporaneously increases crude-petroleum prices, which rise as a result of increased demand. The rise in crude-petroleum prices leads to higher input costs for organic-chemicals firms, causing the organic-chemicals market supply curve to shift upwards, thereby increasing prices for organic chemicals, as indicated in equation (7). Equation (8) shows that the increase in organic-chemicals prices shifts the supply curve for plastics products upwards, causing plastics prices to rise and quantities to fall. Finally, equation (9) demonstrates that the rise in industrial production increases demand for plastics products, causing both prices and quantities of plastics to increase. Note that although the industrial production shock unambiguously increases plastics prices, its effect on the quantity of plastics is uncertain, because the outward shift in the demand curve increases quantity, but the upward shift in the supply curve decreases quantity.

A positive one-standard-deviation, 0.6-percent shock to industrial production contemporaneously increases plastics prices and quantities approximately 0.06 percent and 0.6 percent, respectively. However, the VAR model implies that shocks to industrial production can affect variables beyond the current period. Indeed, the industrial production shock continues to change the prices of plastics products for approximately 12 months and eventually leads to a 0.44-percent increase in the PPI for Plastics Products. The industrial production shock results in an approximate 1.3-percent increase in the quantity of plastics after 6 months.

THIS ARTICLE HAS CONDUCTED AN EMPIRICAL INVESTIGATION of price transmission from crude petroleum to organic chemicals and plastics products. The analysis began with a visual examination of price index data. The examination suggests that in 21 out of 28 cases the initial acceleration, peak, or trough in crude-petroleum prices, resulting from 5 crude petroleum supply shocks, *preceded* the similar event in prices for organic chemicals or plastics products. Thus, the visual evidence supports the hypothesis that crude-petroleum price changes are passed forward to prices for organic chemicals and plastics products.

In order to analyze price transmission from crude petroleum to organic chemicals and plastics products more rigorously, a structural VAR model of supply and demand in the plastics market was developed and estimated. The model included the PPI's for Crude Petroleum, Organic Chemicals, and Plastics Products, as well as the Federal Reserve indexes for plastics production and industrial production. Impulse response functions and variance decompositions, calculated from the structural VAR, showed that crude-petroleum price shocks are transmitted forward to prices for organic chemicals and plastics products.

Impulse response functions indicate that an unanticipated change in the price of crude petroleum results in significant positive changes in the prices for both organic chemicals and plastics products and also tends to negatively affect the quantity of plastics products. In particular, a one-standard-deviation, 8.2-percent, positive crude-petroleum price shock eventually increases the prices for organic chemicals and plastics products by 2.02 percent and 0.6 percent, respectively. The crude petroleum price shock begins affecting prices for both organic chemicals and plastics products in the same period in which the shock occurred, and the effects continue for 14 months in each case. The crude-petroleum price shock causes the quantity of plastics products to fall 0.24 percent after 11 months.

The impulse response functions also demonstrate that organic-chemicals price shocks significantly affect both the price and quantity of plastics. A one-standard-deviation, 1.6-percent, positive shock to organic-chemicals prices begins affecting plastics prices in the current period, and the effects of the shock continue for 12 months, after which the shock leads to a 1.3-percent increase in plastics prices. The organic-chemicals price shock begins affecting the quantity of plastics products in the current period and results in a 0.7-percent decrease in the quantity of plastics after 12 months.

The variance decompositions also confirm that prices for crude petroleum and organic chemicals have important effects on the market for plastics. The variance decompositions show that 6.2 percent and 36.4 percent of the variance in the forecast error for plastics prices can be explained by price shocks to crude petroleum and organic chemicals, respectively. In addition, the variance decompositions indicate that crude petroleum price shocks explain approximately 17 percent of the forecast error variance in prices for organic chemicals. □

Notes

[1] Nathan Balke, Stephen Brown, and Mine Yucel, "Crude Oil and Gasoline Prices: An Asymmetric Relationship," *Federal Reserve Bank of Dallas Economic Review*, first quarter 1998, pp. 1–11.

[2] Michael Burdette and John Zyren, *Gasoline Price Pass-through* (U.S. Department of Energy, January 2003), on the Internet at **www.eia.doe.gov/pub/oil_gas/petroleum/feature_articles/2003/gasolinepass/gasolinepass.htm**.

[3] Jonathan C. Weinhagen, "Consumer gasoline: an empirical investigation," *Monthly Labor Review*, July 2003, pp. 3–10.

[4] Historical explanations of all but the final crude-petroleum supply shock are from *Petroleum Chronology of Events 1970–2000* (Energy Information Administration, May 2002), on the Internet at **www.eia.doe.gov/pub/oil_gas/petroleum/analysis_publications/chronology/petroleumchronology2000.htm**.

[5] Takatoshi Ito, "Use of (Time-Domain) Vector Autoregression to Test Uncovered Interest Parity," *Review of Economics and Statistics* (May 1988), pp. 206–305.

[6] William Greene, *Econometric Analysis* (Upper Saddle River, NJ, Prentice Hall, 1997), esp. pp. 815–16.

[7] See 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, vol. 25, autumn 1986 (Amsterdam, North-Holland, 1986), pp. 49–99; and Christopher Sims, "Are Forecasting Models Usable for Policy Analysis?" *Federal Reserve Bank of Minnesota Quarterly Review*, winter 1986, pp. 2–16.

[8] Greene, *Econometric Analysis*, p. 846.

[9] For a detailed explanation of augmented Dickey-Fuller testing, see Green, *Econometric Analysis*, pp. 848–51.

[10] For a discussion of the Schwarz criterion, see Jack Johnston and John Dinardo, *Econometric Methods* (New York, McGraw Hill College Division, 1996), p. 74.

[11] *Ibid.*, p. 787.

[12] Johnston and Dinardo, p. 288.

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

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

[15] Sims, "Are Forecasting Models Usable?"; Bernanke, "Money-Income Correlation."

[16] *Ibid.*

[17] See Quantitative Micro Software's *EViews 5.0 Users Guide*, p. 723.

[18] Johnston and Dinardo, *Econometric Methods*, pp. 299–300.

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