An empirical analysis of price transmission by stage of processing

An empirical examination of causal price relationships from a stage-of-processing approach reveals that changes in the indexes for crude- and intermediate-goods prices often preceded changes in the CPI during the 1970s and 1980s; since the early 1990s, however, the relationship has become more tenuous

Jonathan Weinhagen

In 1978, the Bureau of Labor Statistics began emphasizing the stage-of-processing (SOP) system as the key structure used in analyzing the behavior of producer prices. This system allocates commodities among three categories: crude goods, intermediate goods, and finished goods. *Crude goods* are defined as unprocessed commodities that are not sold directly to the consumer. *Intermediate goods* are either commodities that have been processed, but that still require further processing, or nondurable, physically complete goods purchased by business firms as inputs for their operations. *Finished goods* are commodities that are ready for sale to the final-demand user, either an individual consumer or a business firm.[1] The SOP model can be extended to encompass consumer prices by including the Consumer Price Index (CPI) as the fourth "stage of processing."

According to the SOP system, commodities at earlier stages of processing can be considered inputs to commodities at later stages of processing. Economic theory predicts that price changes may be transmitted forward through the stages of processing. The study presented in this article (1) uses econometric techniques to determine the causal directions of price changes by means of the SOP system and (2) examines the stability over time of the causal relationships found.

Several authors have investigated the causal relationship between commodity prices and consumer inflation. S. Brock Blomberg and Ethan S. Harris examined the relationship between the core CPI, on the one hand, and the Commodity Research Bureau spot index, the Journal of Commerce index, the crude-goods PPI, the National Association of Purchasing Managers price index, and the Federal Reserve Bank of Philadelphia's prices-paid index, on the other.[2] The authors discovered that the commodity indexes had a statistically significant positive effect on core CPI inflation from 1970 to 1986, but that from 1987 to 1994 all of the commodity indexes, except for the Journal of Commerce index, had a negative effect on core CPI inflation. Fred Furlong and Robert Ingenito analyzed the relationship between CPI inflation and the Commodity Research Bureau's indexes for all commodities and for raw materials.[3] The authors showed that both price indexes, excluding oil prices, were strong indicators of CPI inflation in the 1970s and early 1980s, but from the mid-1980s to the mid-1990s, the indexes performed poorly as CPI inflation indicators. Todd Clark studied the relationship between PPI SOP models and the CPI by building models that forecast the CPI using producer price indexes.[4] He found that using information about the PPI improved forecasts of the CPI for the overall period from 1977 to 1994 and for the subperiod from 1977 to 1980. However, for the subperiods from 1986 to 1989 and 1991 to 1994, including the PPI in

Jonathan Weinhagen is an economist in the Division of Producer Price Indexes, Bureau of Labor Statistics. The opinions expressed here are the author's and do not necessarily reflect those of the Bureau of Labor Statistics.

forecasts of the CPI detracted from the forecasts, suggesting a breakdown in the relationship between producer price indexes and the CPI. C. Alan Garner discovered that the explanatory power of the price of gold, the Commodity Research Bureau index of commodities futures prices, the Journal of Commerce index, the Center for International Business Cycle Research index, the Paine Weber index, and the past CPI to explain movements in the current CPI decreased significantly since 1983.[5] Tae-Hwy Lee and Stuart Scott used vector error correction models to examine price transmission within the SOP system and found significant forward price transmission from 1985 to 1996.[6] The common finding in the majority of these studies was that the power of commodity prices to predict CPI inflation has diminished since the 1980s.

The next section of this article visually examines historical movements of various PPIs and the CPI in order to study the link between producer and consumer prices. The aim is to confirm or disconfirm previous authors' findings that a change in the nature of the inflationary relationships within the SOP system occurred in the late 1980s. The section that follows estimates unrestricted vector autoregression (VAR) models to further investigate the causal price transmission relationships between the PPI SOP indexes and the CPI. The final section constructs impulse response functions and variance decompositions from the VAR models to show how price changes at various stages of processing are transmitted throughout the SOP system.

Historical movements of the SOP indexes

This section visually examines historical trends of SOP indexes in order to determine whether movements of PPIs lead movements of the CPI. Toward that end, instances are sought in which changes in PPIs appear to precede changes in the CPI. The examination also attempts to discern whether the causal relationship between producer and consumer prices has changed over time. Chart 1 presents the 12-month percent changes in the PPIs for crude, intermediate, and finished goods from 1975 to 2001 and in the CPI for commodities for those same years. All indexes exclude food and energy.

The top panel of the chart compares price movements in the PPI for crude materials with changes in the CPI. In some instances, price changes in the index for crude materials appear to precede changes in the CPI. In October 1977, prices for crude materials began accelerating, a trend that continued through March 1979. The CPI went through a similar period of acceleration; however, it did not begin until March 1978, 5 months after the acceleration in prices for crude goods began, and it persisted 8 months longer. In July 1985, the index for crude goods began a long period of acceleration that lasted through May 1988. This acceleration preceded a run-up in consumer prices that began in May 1986 and continued through February 1989. In contrast, since the early 1990s, crude-goods prices have exhibited three noteworthy periods of acceleration that were not followed by significant run-ups in the CPI. These periods of faster increase in the prices of basic industrial materials began in September 1991, July 1996, and January 1999, respectively.

The middle panel of the chart presents historical price movements in the PPI for intermediate materials and in the CPI. Prior to the early 1990s, there were several periods of acceleration and deceleration in the prices of intermediate materials that foreshadowed similar movements in the CPI. A rise in the rate of increase for intermediate-materials prices beginning in March of 1976 was followed by a period of acceleration in the CPI that started in May 1976. An extended period of *de*celeration in intermediate-goods prices began in March 1980 and lasted through January 1983. This slower rate of increase in the prices of intermediate goods preceded a similar deceleration in the CPI that began in December 1980. Periods of slowing price increases for intermediate goods beginning at the end of 1988 and the early part of 1991 were followed by similar decelerations in the CPI. However, three significant periods of price acceleration in intermediate goods since the early 1990s cannot be traced to similar movements in the CPI.

The bottom panel of the chart compares historical movements of the PPI for finished goods with changes in the CPI. An examination of these historical price changes reveals that, since 1975, movements of the PPI for finished goods and changes in the CPI have been similar. In most instances, the two time series' movements actually coincide with each other, so a visual examination does not reveal any distinct causal trend between them.

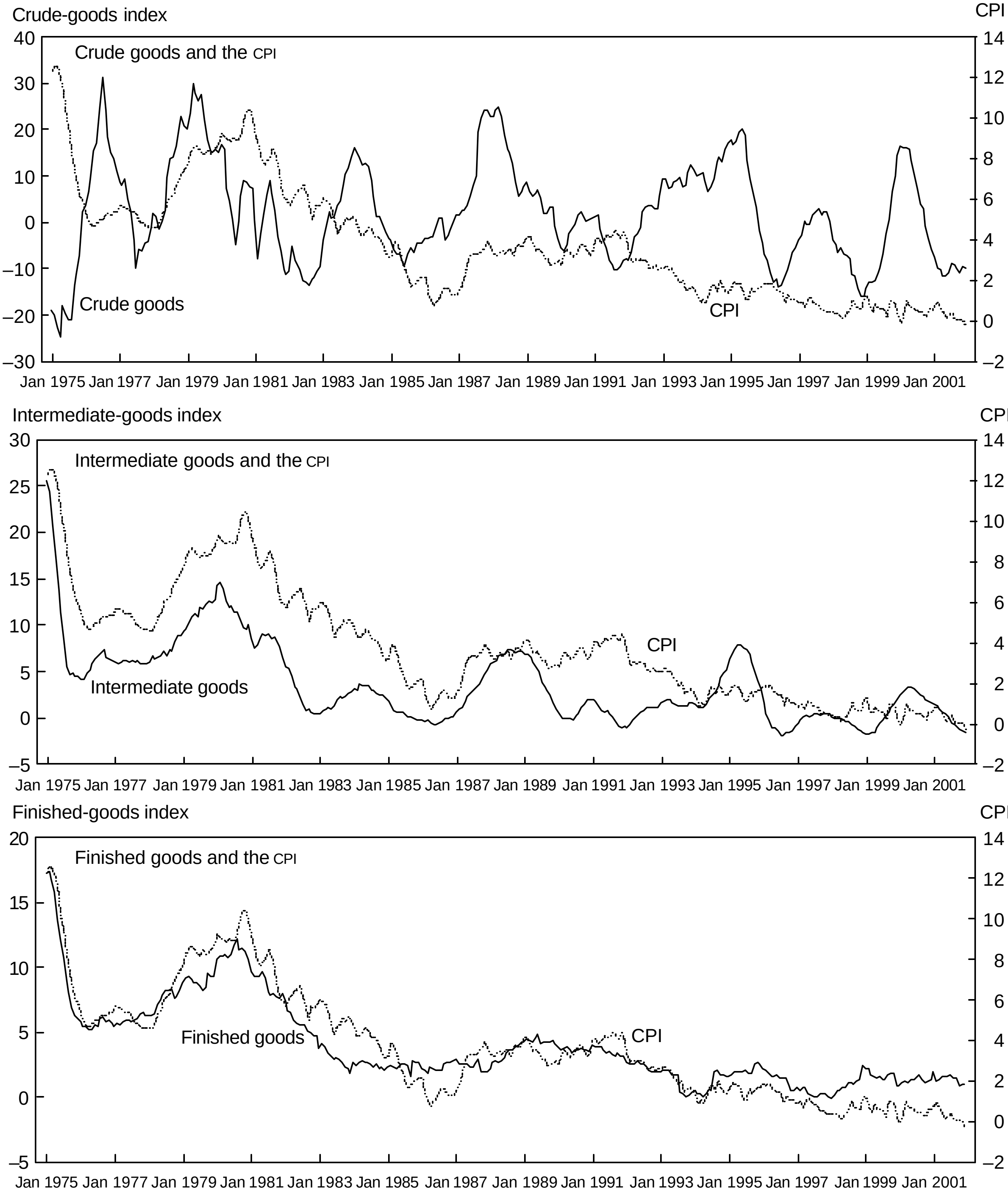
A visual comparison of the PPIs for crude and intermediate materials with the CPI indicates that the link between them may have weakened since early 1990. However, such a simple visual inspection may not reveal the intricate causal relationships between the SOP indexes. To examine the issue further, more rigorous empirical testing is necessary.

Unrestricted vector autoregression model

This section uses VAR models to examine the nature and consistency of causal price transmission relationships among price indexes at various stages of processing. VAR modeling involves estimating a system of equations in which each variable is expressed as a linear combination of lagged values of itself and all other variables in the system.[7]

VARs were estimated from the PPIs for crude materials, intermediate goods, and finished goods and from the CPI for commodities, using monthly data from January 1974 through December 2001. Core price indexes, which exclude food and energy, were chosen because the excessive volatility of food and energy prices can distort underlying trends between SOP indexes. All data were seasonally adjusted and converted to

Chart 1. Historical movements of various price indexes, percent change, January 1975–December 2001



NOTE: All plots exclude prices for food and energy. CPI is CPI for commodities.

annualized percentage growth form by multiplying the change in the logged data by 1,200.

A time series is stationary if the mean, variance, and covariances of the series are not dependent on time. The construction of a VAR with nonstationary data is problematic, because the tests used to estimate the significance of the coefficients of the VAR will not be valid. To test for stationarity, the Dickey-Fuller test was applied; in this one-tailed test, the null hypothesis is that the time series is not stationary. A large negative test statistic rejects the null hypothesis and implies that the time series is stationary.[8] Dickey-Fuller tests performed on the SOP indexes indicated that, when the data are converted to annualized percentage growth form, all of the time series involved are stationary.

The Akaike and Schwarz information criteria were used to determine the optimal number of lags to include in the VARs.[9] The Schwarz criterion suggested that estimating the VARs by using one lag was optimal, whereas the Akaike criterion indicated that four lags were best. Residual tests implied that estimating the model with one lag would result in significant levels of autocorrelation; therefore, the VARs were constructed by using four lags of all variables.

In order to investigate the stability of the causal price transmission relationships, two separate VARs were estimated, using data from 1974 to 1989 and from 1990 to 2001. The 1989–90 breakpoint was chosen because the visual examinations conducted in the previous section suggested that the causal relationships between PPIs and the CPI weakened around 1990. Furthermore, a couple of earlier studies found that in the late 1980s there was a breakdown in the usefulness of commodity prices as predictors of consumer inflation.[10] These studies were conducted with the use of data that began in either 1959 (Clark) or the 1970s (Blomberg and Harris), ran through the mid-1990s, and focused on price transmission from early stages of processing to the CPI. This article expands the earlier investigations by including data through 2001 and examining relationships among all of the SOP indexes.

Table 1 shows the results of VAR-model tests of the joint statistical significance of the lagged values of the SOP indexes in predicting the PPIs for crude, intermediate, and finished goods, as well as in predicting the CPI. Wald tests were used to test the null hypothesis that the joint significance of the explanatory variables is zero. Wald tests are based on measuring the extent to which the unrestricted estimates fail to satisfy the restrictions of the null hypothesis.[11] A small p-value of the Wald statistic rejects the null hypothesis of no feedback from lagged SOPs to the dependent variable, and a large p-value of the Wald statistic implies that the null hypothesis is not rejected.

Table 1 also shows the R-squared values of the equations within the VAR systems. R-squared values measure the amount of variation of the dependent variables explained by the regression equation. An R-squared close to unity indicates a good overall fit of the regression, while an R-squared of zero suggests a failure of the regression equation to explain variations of the dependent variable any better than could be explained by the sample mean of the dependent variable.[12]

The results presented in table 1 indicate that, during both subperiods, price movements within each stage of production can be explained by price changes occurring at *earlier* stages. Highlighting this result is the finding that, in the regression equations for intermediate goods, finished goods, and the CPI from both subperiods, the coefficients of the lagged explanatory variables of previous processing stages are jointly significant. For example, during both subperiods, the lagged values of crude and intermediate goods are jointly significant in the finished-goods equation.

The Wald tests also suggest that in most cases price changes within the SOP model cannot be explained by price movements at *later* stages of processing. Only in the finished-goods equation from 1990–2001, in which the lagged values of the CPI are jointly significant, is an explanatory variable (or a combination of explanatory variables) at a stage of processing *after* the dependent variable statistically significant.

Results of the VAR estimation do not imply that commodity prices have lost their power as predictors of consumer inflation. The R-squared values, however, indicate a decrease in the usefulness of commodity prices in that regard: R-squared fell from 0.59 in the 1974–89 CPI equation to 0.30 in the 1990–2001 CPI equation. The R-squared values in the finished-goods equations behaved similarly. In addition, in the CPI equations, the chi-square statistics testing the joint significance of crude, intermediate, and finished goods suggest that the coefficients are statistically significant in both periods, but that the level of significance declined in the 1990–2001 period. Similarly, in the finished-goods equations, the combined lagged values of crude and intermediate goods are statistically significant in both estimation periods; however, the level of significance decreased from 1990 to 2001.

Year-ahead, out-of-sample forecasts also were constructed, using 8-year blocks of data to estimate the VARs. The 8-year blocks were rolled forward on a monthly basis. In contrast to the previous R-squared values and Wald tests, the average absolute error of the forecasts from 1982 to 1988 was higher than from 1990 to 2001, indicating greater predictive power in the second period. However, the out-of-sample tests were somewhat limited, because 8 years of data were necessary to estimate the VAR models. Accordingly, because the time series began in 1974, no forecasts could be constructed prior to 1982.

Impulse response, variance decomposition

VAR coefficients are difficult to interpret, due to the multivariate nature of the models. Accordingly, impulse response functions

Table 1. VAR test results

Null hypothesis	1974–89		1990–2001	
	Chi-square	Probability	Chi-square	Probability
Dependent variable: crude				
Intermediate = 0	3.0820	0.5442	4.2260	0.3763
Finished = 0	5.2486	.2627	5.9309	.2044
CPI = 0	3.5224	.4745	4.9347	.2941
Intermediate/finished/CPI = 0	17.7327	.1241	13.4744	.3355
R^2	.25	…	.38	…
Dependent variable: intermediate				
Crude = 0	21.3029	.0003	10.4637	.0333
Finished = 0	.7899	.9398	4.5748	.3338
CPI = 0	3.0544	.5488	1.5539	.8170
Finished/CPI = 0	3.6722	.8854	5.6183	.6899
R^2	.69	…	.61	…
Dependent variable: finished				
Crude = 0	7.9022	.0952	8.1216	.0872
Intermediate = 0	40.7242	.0000	14.7711	.0052
Crude/intermediate = 0	44.3922	.0000	15.6977	.0469
CPI = 0	7.5823	.1081	10.0163	.0402
R^2	.59	…	.19	…
Dependent variable: CPI				
Crude = 0	6.1217	.1902	13.1299	.0107
Intermediate = 0	5.7063	.2222	1.8955	.7550
Finished = 0	11.6461	.0202	23.4214	.0001
Crude/intermediate/finished = 0	49.8345	.0000	37.5086	.0002
R^2	.59	…	.30	…

NOTE: Probability is the *p*-value of the Wald statistic.

and variance decompositions were developed to overcome this difficulty. Impulse response functions measure the effect of a one-standard-deviation innovation of a variable on current and future values of the variables in a system of equations. Variance decompositions show the percentage of forecast variance (that is, the percentage of variance in the forecast) in one variable of the VAR that is explained by innovations of all variables within the VAR.[13] This section constructs impulse response functions and variance decompositions that examine the causal relationships between the SOP indexes and the CPI.

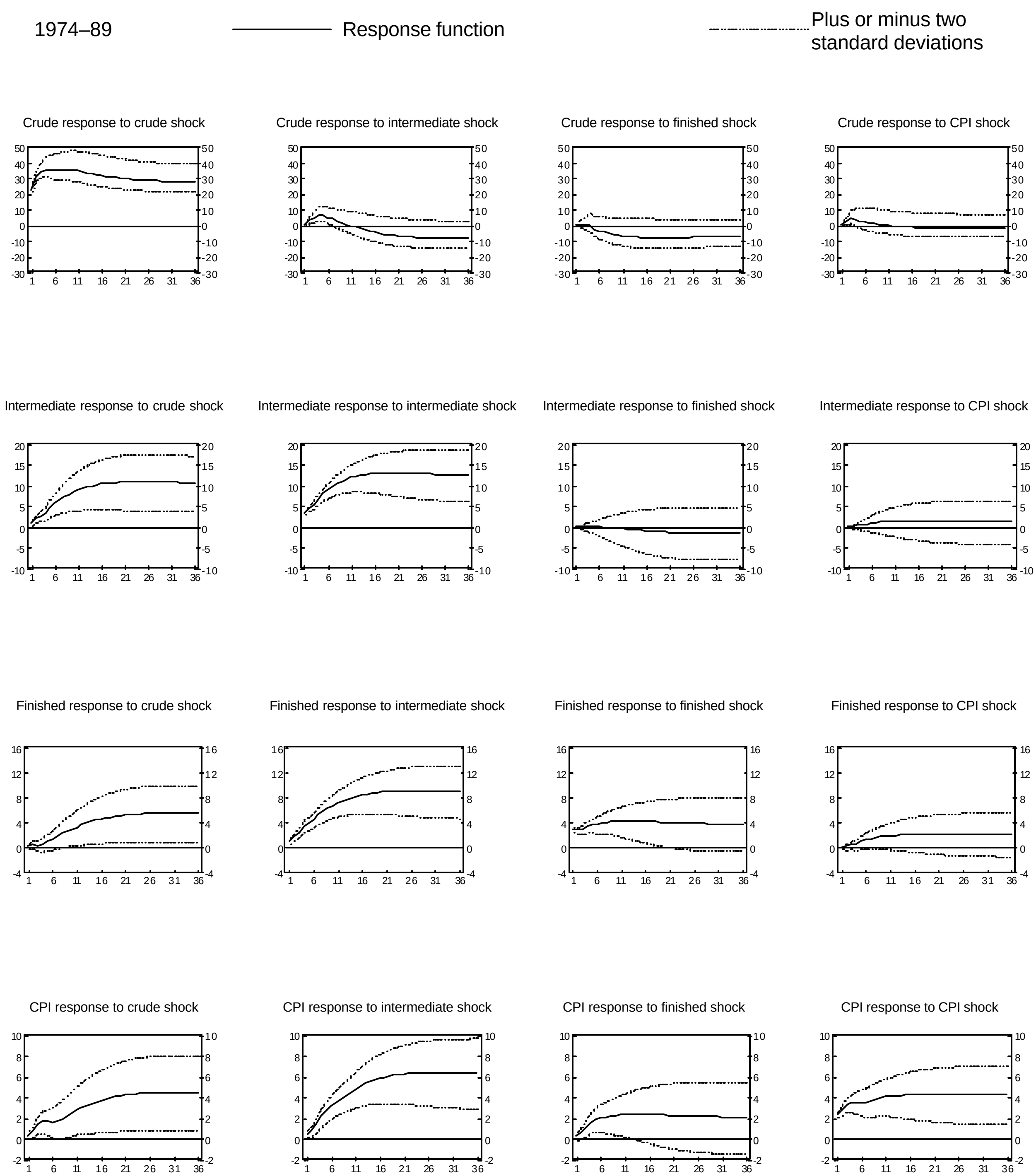
Innovations within a VAR are generally not contemporaneously independent of each other: a random innovation to one variable often occurs simultaneously with innovations to other variables in the system. To overcome this problem, innovations can be orthogonalized by a Cholesky decomposition in which the covariance matrix of the resulting residuals is lower triangular. Therefore, an innovation to one variable within a VAR affects only variables ordered after that variable, and the VAR is given a causal interpretation.[14]

In order to calculate the impulse response functions and variance decompositions, the innovations were orthogonalized by a Cholesky decomposition following the ordering crude goods, intermediate goods, finished goods, CPI. This ordering was chosen because economic theory predicts that price changes transmit forward through the stages of processing as input costs of producers change. The unrestricted VARs estimated in the previous section suggest that this has been the case historically. Chart 2 presents cumulated impulse response functions of one-standard-deviation innovations from 1974 to 1989 and from 1990 to 2001. In addition, standard-error bands of two standard deviations representing the statistical significance of the responses are shown. The standard-error bands were calculated with the software package EVIEWS 4.0.

The impulse response functions in chart 2 indicate that during both subperiods price changes at various stages of processing were transmitted forward through the SOP system. While some causal price relationships appear to have weakened since the 1990s (as previous analysis has suggested), others have remained stable or even have strengthened.

From 1974 to 1989, price changes at the producer level were transmitted forward to the CPI. During this period, shocks to crude goods, intermediate goods, and finished goods produced statistically significant responses from the CPI. (The impulse response function is statistically significant when both standard-error bands are above or below zero on the *y*-axis.) For example, a one-standard-deviation shock to crude goods (approximately

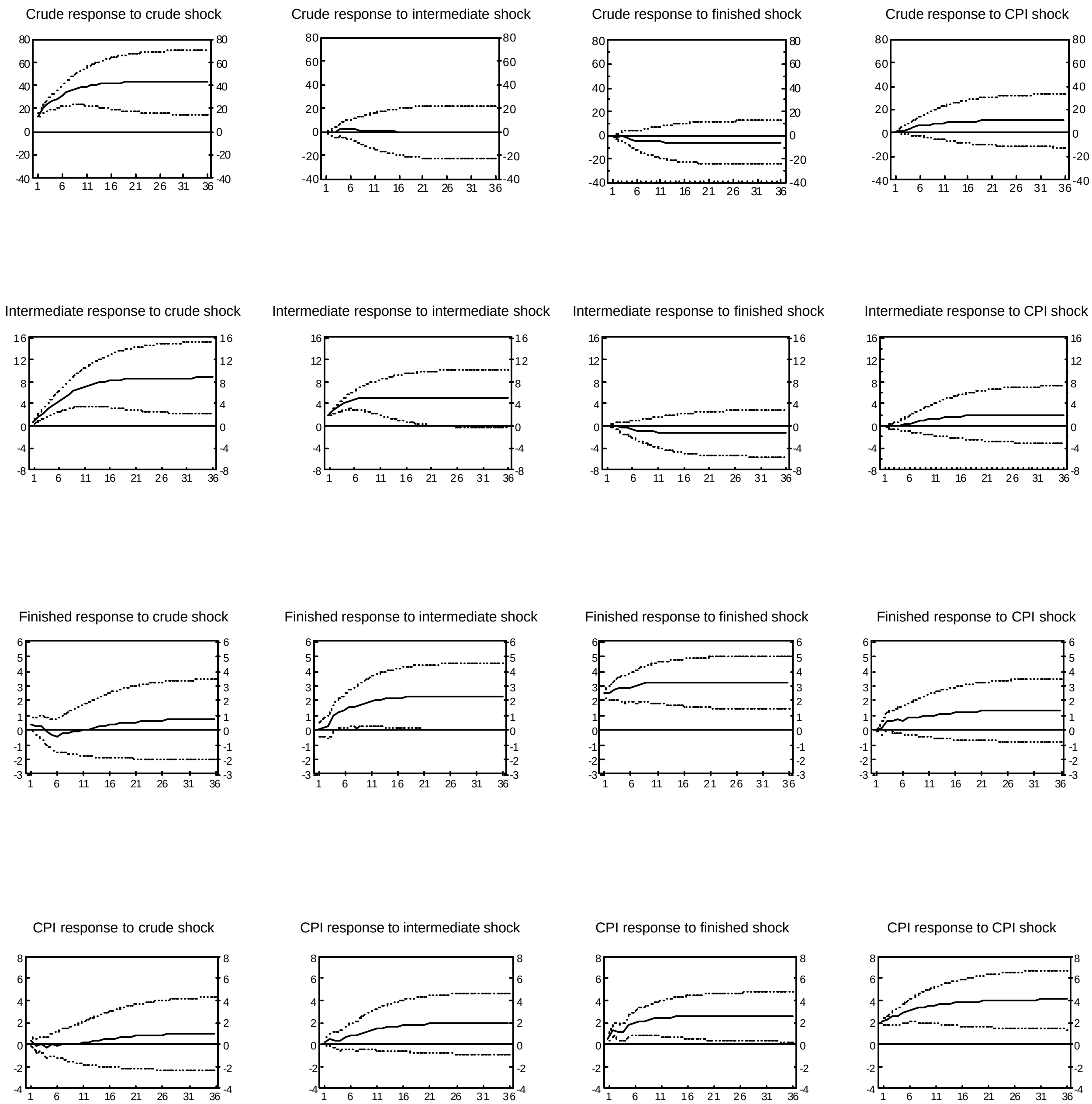
Chart 2. Accumulated responses to a one-standard-deviation shock, 1974–89 and 1990–2001



NOTE: For each plot, horizontal axis is number of months and vertical axis is percent change.

Chart 2. Continued—Accumulated responses to a one-standard-deviation shock, 1974–89 and 1990–2001

1990–2001 ——— Response function ········ Plus or minus two standard deviations



NOTE: For each plot, horizontal axis is number of months and vertical axis is percent change.

22.1 percent) resulted in a 4.4-percent increase in the CPI. Beginning in 1990, the power of commodity indexes as predictors of CPI inflation appears to have declined: only innovations in the finished-goods index affected the CPI significantly since then. However, in comparison with the earlier subperiod, shocks to finished goods resulted in stronger and more statistically significant responses from the CPI.

Price changes at the crude and intermediate stages of processing were passed forward to finished goods from 1974 to 1989. Shocks to the indexes for crude and intermediate goods caused statistically significant changes in the prices of finished goods. Over the 1990–2001 subperiod, the power of the crude- and intermediate-goods indexes to predict movements in finished-goods prices decreased substantially. Impulse response functions estimated during this period show that changes in crude-goods prices did not significantly affect the finished-goods index and that shocks to intermediate-goods prices produced only marginally significant responses from the finished-goods index.

Price changes in crude goods have consistently caused changes in the index for intermediate goods. During both subperiods, an unanticipated shock to crude-goods prices can be traced forward to a statistically significant movement in the index for intermediate goods.

Table 2 presents variance decompositions of the SOP indexes after 36 months. Like the impulse response functions, the variance decompositions were estimated from the two subperiods 1974–89 and 1990–2001.

The variance decompositions in table 2 reinforce the earlier finding in this article that the nature of the transmission of inflation within the SOP system has changed over the past three decades. The share of the CPI's forecast error variance that can be explained by commodity price shocks differed substantially between the two subperiods. Innovations to crude and intermediate goods accounted for a significantly larger share of the CPI's forecast error variance from 1974 to 1989 than from 1990 to 2001. However, the share of the CPI's forecast error variance explained by shocks to finished goods has increased approximately 12 percent since 1990.

Variance decompositions at the earlier stages of processing also differ between the two subperiods. Shocks to crude and intermediate goods accounted for a considerably smaller share of finished goods' forecast error variance from 1990 to 2001 than from 1974 to 1989. However, since 1990, the portion of intermediate goods' forecast error variance that can be explained by price changes in crude goods has increased by approximately 15 percent.

THIS ARTICLE HAS PRESENTED AN EMPIRICAL INVESTIGATION of the nature and consistency of causal price relationships within the stage-of-processing (SOP) system. A visual examination of price movements shows that, during the 1970s and 1980s, changes in the indexes for the prices of crude and intermediate goods often preceded changes in the CPI. Since the early 1990s, however, price movements at early stages of processing do not appear to have foreshadowed movements in the CPI. Wald tests of VAR coefficients estimated with data from 1974 to 1989 and from 1990 to 2001 indicated that, in the equations for the CPI, finished goods, and intermediate goods, the combined lagged values of all variables in earlier stages of processing to the dependent variable were jointly significant. However, the levels of significance, as well as the equations' R-squared values, declined in the 1990–2001 subperiod.

Confidence regions of impulse response functions estimated from the VAR models' coefficients illustrate that, from 1974 to 1989, price movements in crude, intermediate, and finished goods were transmitted forward to the CPI. In comparison, from 1990 to 2001, only changes in the PPI for finished goods caused movements in the CPI. Variance decompositions told a similar story, with the share of the CPI's forecast error variance explained by shocks to crude and intermediate goods declining from 1990 to 2001. However, the share of the CPI's forecast error variance explained by finished goods increased over the same period.

Table 2. Variance decompositions

Decomposition variable	Percentage of forecast errors due to—			
	Crude	Intermediate	Finished	CPI
Variance decompositions after 36 months, 1974–89:				
Crude	92.03	4.05	2.14	1.79
Intermediate	29.69	68.54	.56	1.21
Finished	10.35	32.99	53.45	3.20
CPI	12.06	24.43	8.05	55.46
Variance decompositions after 36 months, 1990–2001:				
Crude	92.01	2.24	2.51	3.23
Intermediate	44.87	50.29	2.24	2.60
Finished	5.24	9.89	79.83	5.03
CPI	8.02	4.58	20.06	67.34

At the earlier stages of processing, impulse response functions show that innovations to crude- and intermediate-goods prices caused changes in the finished-goods index from 1974 to 1989. As with the CPI, movements in the prices of crude goods were not passed forward to finished-goods prices from 1990 to 2001. Price changes at the intermediate stage of processing were passed forward from 1990 to 2001; however, the relationship was relatively weaker during that subperiod. Variance decompositions show a dramatic decrease in the forecast error variance of finished-goods prices explained by innovations to crude- and intermediate-goods prices between the two subperiods. Impulse response functions and variance decompositions illustrate that there was a causal link between the prices of crude goods and the prices of intermediate goods during both periods. In fact, the relationship was relatively stronger in the second subperiod.

Taken as a whole, the results from the various empirical tests suggest that there was significant forward price transmission in both subperiods examined. However, from 1990 to 2001, price transmission from the earlier stages of processing—crude and intermediate goods—to the later stages of processing—finished goods and the CPI—was weaker relative to the earlier subperiod. By contrast, the causal price relationships between the finished-goods index and the CPI and between crude- and intermediate-goods prices have strengthened since 1990. □

Notes

[1] *Handbook of Methods* (Bureau of Labor Statistics, 1997), esp. Chapter 14, "Producer Price Indexes."

[2] S. Brock Blomberg and Ethan S. Harris, "The Commodity-Consumer Price Connection: Fact or Fable?" *Federal Reserve Bank of New York Economic Policy Review*, October 1995, pp. 21–38.

[3] Fred Furlong and Robert Ingenito, "Commodity Prices and Inflation," *Federal Reserve Bank of San Francisco Economic Review*, 1996, no. 2, pp. 27–47.

[4] Todd Clark, "Do Producer Prices Lead Consumer Prices?" *Federal Reserve Bank of Kansas City Economic Review*, third quarter, 1995, pp. 26–39.

[5] C. Alan Garner, "How Useful Are the Leading Indicators of Inflation?" *Federal Reserve Bank of Kansas City Economic Review*, second quarter, 1995, pp. 5–18.

[6] Tae-Hwy Lee and Stuart Scott, "Investigating Inflation Transmission by Stages of Processing," in Robert F. Engle and Halbert White (eds.), *Cointegration, Causality, and Forecasting: A Festschrift in Honor of Clive W. J. Granger* (Oxford, U.K., Oxford University Press, 1999), pp. 283–300.

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

[8] David A. Dickey and Wayne A. Fuller, "Distribution of the Estimators for Autoregressive Time Series with a Unit Root," *Journal of the American Statistical Association*, vol. 74, 1979, pp. 427–31. Also in John Dinardo and Jack Johnston, *Econometric Methods* (New York, McGraw Hill, 1996), esp. pp. 224–25.

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

[10] See Clark, "Do Producer Prices Lead Consumer Prices?" and Blomberg and Harris, "The Commodity-Consumer Price Connection."

[11] Greene, *Econometric Analysis*, p. 161.

[12] *Ibid.*, p. 253.

[13] Dinardo and Johnston, *Econometric Methods*, pp. 298–301.

[14] *Ibid.*