A Time-Series Analysis of U.S. Petroleum Industry Inventory Behavior

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This paper examines inventory behavior in the U.S. petroleum industry. Inventories of crude oil and its three major products—gasoline, distillate and residual fuel oil—are studied.

Earlier empirical studies of inventory behavior have been unable to provide evidence of the production smoothing role of inventories emphasized in the theoretical literature (see Blinder, 1984). We suggest that these results are due to a tradition of relying on a partial-adjustment model to explain inventory behavior. We feel that the partial-adjustment model ignores potentially significant relationships between lagged values of explanatory variables and inventories implied by dynamic analysis. This leads us to investigate the time-series properties of petroleum inventories using the vector autoregression (VAR) methodology developed by Sims (1980).[1]

Petroleum industry inventory behavior is particularly interesting for several reasons. First, there is the perception that changes in inventory holdings have a destabilizing effect on world crude-oil prices. Second, data are available to study the interaction between product and input inventories.

The first section focuses on the theory of inventory behavior and prior attempts to test it empirically. Next, we explain how vector autoregression solves some of the problems common to the more traditional techniques. Finally, we present the results of two VAR models estimated for oil and refined product inventories.

The Energy Journal, Vol. 8, No. 4

1. In addition to Sims' work, detailed introductions to the statistical theory and uses of VAR's can be found in Sargent (1979) and Hakkio and Morris (1984).

The authors would like to thank Lee Ohanian and an anonymous referee for helpful comments.

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MODELING INVENTORY BEHAVIOR

The partial-adjustment model has been the standard model of inventory behavior. Underlying the model is the theoretical assumption of profit maximization on the part of the firm. A firm weights the marginal benefits of holding additional inventories (allowing cost-saving production smoothing in the face of variations in demand and rising marginal costs of production) against the interest and storage costs of holding stocks. (See Rowley and Trivedi, 1975, and Maccini and Rossana, 1984, for a more complete discussion.) Once the optimal level of inventories is chosen—based on such variables as expected sales, the cost of capital, and expected changes in price—the change in inventories held in any one period is determined by the costs of adjusting inventories to the desired level and by the magnitude and direction of unanticipated sales. Originally used by Lovell (1961), the univariate flexible accelerator or partial-adjustment model takes the following form. Inventories adjust only partially to desired levels in any one period:

$$I_t - I_{t-1} = \alpha(I_t^* - I_{t-1}) + \beta(S_t^e - S_t). \qquad (1)$$

Here I_t refers to the actual level of inventories in period t, I_t^* is the desired level of inventories, S_t and S_t^e stand for actual and expected sales (frequently represented by S_{t-1}), respectively, and α is the partial-adjustment coefficient. Assuming desired inventories depend linearly on sales ($I_t^* = \gamma_0 + \gamma_1 S_t$) and expected sales are measured simply by last period sales ($S_t^e = S_{t-1}$), then a standard partial-adjustment model might take on the form represented by equation 2.

$$I_t = \alpha\gamma_0 + \alpha\gamma_1 S_t + \beta(S_{t-1} - S_t) + (1 - \alpha)I_{t-1} \qquad (2)$$

The optimal or desired level of inventories may depend on more than just sales. One common modification includes the cost of capital as an additional explanatory variable. However, the expected negative influence of interest rates on inventory holdings has been shown with only a limited degree of success (see Akhtar, 1983). Verleger (1982) and others have added a proxy for expected increases in price. Maccini and Rossana (1984) extend the model to capture the interaction between finished goods inventories and other relevant stocks. Of particular interest is their use of raw material stocks to explain finished goods inventory investment.

The problems with the partial-adjustment model are well known. One is that the estimated magnitudes of α and β have been generally perplexing to economists. Estimates of α turn out to be relatively low, suggesting that the costs of adjusting inventories to the desired level are quite high. These results are difficult to reconcile with large estimates of β, which suggest an immediate adjustment in inventories to compensate for unanticipated sales.

Puzzled by the slow adjustment of actual inventories to their desired levels and their rapid adjustment to unanticipated sales, Feldstein and Auerbach (1976) propose and test a "target adjustment" model with some success. In their model, the desired or target level of inventories adjusts rather slowly, but inventories adjust immediately to changes in the target level.

A second problem raised by empirical tests of inventory behavior is that there appears to be a positive relationship between unanticipated sales and inventories ($\beta > 0$). This contradicts the supposed production smoothing function of inventories. In an attempt to explain this result, Blinder (1984) suggests that the high observed β's may reflect the fact that much of what econometric estimation labels as unanticipated sales is really known to the firm. He also notes that, if a producer reads a positive change in sales as a signal of future sales growth, then it is not inconsistent with production smoothing to see inventories increase. Production will increase in anticipation of a higher level of future sales, causing both sales and inventories to grow.

A third problem with empirical tests of inventory behavior is raised by Benjamin Friedman in the discussion following Blinder (1981). Friedman questions the use of a one-period lag. While Friedman is commenting specifically about problems in Blinder (1981), his point is well taken when considering the one-period lag structure assumed by the partial-adjustment model. There is no reason to assume that inventory adjustments in any one period are in response to discrepancies between current desired inventories and actual inventories in the previous period alone.

Previous investigations of oil industry inventory behavior have not been extremely fruitful. Griffin (1971) estimated a standard partial-adjustment model for three products: gasoline, kerosene and distillate. He found rather small estimates of the rate of adjustment to desired inventory levels (ten to fifteen percent per month). Seasonal dummy variables were generally significant, showing the expected seasonal trends for the three products.

Verleger (1982) adds a measure of the speculative motive for holding crude and products which he suggests is a significant determinant of crude and product inventory behavior. For crude and an aggregate of products, Verleger estimates a standard partial-adjustment model. He adds the spread between the expected increase in the price of crude (measured as the difference between spot market values and official crude oil prices) and the opportunity cost of carrying the oil through to the next period. Despite weak empirical results, Verleger concludes that the difference between spot values and contract prices explains some of the variance in petroleum inventories.

Blinder (1984) presents the results from a simple stock-adjustment model for the petroleum and coal products sector of the economy. The speed of inventory adjustment is found to be twelve percent per month. Blinder's estimates for this sector of the economy and others convince him that relatively low estimates of the speed of inventory adjustment are accurate and that the faster adjustment speeds found by Maccini and Rossana (1984) can be ascribed to errors in their estimation technique.

USING THE VECTOR AUTOREGRESSION ESTIMATION TECHNIQUE

There are several advantages of using a vector autoregression (VAR) to examine petroleum industry inventory behavior. First, in previous studies, the explanatory variables (sales, cost of capital, price) are generally assumed to be exogenous with respect to the dependent variable (inventories). However, failure to take into account any simultaneous relationships that might exist between a particular explanatory variable and the dependent variable results in biased and inconsistent parameter estimates. Hypothesis testing under these conditions can be misleading. By using a VAR, the seriousness of the problem can be determined and the problem avoided. This is particularly valuable when looking at crude and product inventories—since prices and inventories are thought by many to be simultaneously determined. Using the VAR, each variable in the model is treated as endogenous to the system. Each variable is regressed on past values of itself and past values of all other variables in the system. Simultaneous equation bias is avoided, yet estimation remains fairly simple (i.e. ordinary least squares).

Second, standard empirical inventory models have used estimation methods and specifications which focus on only the contemporaneous relationship between explanatory variables and inventories. These models are arbitrarily restricted so that past values of key variables are excluded from the analysis; many possible interactions among the variables are completely ignored. Naturally, if important variables are omitted so that the models are misspecified, the coefficient estimates will be biased and inconsistent. A major advantage of using the VAR model is that it is designed to characterize the dynamic response of inventories by including lags for each variable in the system. Moreover, the VAR methodology does not require a predetermination of appropriate lag lengths; the lag length is determined econometrically. The likelihood ratio test suggested by Sims (1980) is used to determine the lag lengths used here.

Finally, the VAR impulse-response functions let us examine how an unanticipated change in sales (or any other variable in the system) in one period influences the level of inventories in both current and future periods. This gives a better understanding of the relationship between these variables that does the partial-adjustment model.

Technically, a VAR is the unrestricted reduced form of an unknown underlying structural model. To begin with, we estimate a four-variable VAR for crude oil and for each of three refined products—gasoline, distillate, and residual fuel oil. These four-variable models include the key variables traditionally used in inventory models: the short-term interest rate (r), crude or each products' own price (P), own sales (S), and own inventories (I). The "standard" four-variable VAR is shown in equation 3 (seasonal dummy variables and constants are omitted for ease of exposition).

$$X(t) = \sum_{i=1}^{m} A(i)\, X(t - i) + e(t) \tag{3}$$

where $X(t)' = [r_t, P_t, S_t, I_t]$ and $e(t)' = [e_{1t}, e_{2t}, e_{3t}, e_{4t}]$, a vector of white-noise disturbance terms. $A(i)$ is a 4 by 4 coefficient matrix, m represents the lag length and t, the time period.

An extended model is also estimated which attempts to capture the interaction of crude and product inventories by including crude inventories in the product models and vice versa. Rather than including the products separately, an aggregate measure of product inventories is constructed for the crude model.

In estimating the VAR models we use monthly data from January 1969 to December 1983. All variables are expressed in natural logarithms. Since the data are not seasonally adjusted, seasonal dummy variables were included in each equation when estimated.[2] Because all the right-hand-side variables in the VAR are predetermined, each equation in the VAR is estimated by ordinary least squares. This estimation procedure results in consistent and asymptotically efficient estimates.

ECONOMETRIC RESULTS

The Standard Model

The likelihood ratio test elaborated on by Sims (1980) determined lag lengths (m) of two, four, four and four for the crude, gasoline, distillate and residual fuel oil standard models, respectively. A useful way to summarize the results of the estimated models is to examine F-tests of the null hypothesis that all of the coefficients of a lagged variable in an equation are jointly equal to zero. Table 1 presents significance levels for the F-statistics calculated for the

2. The interest rate used is the annualized market yield on three-month U.S. Treasury bills. Prices of refined products are measured in cents per gallon and crude oil prices are measured using a crude-oil price index. Inventories are measured in millions of barrels. Crude oil sales equals crude oil production minus the change in crude oil inventories. Refined product sales equals domestic product supplied minus imports plus exports. Domestic product supplied equals total sales in the U.S. by domestic and foreign refiners.

Table 1. Significance Levels of F-Tests—Standard Model

		(1)	(2)	(3)	(4)
	Crude:	r^*	P^*	S^*	I^*
(1)	r	A	A	.59	.76
(2)	P	.35	A	.09	.18
(3)	S	.33	.93	A	.23
(4)	I	.76	.06	A	A
	Gasoline:				
(5)	r	A	.10	.03	.15
(6)	P	.77	A	.26	.01
(7)	S	.92	.01	A	A
(8)	I	.80	.13	.01	A
	Distillate:				
(9)	r	A	.01	.90	.76
(10)	P	.51	A	.03	.01
(11)	S	.22	.13	A	A
(12)	I	.62	.67	A	A
	Residual fuel oil:				
(13)	r	A	.22	.09	.18
(14)	P	.02	A	.54	.05
(15)	S	.19	.06	A	.02
(16)	I	.45	.05	A	A

Notes:
A implies less than one percent.
* denotes the dependent variable.

standard model. Except for the short-term interest rate, all the variables in the refined product inventory equations are significant at the five percent level (see column 4, rows 5–16). In the crude-oil model, only past values of its own inventories are significant (at the one percent level) (see column 4, rows 1–4). It appears that product inventories are more responsive than crude inventories to price and sales. This is consistent with the relatively greater supply elasticity of individual refined products. In comparison, the supply of crude oil is fairly inelastic in the short run.

The results in Table 1 can be used to determine which explanatory variables are econometrically exogenous. If a particular variable is exogenous with respect to inventories, the F-statistic for inventories should not be significant in the equation which explains the variable in question (see Sims, 1980). As Table 1 shows, inventories are always highly significant in each sales equation (column 3) and in two out of the four price equations (column 2). Our conclusion is that at least sales are not econometrically exogenous with respect to inventories. This does not bode well for the simple partial-adjustment model, which treats sales as if they were exogenous. We can also comment on the many references to the impact of inventory stocking and de-stocking on prices (see, for example, Verleger, 1982, or Danielson, 1979). There appears to be evidence supporting this hypothesis for crude and for its closest substitute, residual fuel oil. There is evidence of unidirectional causality from crude inventories to crude prices at the 6 percent level (Table 1, column 2, row 4) and of a simultaneous relationship between residual fuel oil prices and inventories (see column 2, row 16 and column 4, row 14). While gasoline and distillate inventories appear affected by prices (column 4, rows 6 and 10), the reverse is not true (column 2, rows 8 and 12). The lack of a two-way relationship between gasoline and distillate inventories and price may reflect the relatively greater supply elasticity generally attributed to these products due to the nature of the refining process.

Tables 2 and 3 provide evidence from an equivalent moving-average representation of the standard inventory model.[3] From the moving-average representation, we can examine the impulse-response function for inventories with respect to other variables in the system. The impulse-response function quantifies the response of a one unit increase in variable i on future values of the jth variable.[4]

The results of the impulse-response function can be sensitive to the ordering of the variables. The interest rate is placed first because it represents an aggregate variable and should be exogenous with respect to the petroleum industry. Price is ordered second, ahead of sales. Our focus variable (inventories) is placed last. We interpret this to mean that an interest rate innovation contemporaneously influences price, sales and inventories, while an inventory innovation does not contemporaneously influence any other variable in the system. When the contemporaneous correlation between variables in the system is low, the particular order is less important. Here, the contemporaneous correlation is generally low.[5]

The impulse-response functions are given in Table 2. Clear patterns emerge for the three refined product inventories. Of greatest interest is the result that,

3. The standard VAR can be represented as $A(L)X(t) = e(t)$ where $A(L)$ is an m by n matrix polynomial lag operator, m equals the lag length, n the number of variables in the model, and $A(0)$ is the identity matrix. $X(t)$ is an n by 1 vector of variables in the model. $e(t)$ is an n by 1 white-noise stochastic error term and $E[e(t), e(t)'] = \Sigma$. We can normalize the VAR into a recursive system with a covariance matrix equal to the identity matrix. Let H be a lower triangular matrix of appropriate dimension such that $H \Sigma H' = I$. Pre-multiplying the VAR by H results in the recursive system $HA(L)X(t) = He(t)$ with $E[He(t)e(t)'H'] = H \Sigma H' = I$. The transformed covariance matrix results in the contemporaneous error terms of each individual equation being orthogonal to one another with a variance of one. Assuming that $X(t)$ is stationary, the equivalent moving-average representation of the VAR is $X(t) = B(L)u(t)$ where $B(L)$ equals $[HA(L)]^{-1}$ and $u(t)$ equals $He(t)$ [see Sims (1980) or Hakkio and Morris (1984)].

4. The impulse-response function of x_j with respect to x_i (i less than or equal to j) equals $b_{ij}(L)$, an element of $B(L)$ (see footnote 3).

5. The only exception is between sales and inventories. These two variables were reversed and the model was re-estimated with little change in results.

Table 2. Response of Inventories to One-Standard Deviation Shocks in *r, P, S* and *I*

	Crude				Gasoline				Distillate				Residual Fuel Oil			
	r	*P*	*S*	*I*	*r*	*P*	*S*	*I*	*r*	*P*	*S*	*I*	*r*	*P*	*S*	*I*
1	−.0024	.0009	.0022	.0195	−.0035	.0028	−.0151	.0169	−.0017	.0040	−.0232	.0304	.0004	.0022	−.0334	.0333
2	−.0008	.0027	.0063	.0175	−.0054	.0058	−.0145	.0204	−.0015	.0116	−.0298	.0394	−.0018	−.0002	−.0289	.0298
3	−.0004	.0037	.0056	.0168	−.0073	.0081	−.0085	.0200	.0003	.0198	−.0267	.0342	−.0072	.0074	−.0251	.0237
4	−.0001	.0042	.0054	.0165	−.0039	.0098	−.0078	.0145	−.0001	.0233	−.0269	.0273	−.0027	.0107	−.0182	.0178
5	.0003	.0046	.0052	.0161	−.0001	.0104	−.0018	.0079	−.0006	.0232	−.0051	.0213	−.0023	.0118	−.0077	.0166
6	.0008	.0050	.0051	.0158	.0008	.0107	.0030	.0039	−.0003	.0219	.0074	.0175	−.0048	.0148	−.0033	.0173
7	.0012	.0052	.0050	.0154	.0006	.0179	.0037	.0006	.0001	.0208	.0155	.0163	−.0060	.0149	.0009	.0199
8	.0017	.0055	.0049	.0151	.0003	.0101	.0056	−.0012	.0008	.0203	.0200	.0170	−.0067	.0150	.0048	.0216
9	.0022	.0058	.0048	.0147	−.0001	.0093	.0060	−.0011	.0015	.0203	.0189	.0189	−.0067	.0157	.0074	.0227
10	.0027	.0060	.0047	.0143	.0000	.0087	.0053	−.0006	.0023	.0204	.0153	.0212	−.0061	.0163	.0097	.0235
11	.0031	.0062	.0047	.0140	.0003	.0081	.0054	.0002	.0035	.0206	.0111	.0231	−.0060	−.0170	.0112	.0239
12	.0036	.0064	.0046	.0136	.0007	.0076	.0053	.0010	.0045	.0206	.0072	.0242	−.0060	.0179	.0131	.0242
13	.0040	.0065	.0045	.0133	.0013	.0073	.0051	.0014	.0054	.0203	.0051	.0245	−.0061	.0185	.0146	.0244
14	.0044	.0067	.0045	.0129	.0019	.0070	.0054	.0017	.0059	.0198	.0046	.0241	−.0062	.0191	.0158	.0246
15	.0048	.0068	.0045	.0125	.0023	.0068	.0055	.0018	.0062	.0191	.0054	.0235	−.0063	.0196	.0170	.0247
16	.0052	.0069	.0044	.0122	.0026	.0065	.0055	.0018	.0063	.0184	.0069	.0228	−.0064	.0201	.0180	.0249
17	.0056	.0069	.0044	.0119	.0027	.0063	.0057	.0018	.0062	.0176	.0085	.0224	−.0065	.0205	.0188	.0251
18	.0059	.0070	.0044	.0115	.0027	.0061	.0058	.0019	.0060	.0170	.0096	.0222	−.0065	.0209	.0196	.0252
19	.0062	.0070	.0043	.0112	.0026	.0059	.0058	.0019	.0057	.0164	.0101	.0222	−.0065	.0212	.0202	.0253
20	.0065	.0070	.0043	.0109	.0025	.0058	.0058	.0020	.0055	.0160	.0101	.0224	−.0065	.0215	.0208	.0254
21	.0068	.0070	.0043	.0106	.0023	.0056	.0058	.0020	.0053	.0152	.0096	.0226	−.0065	.0218	.0213	.0255
22	.0070	.0070	.0042	.0103	.0022	.0055	.0058	.0021	.0050	.0149	.0090	.0228	−.0064	.0220	.0217	.0256
23	.0072	.0070	.0042	.0100	.0020	.0054	.0058	.0021	.0048	.0145	.0084	.0228	−.0064	.0233	.0221	.0257
24	.0074	.0069	.0042	.0097	.0018	.0054	.0058	.0021	.0045	.0141	.0079	.0228	−.0064	.0255	.0224	.0257

Table 3. Decomposition of Variance—Standard Model

	Crude				*Gasoline*			
t + k	*r*	*P*	*S*	*I*	*r*	*P*	*S*	*I*
1	1.5	.2	1.2	97.2	2.2	1.5	42.9	53.4
2	.9	1.1	5.6	92.1	3.4	3.4	36.0	57.3
3	.6	2.1	7.1	90.1	5.2	5.9	28.3	60.7
4	.5	2.9	7.5	89.1	4.9	9.2	26.1	59.7
6	.4	4.3	7.9	87.5	4.4	17.0	23.4	55.3
12	1.3	8.0	8.1	82.7	3.5	29.2	23.7	43.7
24	7.5	13.4	8.1	71.1	4.2	33.6	27.5	34.7
	Distillate				*Residual Fuel Oil*			
t + k	*r*	*P*	*S*	*I*	*r*	*P*	*S*	*I*
1	.2	1.1	36.3	62.4	.0	.2	50.1	49.7
2	.1	3.7	35.2	61.0	.1	.1	49.3	50.5
3	.1	8.6	33.8	57.5	1.1	1.1	49.1	48.7
4	.1	13.5	31.9	54.5	1.0	2.9	48.4	47.7
6	.1	21.2	26.8	52.0	1.3	7.6	42.3	48.9
12	.3	28.2	24.8	46.7	2.6	16.9	27.9	52.6
24	1.5	29.8	17.7	50.9	2.7	24.2	26.5	46.7

following an innovation in sales, it appears that refined product inventories decrease for five or six months before inventory building begins. These results support the production smoothing role of inventories, a result that the partial-adjustment model has been unable to detect. When sales unexpectedly increase, inventories decline (as one would expect if production smoothing were an important aspect of holding inventories). Once the sales increase is perceived as being more permanent, inventory building occurs. Crude inventories do not appear to be responsive to innovations in crude sales.

Also, there seems to be a clear positive relationship between innovations in price and refined product inventories, with at least three possible explanations. First, if increases in price are due to disruptions in supply, we would expect inventories to adjust upward to reflect the increased uncertainty of supply. Alternatively, if increases in price are the result of an increase in demand, then we would expect inventories to grow more or less proportionately to sales. Finally, the positive effect of price on inventory accumulation may reflect speculative behavior. An increase in the expected future price on the part of those who hold crude and product inventories results in higher inventories and higher prices.

More information comes from the results of the variance decomposition (see Table 3). The decomposition of variance measures the percentage of the k-period ahead ($t + k$) squared forecast error in one variable produced by innovations in each of the other variables in the system. The entries in Table 3 can be read as showing the percent of variation in (crude or product) inventories in period $t + k$ that can be accounted for by innovations in r, S, P, and by (crude or product) inventories (I) themselves in period t. Table 3 shows that, even after one year ($t + k = 12$), the effect on refined product inventories of innovations in sales are of almost as great as the effect of innovations in inventories themselves. After two years, the effect of a change in sales is still fairly strong—explaining approximately one-quarter of the squared forecast error. Despite the substantial adjustment in the first year, the variance decomposition suggests a fairly slow adjustment of inventories over time to changes in sales. Turning to the effect of innovations in price, we see that, at horizons of more than one year, price innovations have effects that are generally as large or larger than those caused by innovations in sales. This may be interpreted to mean that inventory levels do not adjust to price innovations until the changes in price are viewed as being permanent. We conclude that the adjustment of refined product inventories to innovations in both price and sales is fairly slow. Finally, the effect of innovations in price and sales on crude inventories appears to be quite small, as forecast errors in crude inventories are primarily due to own innovations at both short and long horizons.

The Extended Model with Intermediate Inputs

There is probably some interaction among the various petroleum inventories. We suspect that inventories of crude oil, as the principal input in the refining process, are a substitute for holding refined products in stock. To test the relationship between the demand for crude and refined product inventories, as extended, a five-variable vector autoregression model is estimated. In each of the three standard refined product models estimated above, crude inventories (CI) are included as an additional variable, placed third in order (following the price variable and before sales). Total refined product inventories (TPI)—the sum of the three individual refined product stocks (in barrels)—is added to the standard crude model, also placed third in order. Lag lengths of two, four, three, and four were chosen for the crude, gasoline, distillate, and residual fuel oil models, respectively.

Table 4 presents F-tests for the expanded VAR. The level of significance of all the variables in the crude inventory equation increases with the addition of total product inventories as an additional variable. However both the interest rate and price remain insignificant (column 5, rows 1–5). The significance of crude inventories in the TPI and sales equations (columns 3 and 4, row 5) suggests that neither are exogenous. These data support our expectation that crude and product inventories are simultaneously determined. Of the refined product models, only the distillate model shows crude inventories to be significant in determining product inventories (column 5, row 13). Not surprisingly, there appears to be less substitution between inventories of crude oil and any particular product than between crude oil and aggregate product inventories. For once, the interest rate comes in as significant in the residual fuel oil model (column 5, row 16).

Table 4. Significance Levels of F-Tests—Extended Model

		(1)	(2)	(3)	(4)	(5)
	Crude	*r*	*P*	*TPI/CI*	*S*	*I*
(1)	*r*	*A*	.04	.87	.32	.69
(2)	*P*	.22	*A*	.16	*A*	.09
(3)	*TPI*	.97	.43	*A*	.74	.04
(4)	*S*	.35	.76	.67	*A*	.02
(5)	*I*	.79	.22	.02	*A*	*A*
	Gasoline:					
(6)	*r*	*A*	.13	.86	.01	.29
(7)	*P*	.82	*A*	.56	.15	.12
(8)	*CI*	.65	.13	*A*	.17	.37
(9)	*S*	.99	.02	.48	*A*	.01
(10)	*I*	.80	.19	.10	.03	*A*
	Distillate:					
(11)	*r*	*A*	.01	.56	.42	.66
(12)	*P*	.53	*A*	.04	.99	.17
(13)	*CI*	.67	.10	*A*	.61	*A*
(14)	*S*	.36	.05	.76	*A*	.65
(15)	*I*	.96	.34	.10	.01	*A*
	Residual Fuel Oil:					
(16)	*r*	*A*	.08	.86	.01	.04
(17)	*P*	.03	*A*	.46	.10	.02
(18)	*CI*	.89	.23	*A*	*A*	.09
(19)	*S*	.27	.51	.27	*A*	.01
(20)	*I*	.58	.08	.15	*A*	*A*

The impulse-response functions from the extended model are presented in Table 5. Once again, what appears to be a production smoothing result is observed in the response of refined product inventories to innovations in sales. The interaction between crude and product inventories is seen in the third column, which describes the response of crude inventories to innovations in refined product inventories (TPI) over time. For ten months, innovations in product inventories are accompanied by increases in crude oil inventories. A similar result, but for a shorter period, is seen in the response of product inventories to crude inventory innovations. Not surprisingly, in the short run, the ability to substitute crude and product inventories for one another results in the simultaneous increase or decrease in both inventories in response to movements in either. For example, if residual fuel oil stocks are drawn in response to an unanticipated increase in demand, we would expect refinery production to pick up, causing a parallel reduction in crude oil inventories. In the longer run, however, the ability to substitute crude and product inventories for one another means that holding more or less of either

Table 5. Response of Inventories to One-Standard Deviation Shocks in *r, P, TPI/CI, S* and *I*

	Crude					Gasoline					Distillate					Residual Fuel Oil				
	r	*P*	*TPI*	*S*	*I*	*r*	*P*	*CI*	*S*	*I*	*r*	*P*	*CI*	*S*	*I*	*r*	*P*	*CI*	*S*	*I*
1	-.0023	.0005	-.0018	.0026	.0190	-.0036	.0032	-.0006	-.0153	.0169	-.0006	.0038	-.0044	-.0126	.0290	-.0004	.0043	-.0034	-.0317	.0333
2	-.0009	.0022	.0023	.0066	.0117	-.0061	.0052	.0000	-.0151	.0213	.0022	.0083	.0022	-.0381	.0382	-.0026	.0024	.0046	-.0252	.0298
3	-.0004	.0037	.0023	.0060	.0171	-.0077	.0068	.0019	-.0103	.0215	.0049	.0106	.0027	-.0372	.0357	-.0081	.0100	.0031	-.0199	.0237
4	.0000	.0046	.0021	.0057	.0166	-.0041	.0085	-.0011	-.0107	.0161	.0052	.0118	-.0006	-.0277	.0283	-.0032	.0135	.0012	-.0117	.0178
5	.0005	.0053	.0017	.0054	.0161	-.0005	.0084	-.0011	-.0061	.0093	-.0048	.0123	-.0036	-.0160	.0196	-.0036	.0147	.0019	-.0013	.0166
6	.0009	.0058	.0012	.0051	.0156	.0009	.0081	-.0015	-.0020	.0048	-.0052	.0122	-.0057	-.0055	.0120	-.0074	.0170	.0008	-.0023	.0173
7	.0013	.0062	.0008	.0049	.0151	.0011	.0081	-.0033	-.0015	.0015	.0061	.0117	-.0072	.0018	.0068	-.0094	.0155	.0005	.0044	.0199
8	.0017	.0067	.0005	.0047	.0146	.0007	.0072	-.0033	.0002	-.0004	.0070	.0112	-.0081	.0057	.0038	-.0098	.0141	.0004	.0059	.0216
9	.0022	.0071	.0002	.0045	.0142	.0004	.0064	-.0033	.0011	-.0007	.0076	.0108	-.0085	.0070	.0027	-.0088	.0135	-.0009	.0055	.0227
10	.0026	.0076	.0000	.0044	.0138	.0005	.0058	-.0036	.0007	-.0005	.0080	.0105	-.0086	.0069	.0027	-.0069	.0181	-.0018	.0050	.0235
11	.0030	.0080	-.0002	.0042	.0135	.0007	.0052	-.0032	.0012	-.0002	.0082	.0103	-.0086	.0060	.0032	-.0051	.0183	-.0027	.0044	.0239
12	.0034	.0085	-.0003	.0041	.0113	.0011	.0048	-.0030	.0015	-.0002	.0083	.0102	-.0085	.0049	.0038	-.0036	.0187	-.0038	.0036	.0242
13	.0038	.0089	-.0003	.0040	.0126	.0016	.0045	-.0029	.0014	.0004	.0083	.0101	-.0085	.0040	.0044	-.0023	.0140	-.0049	.0031	.0244
14	.0042	.0094	-.0004	.0039	.0122	.0020	.0042	-.0027	.0018	.0003	.0083	.0094	-.0085	.0033	.0048	-.0013	.0143	-.0060	.0029	.0246
15	.0046	.0099	-.0003	.0038	.0119	.0024	.0039	-.0026	.0021	.0003	.0082	.0098	-.0086	.0029	.0050	-.0004	.0144	-.0071	.0026	.0247
16	.0050	.0103	-.0003	.0037	.0115	.0026	.0037	-.0026	.0021	.0002	.0082	.0097	-.0087	.0027	.0050	.0003	.0144	-.0081	.0024	.0249
17	.0055	.0108	-.0003	.0036	.0112	.0026	.0034	-.0026	.0023	.0001	.0081	.0096	-.0088	.0026	.0050	.0009	.0142	-.0090	.0021	.0251
18	.0059	.0112	-.0002	.0035	.0108	.0026	.0033	-.0025	.0024	.0001	.0081	.0095	-.0089	.0025	.0050	.0014	.0139	-.0099	.0018	.0252
19	.0063	.0117	-.0001	.0034	.0105	.0026	.0031	-.0026	.0024	.0001	.0081	.0093	-.0090	.0025	.0049	.0018	.0136	-.0107	.0013	.0253
20	.0068	.0121	.0000	.0033	.0102	.0025	.0030	-.0025	.0026	.0002	.0080	.0092	-.0091	.0024	.0049	.0022	.0133	-.0115	.0009	.0254
21	.0072	.0126	.0001	.0032	.0099	.0023	.0028	-.0025	.0025	.0002	.0081	.0090	-.0092	.0023	.0049	.0025	.0129	-.0123	.0004	.0255
22	.0076	.0130	.0003	.0031	.0096	.0022	.0027	-.0026	.0024	.0002	.0079	.0088	-.0093	.0022	.0048	.0027	.0126	-.0130	-.0001	.0256
23	.0080	.0135	.0004	.0030	.0093	.0021	.0027	-.0026	.0025	.0002	.0079	.0087	-.0094	.0021	.0048	.0027	.0122	-.0164	-.0005	.0257
24	.0085	.0139	.0005	.0029	.0090	.0019	.0026	-.0026	.0025	.0002	.0078	.0085	-.0094	.0020	.0048	.0027	.0119	-.0143	.0009	.0257

Table 6. Decomposition of Variance—Extended Model

	Crude					*Gasoline*				
t + *k*	*r*	*P*	*TPI*	*S*	*I*	*r*	*P*	*CI*	*S*	*I*
1	1.4	.1	.8	1.7	96.0	2.4	1.8	.1	43.2	52.5
2	.8	.7	1.2	6.9	90.4	3.9	2.9	.0	35.8	57.4
3	.6	1.8	1.3	8.0	88.3	5.5	4.3	.2	28.9	61.2
4	.4	2.9	1.3	8.5	86.9	5.2	6.5	.2	28.1	60.1
6	.4	5.0	1.1	8.6	84.9	4.7	10.7	.3	26.6	57.7
12	1.2	11.6	.6	8.0	78.6	4.3	17.6	2.4	24.0	51.7
24	7.1	27.8	.3	6.0	58.8	5.7	19.8	4.6	23.4	46.5
	Distillate					*Residual Fuel Oil*				
t + *k*	*r*	*P*	*CI*	*S*	*I*	*r*	*P*	*CI*	*S*	*I*
1	.0	.9	1.2	43.9	54.0	.0	.9	.6	47.6	50.9
2	.1	1.8	.5	47.0	50.6	.2	.6	.9	43.8	54.5
3	.4	2.6	.4	47.9	48.7	1.5	2.5	.9	40.8	54.4
4	.6	3.7	.3	47.2	48.2	1.5	5.3	.8	38.0	54.5
6	1.1	6.2	.7	44.4	47.7	2.2	11.5	.7	30.0	54.8
12	3.8	11.1	4.0	39.6	41.6	4.3	17.0	.6	20.1	57.9
24	8.1	15.7	9.5	31.9	34.8	3.0	22.9	7.6	13.0	53.5

reduces the demand for holding the other, leading to the negative effect observed.

Table 6 presents the decomposition of variance for the extended model. The results are generally comparable to the standard model. One change from the results of the standard model is that, for crude oil, price innovations appear to be somewhat more important at the twelve and twenty-four month horizon.[6]

CONCLUSION

We have used vector autoregression to examine petroleum industry inventory behavior in the U.S. Evidence of a simultaneous relationship between inventories and sales and inventories and price, and more than a simple contemporaneous relationship between petroleum inventories and explanatory variables, confirms the value of using a VAR over the more simple partial-adjustment model. The VAR's equivalent moving-average representation also produces impulse-response functions that demonstrate the previously unobserved production smoothing role of inventories. The results of the variance decomposition for refined product inventories contribute to the rate-of-adjustment debate with evidence of a fairly slow adjustment of inventories over time.

6. We also estimated a VAR which included the Strategic Petroleum Reserve. The results showed some negative interaction between the Strategic Petroleum Reserve and privately held inventories. These results are available from the authors upon request.

The evidence seems to show that crude oil inventory stocking and de-stocking affect crude prices. Also, tests of an extended model confirm our expectation of a relationship between crude and total product inventories. Crude and total product inventories appear to move together in the short run, as unanticipated shocks to one or the other create substitution effects that cause both to move in the same direction. In the longer run, increases in crude inventories appear to be accompanied by reductions in total product inventories.

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