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RELATIVE PRICE VARIABILITY:
EVIDENCE FROM SUPPLY AND DEMAND EVENTS

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by LAWRENCE S. DAVIDSON and R.W. HAFER

I. INTRODUCTION

This paper extends previous theoretical and empirical inquiries into causes of relative price dispersion in the U.S. Earlier works, stemming from the original models of Lucas (1972, 1973) and Barro (1976) as modified by Cukierman and Wachtel (1979) and Hercowitz (1981a, b), emphasize the role of unanticipated supply (natural or nonpolicy) events and unanticipated demand (generally monetary policy) shocks in causing changes in relative prices. This previous work, which has specified a role for aggregate supply shocks in individual market supply functions, also specifies that all aggregate supply effects are totally unanticipated and that they impact on all markets identically with a supply elasticity equal to unity.

Our theoretical model proposes and our empirical work will test the importance of anticipated supply events as an additional determinant of changes in relative price dispersion. This addition of anticipated supply changes in the theoretical expression for relative price dispersion arises from generalizing previous models in two important ways: First, we assume that some aggregate supply "shocks" are anticipated. For example, not all energy price increases in the 1970's were completely unanticipated. Second, we assume that individual markets and their commodity's price changes differ according to their respective

supply elasticities. For example, because the intensity of energy use in producing various commodities differs, an increase in the price of oil, anticipated or unanticipated, would elicit differential supply responses across producers.

These two generalizations imply that an anticipated supply change can cause relative price dispersion. In this paper, we present results from empirically testing the importance of differentiating between anticipated and unanticipated supply events. Because of the difficulty in forming adequate measures for anticipated and unanticipated demand and supply events, we experiment with several. In all cases, relative price dispersion is defined as the nonproportional movement (the weighted squared deviations from the rate of change of a fixed weight personal consumption expenditures price index (PCE)) of the rate of change of the PCE's eighteen major subcomponents.

The significance of this research is the light it sheds on the causal factors of relative price change. By not decomposing supply events into anticipated and unanticipated components, previous studies are involved in misspecifications and, consequently, are generating misleading policy conclusions. For example, if supply events are widely anticipated so that agents have opportunity to adjust to them in advance, even though these events may increase price dispersion, they will have minimal adverse cyclical effects. Thus all changes in relative price dispersion are not signals of impending economic upheaval. In fact, our results indicate that a large portion of relative price change is a lagging indicator of past events.

The format of the paper is as follows. An overview of previous models is found in Section II. Our model, a generalization of that presented in Hercowitz, forms the basis for Section III. Section IV describes the data used in our study. Section V presents a discussion of the empirical results obtained from estimating our model for the U.S. over the period I/1960-IV/1981. The basic theoretical model tested in Section V is extended in Section VI wherein lagged effects of supply and demand changes are allowed to influence relative price dispersion. Section VII closes the paper with concluding remarks.

II. THE MARKET SETTING

Lucas and Barro each formulate models that explicitly formalize the role of information disparity in rational expectations macro models. Suppliers act as if they live on distinct market "islands" defined in terms of their informational idiosyncrasies. Because inhabitants of each island are not privy to price information on other islands in the current period, they do not observe the current (aggregate) price level. Consequently, they cannot distinguish between shifts in the relative composition of demand across islands from changes in aggregate demand. Unforeseen aggregate demand shocks, in this setting, lead to output adjustments, because suppliers mistake the demand shock for a change in the composition of demand.

Cukierman and Wachtel (1979, hereafter CW) expand these models to explicitly account for many different goods and markets, each with its own demand, supply and equilibrium condition. This is an important extension, because it allows the variance of relative prices to become a

variable. CW show that this variance is related to the variance of the general price level--both being endogenous variables related to exogenous impulse variables.

In the CW setting individual producers cannot distinguish aggregate from relative price change. They observe their own changes in individual market price but do not know with certainty if these signal relative or aggregate demand shifts. Consequently, suppliers use observed, own market price and information from the distribution of past prices to forecast the current aggregate price level. Once the aggregate price level is forecast, the supplier can then infer how much of the observed price change in his own market represents a relative price change.

An increase in the variance of aggregate demand shocks causes the variance of relative prices to increase in the CW model. This is because each market is confronted with different information--i.e., each market has different price realizations. Even if they have common knowledge about the intertemporal distribution of the aggregate price level, if past relative demand shocks have differed across markets, each market (even if faced with identical observed market price change) forecasts the inflation rate differently. Given this distribution of relative price forecasts across markets, the more aggregate demand varies the higher is the variance of the expected price level across markets. Thus, when aggregate demand varies more the confusion of separating aggregate and relative prices movements is magnified, and the actual distribution of relative prices is even more dispersed.

Hercowitz (1981a) further modifies the basic model to allow for different price elasticities across markets. In a recent paper,

Hercowitz (1981b) extends the model by incorporating aggregate supply shocks. Thus, in the most general model suggested by Hercowitz, each market has different demand and supply price elasticities. The elasticity of the supply shock variable in each market's own supply equation is, however, equal to unity by construction. Furthermore, all supply effects are unanticipated.

Froyen and Waud (1982) derive supply functions for individual markets in the CW setting, and show how both anticipated and unanticipated supply events (these events are modeled as changes in oil prices and the capital stock) belong in the equations. Froyen and Waud do not, however, assume different supply elasticities across markets. They also are not concerned explicitly with relative price change, but focus attention on the output effects of supply changes.

In all the models mentioned thus far, at least one of the following special assumptions hold:

- i) Exogenous supply effects do not exist,
- ii) Elasticity of supply shocks in all markets is the same, or
- iii) Anticipated supply impacts equal zero; i.e., all supply shocks are unexpected.

Consider the implications of these assumptions: First, anticipated supply changes nor their variance affect relative prices, the price level or the variance of price level expectations.^{1/} Second, studies that have used only unanticipated supply changes in their theoretical derivation, but which use proxies which are measured supply effects, are involved in measurement error.^{2/} In the model presented below, these assumptions are relaxed.

III. THE MODEL

The model presented here is a generalization of Hercowitz's model. There are an infinite number of individual commodities that differ due to non-equal supply elasticities. Supply effects may be anticipated as well as unanticipated. Moreover, both supply and demand shocks may be relative or aggregate in origin. Using (v) to index the markets $(v=1, \dots, n)$ the market supply equation is (all variables are expressed in logarithms)

$$(1) \ y_t^S(v) = \alpha^S(v) [P_t(v) - \bar{P}_t] + \beta^S(v) [U_t + \epsilon_t^S(v)],$$

where y_t is cyclical (nontrend) output and $P_t(v)$ is the price observed in market v and known in the other j ($j \neq v$) markets only with a one period lag. P_t is the average price level across v markets. The expectation of P_t formed by the agents of each local market v -- \bar{P}_t -- is based on past information equally shared in all markets, \bar{P}_{t-1} , and on their own market's currently observed price. The term $\epsilon_t^S(v)$ is a market specific, relative supply shift term. Finally, $\alpha^S(v)$ represents the market specific relative price elasticity of supply.

The discussion of the supply equation thus far has followed familiar terrain. The introduction of the aggregate supply "shock" term, U_t , has been suggested by several studies.^{3/} Their introduction of U_t presumes, however, that all v markets react identically and with unitary elasticity to a change in U_t . The more realistic assumption employed here is that there are differing response elasticities, the $\beta^S(v)$ s,

to a given supply "event". As demonstrated below, relaxing the assumption of identical cross-market responses to a supply "event" greatly enhances the model and yields a more general relative price solution than previous models.

In addition to allowing differing market responses to an aggregate supply change, we further generalize the model by assuming that U_t is comprised of an anticipated and unanticipated component. By definition, $U_t = U_{t-1} + u_t$ where U_{t-1} represents aggregate supply changes occurring last period and known to all markets in period t . Furthermore, the contemporaneous change, u_t , is defined as $u_t = \xi_t + \tilde{u}_t$ where ξ_t represents the anticipated aggregate supply event and \tilde{u}_t is the unanticipated aggregate supply event that affects the local market according to the elasticity $\beta^s(v)$.^{4/} Thus, markets not only respond differently to a given aggregate supply change, but some of the supply disturbances are anticipated by local agents.

The market demand equation is written in the form

$$(2) \ y_t^d(v) = -\alpha^d(v)[P_t(v) - \bar{P}_t] + (M_t - \bar{P}_t) + \epsilon_t^d(v)$$

where $\alpha^d(v) > 0$ and is the price elasticity of aggregate demand (assumed to be equal in all markets). Expected real money balances are $M_t - \bar{P}_t$, where $M_t = M_{t-1} + m_t$ and $m_t = g_t + \tilde{m}_t$. The change in nominal money balances, therefore, has expected (g_t) and unexpected (\tilde{m}_t) components. Market demand also has a random, market specific demand shock, $\epsilon_t^d(v)$.

The values for the relevant expected and unexpected variables in equations (1) and (2) are given by:

$$g_t = E(m_t | \omega_{t-1})$$

$$\xi_t = E(u_t | \omega_{t-1})$$

$$\tilde{m}_t \sim N(0, \sigma_m^2)$$

$$\tilde{u}_t \sim N(0, \sigma_u^2)$$

$$\epsilon_t(v) \equiv (\epsilon_t^d(v) - \epsilon_t^s(v)) \sim N(0, \sigma_\epsilon^2).$$

The equilibrium condition sets $y_t^s(v) = y_t^d(v)$.

Solving equations (1) and (2) for the market price results in:

$$(3) P_t(v) = (1 - \lambda(v)) \frac{EP_t}{V} + \lambda(v) [M_{t-1} + g_t + \tilde{m}_t - \beta(v) (U_{t-1} + \xi_t + \tilde{u}_t) + \epsilon_t(v)] \text{ where } \lambda(v) \equiv (\alpha^s(v) + \alpha^d(v))^{-1}.$$

The method of undetermined coefficients suggests the following reduced form equation for the average price level:

$$(4) P_t = \pi_1 M_{t-1} + \pi_2 g_t + \pi_3 \tilde{m}_t + \pi_4 U_{t-1} + \pi_5 \xi_t + \pi_6 \tilde{u}_t.$$

The π 's are reduced form coefficients whose exact values will be determined below. The expected price level is:

$$\frac{EP_t}{V} = \pi_1 \frac{M_{t-1}}{V} + \pi_2 g_t + \pi_3 \frac{E \tilde{m}_t}{V} + \pi_4 \frac{U_{t-1}}{V} + \pi_5 \xi_t + \pi_6 \frac{E \tilde{u}_t}{V}$$

which can be rewritten as:

$$(5) \frac{EP_t}{V} = \pi_1 \frac{M_{t-1}}{V} + \pi_2 g_t + \pi_3 (\frac{E \tilde{m}_t}{V} - g_t) + \pi_4 \frac{U_{t-1}}{V} + \pi_5 \xi_t + \pi_6 (\frac{E \tilde{u}_t}{V} - \xi_t).$$

The expectations in the above expression are posterior expectations assumed to be influenced by the past information set (ω_{t-1}) and by observed current prices in each market ($P_t(v)$):

$$\frac{EP_t}{V} \equiv E(P_t | \omega_{t-1}, P_t(v)),$$

$$(6) \quad \begin{aligned} E_V m_t &= E(m_t | \Omega_{t-1}, P_t(v)), \\ E_V u_t &= E(u_t | \Omega_{t-1}, P_t(v)). \end{aligned}$$

Using a projection theorem the posterior expectations of m_t and u_t are:^{5/}

$$(6a) \quad \begin{aligned} E_V m_t &= E(m_t | \Omega_{t-1}) + \phi_m (P_t(v) - E(P_t(v) | \Omega_{t-1})) \\ E_V u_t &= E(u_t | \Omega_{t-1}) + \phi_u (P_t(v) - E(P_t(v) | \Omega_{t-1})), \end{aligned}$$

where ϕ_m and ϕ_u are projection parameters. These expressions can be restated as:

$$E_V m_t = g_t + \frac{\sigma_m^2}{\sigma(v)^2} [\tilde{m}_t - \beta^S(v) \tilde{u}_t + \varepsilon_t(v)]$$

(6b)

$$E_V u_t = \xi_t + \frac{\sigma_u^2}{\sigma(v)^2} [\tilde{m}_t - \beta^S(v) \tilde{u}_t + \varepsilon_t(v)]$$

$$\text{where } \sigma(v)^2 = \sigma_m^2 + \sigma_\varepsilon^2 + (\beta^S(v))^2 \sigma_u^2$$

These equations show more explicitly the causes of the expectations of aggregate demand and supply events. The prior expectations (g_t and ξ_t) directly affect these posterior expectations. The effects of unanticipated aggregate and relative demand and supply shocks are revealed only by how they affect the market price. These unobserved shocks are translated into posterior expectations by weighting unexpected market price changes (which equal $\tilde{m}_t - \beta^S(v) \tilde{u}_t + \varepsilon_t(v)$ from equation

(3)) by a ratio of variances. For example, if σ_m^2 is large compared to

$\sigma_\varepsilon^2 + (\beta^S(v))^2 \sigma_u^2$, money has shown more variability than other

exogenous events in the past. Therefore, any unanticipated market price changes would be interpreted as "more of the same", i.e., as mostly an

increase in the aggregate money supply. If, on the other hand, σ_ε^2 has been very large historically, unexpected price changes would be attributed to local market shocks and little of the price increase will be converted into the expected supply and demand events, $E u_t$ and $E \tilde{m}_t$.

We can now substitute equations (6b) into (5) to arrive at the posterior expectation for the price level:

$$(7) \quad E P_t = \pi_1 M_{t-1} + \pi_2 g_t + \pi_4 U_{t-1} + \pi_5 \varepsilon_t + \left(\pi_3 \frac{\sigma_m^2}{\sigma^2(v)} + \pi_6 \frac{\sigma_u^2}{\sigma^2(v)} \right) (\tilde{m}_t - \beta^S(v) \tilde{u}_t + \varepsilon_t(v)) .$$

Substituting (7) into (3) yields:

$$(8) \quad P_t(v) = M_{t-1} [\pi_1(1 - \lambda(v)) + \lambda(v)] + g_t [\pi_2(1 - \lambda(v)) + \lambda(v)] \\ + U_{t-1} [\pi_4(1 - \lambda(v)) - \lambda(v) \beta^S(v)] + \varepsilon_t [\pi_5(1 - \lambda(v)) - g(v) \beta^S(v)] \\ + [\tilde{m}_t - \beta^S(v) \tilde{u}_t + \varepsilon_t(v)] (1 - \lambda(v)) \frac{\pi_3 \sigma_m^2 + \pi_6 \beta^S(v) \sigma_u^2}{\sigma^2(v)} + \lambda(v)$$

Averaging over the densities $\lambda(v)$, $\varepsilon_t(v)$, and $\beta^S(v)$ we arrive

at the average price level:

$$(9) \quad P_t = M_{t-1} [\pi_1(1 - \lambda) + \lambda] + g_t [\pi_2(1 - \lambda) + \lambda] \\ + U_{t-1} [\pi_4(1 - \lambda) - \lambda^\beta] + \varepsilon_t [\pi_5(1 - \lambda) - \lambda^\beta] \\ + \tilde{m}_t \left[\frac{\pi_3 \sigma_m^2 (V_1 - V)}{V_1 V} + \frac{\pi_6 \sigma_u^2 (V_2 - V_3)}{V_2 V_3} + \lambda \right] \\ - \tilde{u}_t \left[\frac{(\beta^S - \lambda^\beta) \pi_3 \sigma_m^2 (V_2 - V_3)}{V_2 V_3} + \frac{\pi_6 \sigma_u^2 (V_4 - V_5)}{V_4 V_5} + \lambda^\beta \right]$$

where

λ is the average over V markets of $\lambda(v)$

β^S	"	"	"	$\beta^S(v)$
$\lambda\beta$	"	"	"	$\lambda(v)\beta^S(v)$
V	"	"	"	$1/\sigma_v^2$
V_1	"	"	"	$\lambda(v)/\sigma^2(v)$
V_2	"	"	"	$\lambda(v)\beta(v)/\sigma^2(v)$
V_3	"	"	"	$\beta(v)/\sigma^2(v)$
V_4	"	"	"	$\lambda(v)(\beta(v))^2/\sigma^2(v)$
V_5	"	"	"	$(\beta(v))^2/\sigma^2(v)$

Equation (9) must equal equation (5). We use that fact to solve for the reduced form parameters (π 's):

$$\pi_1 = \pi_1 (1 - \lambda) + \lambda = 1.0$$

$$\pi_2 = \pi_2 (1 - \lambda) + \lambda = 1.0$$

$$\pi_3 = \frac{\lambda (1 - \sigma_m^2 K_1 (1 - K_3 \sigma_u^2) + K_3 \sigma_u^2)}{(1 - \sigma_m^2 K_1) (1 - \sigma_m^2 (K_1 - \sigma_u^2 (K_2^2 - K_1 K_3))) + K_3 \sigma_u^2}$$

$$\pi_4 = \pi_4 (1 - \lambda) - \lambda^\beta = -\lambda^\beta / \lambda$$

$$\pi_5 = \pi_5 (1 - \lambda) - \lambda^\beta = -\lambda^\beta / \lambda$$

$$\pi_6 = \frac{-\lambda \sigma_m^2 K_2}{1 - \sigma_m^2 (K_1 - \sigma_m^2 (K_2^2 - K_1 K_3)) + K_3 \sigma_u^2}$$

where $K_1 = \frac{V_1 - V}{V_1 V}$

$$K_2 = \frac{V_2 - V_3}{V_2 V_3}$$

$$K_3 = \frac{V_4 - V_5}{V_4 V_5}.$$

Substituting these π values into equations (8) and (9) and subtracting (9) from (8) yields the expression for the relative price in market (v):

$$\begin{aligned} (10) \quad P_t(v) - P_t &= \lambda(v) \left[\frac{\lambda^\beta}{\lambda} - \beta^S(v) \right] \left[U_{t-1} + \epsilon_t \right] \\ &+ \left[(\lambda(v) - \lambda) + (\pi_3 \sigma_m^2 + \pi_6 \beta^S(v) \sigma_u^2) \left(\frac{\sigma^2 (1 - \lambda(v)) - \sigma_v^2 (1 - \lambda)}{\sigma^2(v) \sigma^2} \right) \right] \tilde{m}_t \\ &+ \left[(\beta^S(v) \lambda(v) - \lambda^\beta) + (\pi_3 \sigma_m^2 + \pi_6 \beta^S(v) \sigma_u^2) \right. \\ &\quad \left. \frac{(\sigma^2 \beta^S(v) (1 - \lambda(v)) - \sigma_v^2 (\beta^S - \lambda^\beta))}{\sigma_v^2 \sigma^2} \right] \tilde{u}_t \\ &+ \left[(1 - \lambda(v)) \left(\frac{\pi_3 \sigma_m^2 + \pi_6 \beta^S(v) \sigma_u^2}{\sigma^2(v)} \right) + \lambda(v) \right] \epsilon_t(v). \end{aligned}$$

Equation (10) specifies that all anticipated and unanticipated supply events and unanticipated demand events cause individual market prices to diverge from the average price level. Notice, however, the crucial role played by differential supply shock elasticities. If we assume like earlier studies that the supply event elasticity in each market is equal to unity, $\beta^S(v) = \beta^S = 1.0$, then the term $\lambda(v) \left[\frac{\lambda^\beta}{\lambda} - \beta^S(v) \right]$ equals $\lambda(v) \left[\frac{\lambda}{\lambda} - 1 \right] = 0$. Here we see that with identical market supply event elasticities, an assumption used in previous analyses, relative prices are determined only by "relative" ($\epsilon_t(v)$) and aggregate (\tilde{m}_t, \tilde{u}_t) demand and supply impulses. These simplifying yet restrictive assumptions put us back into the models of CW, Froyen and Waud, and

Hercowitz. A test of the importance of the different supply elasticities investigates the importance of anticipated versus unanticipated supply events in the relative price equation.

It would be interesting to directly test the relevance of equation (10) across markets. Defining such individual markets and then finding data for market specific supply and demand shocks, however, is well beyond the scope of this paper. Instead, we sum across markets to get a measure of aggregate relative price variability, V_t , where,

$$(11) \quad V_t = \sum_{v=1}^n P_t(v) - P_t.$$

Applying this summation to equation (10) yields the simplified expression

$$(12) \quad V_t = V_t (V_t^e, V_t^u, V_t^m, V_t^s, C)$$

where the V^i ($i=e, u, m, s$) refer to variances of unanticipated aggregated relative supply and demand variables, unexpected aggregate demand and supply variables, and the expected supply variable, respectively. The individual coefficients relating these V_t^i s to V_t are complex expressions comprised of the weighted averages of the parameters of the model.^{6/} The model's intuition suggests a positive relationship between V_t and any of the V^i s. That is, unanticipated supply and demand events as well as anticipated supply events cause greater relative price dispersion. The particular way of defining relative price dispersion, equation (11), further implies that increases in the variance (squared values for zero mean variables) of each V^i causes an increase in V_t .^{7/} The C term in equation (12) is a composite for all the covariances among the demand and supply events mentioned above.

The difference between relative and aggregate effects may be confusing in equation (12). For example, V^E is a variance term representing the aggregation of relative excess demand shocks.

The term V^M is the variance of aggregate demand shocks. Hercowitz (1981b) finds a proxy for V^M but in his empirical work subsumes the counterpart of V^E into the estimated constant term. While a strong theoretical distinction between V^E and V^M exists, there is less empirical difference since both are aggregate entities. In fact, if we have no direct measures of relative demand and supply disturbances for the various markets, we have no empirical proxy for V^E . If these variances are constant, then they will be part of the constant term. If not, they belong in the error term and could be a source of autocorrelation problems. We refer to this problem more in the next section where we estimate equation (12).

IV. DATA

This section presents an overview of the basic data used to test the validity of equation (12). The relative price dispersion measure (V) is constructed using quarterly average data on the personal consumption expenditures index (PCE) for the period I/1960 to IV/1981. The PCE index is used for several reasons: First, the consumer price index (CPI) may incorrectly state the nature of inflation during certain times due to its questionable weighting of certain components.^{8/} Second, the PCE represents a final goods' price which more closely matches the spirit of the theoretical model than, say, a measure such as the wholesale price index (WPI).^{9/} Finally, the fixed weight version of the PCE index is

used, because we are concerned with the effects of demand and supply events on relative price behavior and, therefore, a measure of price dispersion that represents only price movements is needed. Consequently, a fixed weight index is used to remove the unwanted impact of quantity changes on the index that would occur if a variable weight index was used.

The calculation of the quarterly price dispersion measure is done in the following manner: First, the rate-of-change in the overall PCE index is subtracted from each of its components' inflation rates. Then the absolute value of each component's difference from the overall measure is multiplied by its respective weight. Summing across the components thus gives the relative price measure for that quarter. This process is repeated for each quarter to derive our time series of relative price dispersion.

The eighteen components that comprise the PCE index used to generate the price dispersion series are listed in Appendix I along with their respective weights. Each component is viewed explicitly as a separate market in keeping with our theoretical model. Although a larger number of subgroups would be preferable, the disparity in price movements represented by our measure is adequate. And, to repeat, the fixed weight nature of our measure lends itself much better to discovering the effect of demand and supply changes on prices than do the variable weight indexes used in some previous studies.

Before going on to the empirical results, a final word about the data is in order. The theoretical model seeks to explain cyclical variability. Consequently, all variables found in the following expressions have been appropriately detrended for each sample period:

once for the full sample period (1960/I to 1981/IV), and once each for the subperiods (1960/I to 1969/IV and 1970/I to 1981/IV). The procedure used to generate the relevant anticipated and unanticipated series from the already detrended ones is similar to that used in Froyen and Waud (1982). For each time period in question an autoregressive model was fitted to the detrended series. The best autoregressive representation was determined by testing the significance of sequentially extending the number of lags for each sample period. Once the best fitting model was found, the predicted values of each variable were taken to be measures of "expected" events.^{10/} "Unexpected" events were measured as the difference between predicted and actual movements.

V. EMPIRICAL RESULTS

The outcome of empirically testing the hypothesis that expected and unexpected supply events have a predictable influence on relative price behavior is reported in this section. The empirical tests use quarterly data from 1960 to 1981, a period characterized by relatively minor economic fluctuations (the 1960s) and significant turbulence among economic variables (the 1970s). The previous section described the derivation of the relative price dispersion term. The right-hand-side variables included in the estimated equations are demand and supply variables. The demand variable used in our tests is the growth rate of the money supply. Preliminary testing revealed that other demand variables, such as nominal GNP, yielded similar qualitative conclusions but quantitatively did not perform as well as money. In addition, it may be argued that a measure such as GNP confounds demand and supply responses to a given shock.^{11/}

Measuring the supply impulse variable is more problematic since this variable should ideally measure only supply changes. Thus, measures such as real GNP do not clarify the origin of events and may confuse supply and demand changes. We have chosen to use two quite different measures for supply changes. The first is the relative price of energy. The relative price of energy is an important factor of production since changes in energy prices affect the unit costs of output. Furthermore, evidence exists showing that the increases in the relative price of energy during the mid-1970s led to a curtailment of capital formation and an effective absence of some of the existing capital stock.^{12/} Thus, expected and unexpected changes in the relative price of energy are used as measures to capture supply events.

One possible argument against using the relative price of energy as a supply measure is that energy prices are a component of the PCE index and therefore of V : changes in one component used to explain contemporaneous changes in the overall index may unfairly favor rejection of the null hypothesis. To circumvent this criticism, potential output also is tried as the supply variable. Potential output is useful in this context since it does not confound demand and supply events. Rather, potential output, by construction, captures the level of supply prevailing at full unemployment. Thus, deviations of full employment output may be viewed as supply dislocations which potentially affect the dispersion of relative prices.^{13/}

The empirical tests involve the estimation of equation (12) using the different supply measures over the different time periods. To reiterate, the contention of our theoretical model is that both

anticipated and unanticipated aggregate supply events affect relative price dispersion. Separating these effects, if our hypothesis is correct, should improve upon the model that combines them.

Estimates of the model for the periods I/1960 - IV/1969 and I/1970 - IV/1981 are presented in table 1.^{14/} All equations are estimated using a first-order GLS autocorrelation correction procedure.^{15/} The results for the 1960s admittedly are disappointing for the model. Only one of the demand and supply variables--the interaction term between unanticipated demand and supply--achieves statistical significance at any reasonable level. The general lack of explanatory power is indicated by the low adjusted R^2 reported for each specification. These results suggest that during this period the variance of relative prices merely fluctuated about some mean value, as indicated by the significance of the constant term. Indeed, this suspicion is borne out by examining a plot (not shown) of the dependent variable during this period: it shows little variation and hovers around a constant value. Finally, the estimated coefficients on unanticipated demand are negative, a result that conflicts with a priori expectations. In each case, however, they are not significantly different from zero.

The results for the 1970's are more supportive of the model. Turning first to the results using the relative price of energy as the supply measure, over 75 percent of the movement in the variance of relative prices has been captured by the independent variables. Both anticipated and unanticipated supply events are statistically significant at the 10 percent and 5 percent levels, respectively. Unanticipated demand is not significant, however, with a t-statistic of 1.2. Moreover,

the covariance term between unanticipated demand and anticipated supply achieves significance at the 1 percent level.

The outcome using potential output as the supply measure is noticeably weaker than the model using the relative energy price variable: this model explains only 24 percent of relative price dispersion. In this estimation, however, only the unanticipated supply variable is statistically significant, with a t-statistic of 2.00. In addition, the constant and both covariance terms are significant at the 5 percent level. It is interesting to note the switch in signs on the covariance terms relative to the results based on using the relative price of energy as the supply measure. The negative sign on DUSA using potential output agrees with the positive sign using energy prices because a rise in energy prices is equivalent to a reduction in supply as measured by potential output.

A stronger test of this paper's hypothesis comes from comparing the explanatory power of the equations reported in table 1 to those in which anticipated and unanticipated supply effects are not separated. Such equations are reported in table 2. Both tables agree that the model explains very little of the movements in relative price dispersion during the 1960s. During the 1970s the equations (especially the energy price variant) achieve a high degree of explanatory power. There are several aspects of these results worth noting: First, with regard to the equation using the relative price of energy, the supply variable(S) significantly influences the dispersion of relative prices. Second, both the anticipated and unanticipated supply variables, SA and SU, significantly affect relative prices. Dichotomizing supply into its

anticipated (SA) and unanticipated (SU) components instead of using the actual measure(S) reduces the standard error of the equation by about 12 percent, from 20.002 to 17.707. An F-test is used to determine the significance of the breakdown (reported in Table 3) and shows that dictotomizing supply effects with the energy price measure during the 1970's sample period is warranted. It is also worth noting that this separation reduces the significance of the theoretically perverse sign on the unanticipated demand variable (DU) in table 2. The statistic falls from -2.39 to -1.20 when the energy price variable is split into its components.

Third, the covariance of unanticipated demand and anticipated supply (DUSA) plays an important role as evidenced by the large statistic (4.26) in the energy price model. The positive sign suggests that the coincident effect of high anticipated energy prices coupled with a positive demand shock is more relative price dispersion.

Finally, the model using potential output as the supply proxy largely confirms the energy price model, though the results are weaker. For the I/1970-IV/1981 period, the unanticipated supply shock and the DUSA covariance agree with the indications of the energy model. While this agreement exists and is favorable to the acceptance of the model, the equation fits more poorly and neither DU or SA are significant. Furthermore, there is little advantage in using SA and SU in place of S.

VI. THE LAGGED MODEL

Recall that the aggregate supply variable is defined as

$$U_t = U_{t-1} + u_t, \text{ where } u_t = \varepsilon_t + \tilde{u}_t.$$

This specifies that changes in supply events are distributed randomly around some expected rate. One specific testable formulation would specify current supply effects as comprised of an unexpected current shock plus a momentum term, λ_t , assumed to be related to the carryover effects of past shocks. Indeed, such a model would seem appropriate for the energy price measure of supply, given the known autocorrelation of this series.

Under this interpretation, $U_t = \lambda_t + \tilde{u}_t$, where $\lambda_t = f_0 + f_1 \tilde{u}_{t-1} + f_2 \tilde{u}_{t-2} + \dots + f_n \tilde{u}_{t-n}$.

This respecification does not alter the theoretical conclusions of the model, but it does alter the estimated equation in one important way:

V_t^ξ is replaced by a distributed lag on V_t^u .^{16/} With this change we rewrite equation (12) as:

$$(13) \quad V_t = V_t(V^e, V^m, \sum_{n=0}^N V_{t-n}^u, C_t).$$

This interpretation of the model is admittedly ad hoc, but seems appropriate for the energy price series. To empirically test equation (13), the equations using the energy price measure of supply changes were reestimated. The estimated equation now consists of a contemporaneous term on unanticipated demand and current and lagged unanticipated supply terms. Note that in this model the anticipated supply term is omitted, but is assumed to be represented in the lag structure.

The results of estimating equation (13) for the two periods are presented in table 4.^{17/} The choice of lag length on the unanticipated supply variable was made on the criterion of minimizing the standard

error of the equation. These results confirm the model's inability to explain relative price dispersion during the 1960s. The adjusted R^2 is very small and only the constant term is significant. The results from the 1970s tell quite a different story: three out of five of the estimated coefficients on the unanticipated supply terms are statistically significant at the 5 percent level. Moreover, the unanticipated demand variable has the expected sign and is close to significance at the 5 percent level. The adjusted R^2 indicates that this model captures 75 percent of the variation in the dispersion of relative prices during the 1970s.

It is interesting to compare the results for the equations in table 4 to their counterparts in table 1. Here we see that on the basis of overall fit, the contemporaneous model and the lagged model are almost equivalent. This outcome should not be surprising, given the theoretical derivation of equation (13). In fact, this finding reinforces the notion that the contemporaneous expected supply measure is influenced by lagged values of unanticipated supply terms. The closeness of fit between these two models indicates that this may well be the case during the 1970s.

The pattern of the effects of unanticipated supply (SU) over time is interesting. The major positive effect ends within two quarters and is significantly negative after four quarters. Unanticipated energy prices disperse relative prices with a short lag, but the effect is not permanent. This outcome suggests that observed changes in a price index may be the result of transitory changes in one component.

Consider an alternative rationale, with perhaps more theoretical intuition, for the lagged model. It is commonplace in macro texts to posit a lagged effect of output change upon aggregate supply. For

example, if current output expansion raises unit costs that are then passed through to prices over the two periods, then aggregate supply would be affected in both periods. Sargent recognizes this persistence effect by explicitly adding lagged output into the supply equation.^{18/}

One way to adapt this idea to the present model is to assume that past output affects current elements in the production process. If $u_t = \tilde{\lambda}_t + u_t$,

where λ_t is a momentum term, i.e., $\lambda_t = f_0 + f_1 \sum y_{t-i}$, then

$$u_t = f_0 + f_1 \sum y_{t-1} + \tilde{u}_t.$$

If the y_{t-i} are influenced largely by past relative price changes, then

$$u_t = f_0 + f_1 \sum (P_{t-i}(v) - P_{t-i}) + \tilde{u}_t.$$

This specification suggests that past relative price change and contemporaneous unanticipated aggregate supply shocks affect output each period. Substituting, the solution for relative prices found in equation (12) into the expression above implies the more general lagged model:

$$(14) \quad V_t = V_t \left(\sum_{i=0}^N \tilde{V}_{t-i}^c, \sum_{i=0}^N \tilde{V}_{t-i}^m, \sum_{i=0}^N \tilde{V}_{t-i}^u, \sum_{i=0}^N C_{t-i} \right).$$

The generality of equation (14) suggests that its empirical version can be identified by adding lagged unanticipated demand terms to the specification that included lagged unanticipated supply terms.

This version of the lagged model, which highlights the role of more general persistent cost factors, seems more appropriate for the potential output version. Table 5 presents the results of the fully lagged potential output model. Here both unanticipated supply and demand shocks are lagged for four quarters and one or two quarters, respectively. These lag lengths produced the lowest standard errors.

In agreement with earlier results, the model only fits well in the 1970-81 sample period. For that period, we get a very noticeable improvement in this lagged model compared to the results of the contemporaneous model (table 1). The contemporaneous and once lagged unanticipated supply variables are statistically significant as are the two interaction terms; DUSU and DUSU1. These results indicate that when past or present aggregate supply shocks (negative supply effects) are combined with positive aggregate demand shocks, increased price dispersion results. Although none of the lagged demand shocks are statistically significant, the overall equation is far superior to its contemporaneous counterpart: adding the lags more than doubles the adjusted R^2 and reduces the standard error from 29.354 to 24.686, a 16 percent drop.

VII. CONCLUSION

Our purpose in this paper was twofold: First, we presented a model of relative price determination that is generalized from previous theoretical constructs presented by Lucas, Barro, Cukierman and Wachtel, and Hercowitz. The distinguishing feature of the theoretical model presented in this paper is that it introduces anticipated supply "events" into the supply function. While this change may seem obvious in light of recent economic developments, previous theoretical specifications of relative price changes have included only actual or unanticipated supply events. Moreover, we relax the assumption used in previous discussions that there exists uniform supply elasticities across all markets. These changes yield a model where both anticipated and unanticipated supply events affect the dispersion of relative prices in the economy. This

suggests that, even though supply changes may be fully anticipated by economic agents, they will affect the dispersion of prices. This was undoubtedly true during the periods of dramatic supply dislocations that occurred during the mid-1970s.

Second, we have tried to empirically capture the essence of the theoretical model by using quarterly data for the U.S. over the period 1960 to 1981. In general, our empirical results support the usefulness of differentiating between anticipated and unanticipated supply changes. The empirical results are, not surprisingly, much stronger for the 1970s than for the 1960s. Moreover, the results are superior when the proxy measure for supply events is the relative price of energy.

Extensions of the basic contemporaneous model were tested. Focusing on the 1970s, the outcome suggests that lagged unanticipated supply events, proxies for the contemporaneous anticipated supply event, have significant effects upon the dispersion of relative prices. In fact, our empirical results using the lagged model suggest that the impact of past supply changes peak and then diminish within only a few quarters. This finding has important policy implications since large, supply-induced price changes may be self-correcting within a relatively short period of time. Furthermore, given the significant role of anticipated supply events, there may be less impact of the manifested relative price variability upon current output. Using aggregate demand policies to quickly offset or reverse observed aggregate price change is not, therefore, the most appropriate remedy. Furthermore, the continued and unpredictable use of such policies may lead to even more relative price dispersion. In this sense, counter-cyclical policies increase the noise to signal ratio in observed prices. Indeed, our results, both

theoretical and empirical, affirm the position that policy, especially monetary policy, can be used as a tool for short-term fine tuning of the economy only at great risk.

FOOTNOTES

1/ Barro (1976) and Froyen and Waud (1982) do include an aggregate anticipated supply event in their models. In these models the elasticity of this supply event is unity. Anticipated supply changes do not affect relative prices but would affect the general price level.

2/ This is simply because all supply events are not completely unanticipated. A correct specification of true supply shocks would purge, or at least attempt to purge, any predictable component of the measured supply event. We discuss this point further below.

3/ See Barro (1976), Froyen and Waud (1982), and Hercowitz (1982).

4/ This type of assumption concerning the make-up of the supply change can also be found in Cukierman and Wachtel (1979) and Cukierman (1982). In these models, however, the assumption of equal response elasticities across the v markets is maintained.

5/ See Sargent (1979) p.327 for an explanation of the use of recursive projections.

6/ The reader can easily verify that the exact form of equation (12) will include a large number of complex terms that add little to the presentation in the text. Thus, in the interest of brevity, we have omitted that exact form of equation (12).

7/ See also, Cukierman (1982) for a similar finding.

8/ See Blinder (1980) for a discussion of this point.

9/ Hercowitz (1981b) uses a variable-weight version of the WPI.

10/ Similar techniques are used often to distinguish between permanent and transitory changes. For an interesting application of these concepts to business cycle theory, see Brunner, Cukierman and Meltzer (1980).

11/ The consistent finding in studies using the so-called St. Louis equation that the cumulative impact of money growth on nominal GNP growth equals unity is support for our assumption. Furthermore, in the models of Barro (1976) and Hercowitz (1981a, b), market demand equations are specified in terms of money.

12/ See, for example, Tatom (1981).

13/ We fully recognize the fact that if supply events affect current output differently than they affect potential output, then even our potential output proxy is imperfect. Such imperfection, unfortunately, afflicts any measure used in this capacity. Furthermore, one may argue that there are other ways to measure potential output which are not identical to the series used here. Our use of the potential series is not to be viewed as the final word, but as an experiment with what we believe is a viable proxy.

14/ For the sake of brevity we do not report the results for the full 1960/I - 1981/IV period. This decision is based on the finding that 1) the full period results are dominated by those for the 1970s and 2) statistical tests indicate that the two subperiods come from different populations.

15/ The necessity of the autocorrelation correction may indicate that the variances of the relative demand and supply disturbances (V^e) in equation (12) are not constant as assumed. This problem, then, is one of misspecification, i.e., omitting the aggregated relative disturbance terms. Because no measures for these variables exist, it appears that the procedure adopted is the second-best alternative available. For a similar problem in estimation of the theoretical model, see Hercowitz (1981b).

16/ In the original approach, an instrument for the variance of expected supply events is generated by regressing current supply changes on past ones. The instrument therefore internalizes past supply changes. In equation (13) the variance of the current and lagged unanticipated supply changes are directly included. Consequently, although both approaches use past supply changes, they do offer different theories about the way these changes affect relative price dispersion. This second approach emphasizes the timing of the effects of unanticipated supply changes.

17/ Note that the number of covariance terms has been restricted to conserve on the degrees of freedom. Moreover, additional terms are of little importance in assessing the success of the theoretical model.

18/ Sargent (1979), p. 326.

APPENDIX I
Components of the PCE Index

<u>Category</u>	<u>Weight</u>
Motor Vehicles	0.052
Furniture	0.045
Other Durables	0.017
Food	0.261
Clothing	0.082
Gas and Oil	0.031
Fuel Oil and Coal	0.012
Other Nondurables	0.081
Housing Services	0.137
Housing Operations	0.060
Transportation Services	0.037
Personal Care Services	0.019
Medical Services	0.058
Personal Business Services	0.054
Education and Research	0.022
Recreation Services	0.013
Religious and Welfare	0.015
Net Foreign Travel	0.003

Table 1
Contemporaneous Model
Dichotomized Supply Effects: Anticipated (SA) and Unanticipated (SU) Supply

Variable ^{1/}	I/1960-IV/1969		I/1970-IV/1981	
	Energy Price	Potential Y	Energy Price	Potential Y
Constant	4.31 (6.05)	4.85 (5.82)	25.95 (2.32)	25.09 (2.49)
DU	-0.127 (1.53)	-0.037 (0.35)	-0.219 (1.20)	0.287 (0.46)
SA	0.759 (0.45)	-20.570 (0.61)	0.014 (1.90)	3.104 (0.19)
SU	0.021 (1.52)	-0.037 (0.19)	0.042 (6.48)	3.171 (2.00)
DUSA	0.381 (0.60)	1.800 (0.62)	0.547 (4.26)	-8.055 (2.58)
DUSU	-0.127 (2.21)	0.168 (0.74)	0.156 (1.34)	-3.629 (2.38)
\bar{R}^2	0.038	-0.080	0.759	0.235
SE	2.717	2.880	17.707	29.354
DW	1.94	1.94	1.89	1.94
$\hat{\rho}$	0.19	0.12	0.78	0.49

^{1/} DU represents unanticipated demand; DUSA and DUSU are covariance terms between unanticipated demand and anticipated and unanticipated supply, respectively. \bar{R}^2 is the adjusted coefficient of determination, SE the standard error of the regression, DW the Durbin-Watson statistic and $\hat{\rho}$ is the estimated first-order serial correlation coefficient. Absolute value of t-statistics appear in parentheses.

Table 2
Contemporaneous Model

Variable ^{1/}	I/1960-IV/1969		I/1970-IV/1981	
	Energy Price	Potential Y	Energy Price	Potential Y
Constant	4.45 (7.07)	4.71 (6.57)	28.79 (2.78)	23.31 (2.60)
DU	-0.133 (1.62)	-0.080 (0.93)	-0.438 (2.39)	0.743 (1.30)
S	.021 (1.45)	-0.036 (0.20)	0.028 (5.38)	2.971 (1.79)
DUS	-0.116 (2.16)	0.144 (0.64)	0.419 (4.27)	-4.756 (3.09)
\bar{R}^2	0.063	-0.054	0.680	0.202
SE	2.683	2.844	20.002	29.902
DW	1.94	1.96	2.24	2.06
$\hat{\rho}$	0.20	0.13	0.72	0.47

^{1/} DUS is the covariance between unanticipated demand and actual supply. See footnote to table 1 for other definitions.

Table 3

Calculated
F-statistics^{1/}

1960-1969:

Energy Price 0.66

Potential Output 0.65

1970-1981:

Energy Price 7.68*

Potential Output 2.05

^{1/} Critical F-values: 1% = 5.11; 5% = 3.21; and 10% = 2.42.

Table 4
Lagged Model: Energy Prices

Variable ^{1/}	I/1960-IV/1969	I/1970-IV/1981
Constant	3.95 (4.69)	24.62 (2.52)
DU	-0.112 (1.30)	0.581 (1.92)
SU	0.015 (1.02)	0.044 (6.40)
SU1	0.031 (1.68)	0.034 (3.05)
SU2	0.006 (0.46)	-0.011 (1.39)
SU3	0.010 (0.72)	0.001 (0.06)
SU4	-0.009 (0.62)	-0.017 (2.17)
DUSU	-0.092 (1.54)	0.128 (1.04)
DUSU1	0.127 (1.76)	0.849 (4.41)
\bar{R}^2	0.060	0.746
SE	2.686	17.841
DW	1.93	2.06
$\hat{\rho}$	0.13	0.73

^{1/} SU_i (i= D,1,2,3,4) refers to contemporaneous and lagged actual supply measures. See footnotes to table 1 for other definitions.

Table 5
Lagged Model: Potential Output

Variable ^{1/}	I/1960-IV/1969	I/1970-IV/1981
Constant	4.63 (3.39)	13.85 (0.84)
DU	-0.028 (0.25)	0.066 (0.12)
DU1	0.070 (0.86)	-0.776 (1.11)
DU2	0.151 (1.99)	
SU	-0.052 (0.20)	4.876 (3.08)
SU1	-0.211 (0.92)	4.513 (2.37)
SU2	-0.176 (0.82)	0.951 (1.64)
SU3	-0.140 (0.65)	2.675 (1.64)
SU4	-0.036 (0.17)	0.202 (0.12)
DUSU	0.144 (0.56)	-4.397 (3.40)
DU1SU1	0.104 (0.55)	0.507 (0.40)
DUSU1	0.011 (0.05)	-4.929 (3.88)
DU1SU	0.047 (0.24)	3.020 (2.24)
\bar{R}^2	-0.131	0.505
SE	2.958	24.686
DW	1.96	1.88
$\hat{\rho}$	0.06	0.70

^{1/} DU_i (i = 0,1,2) and SU_i (i = 0,...,4) refer to lagged values of unanticipated demand and supply. Contemporaneous and one-lagged values of covariance terms are given by DUSU, DU1SU1, DUSU1 and DU1SU terms. See footnote to table 1 for other definitions.

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