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RELATIVE PRICE VARIABILITY:  
EVIDENCE FROM SUPPLY AND DEMAND EVENTS

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## Relative Price Variability: Evidence from Supply and Demand Events

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. Stemming from the original models of Lucas (1972, 1973) and Barro (1976) as modified by Cukierman and Wachtel (1979) and Hercowitz (1981, 1982), the role of unanticipated supply (natural or nonpolicy) events and unanticipated demand (generally monetary policy) shocks has been emphasized in causing changes in relative prices. This previous work, which has specified a role for aggregate supply shocks in individual market supply functions, 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 tests the additional importance of anticipated supply events on observed changes in relative price dispersion. Incorporation 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' price changes may 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 also can cause relative price dispersion.

The format of the paper is as follows. An overview of previous models is presented 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 where lagged effects are allowed to influence relative price dispersion. Section VII closes the paper with concluding remarks.

## II. THE MARKET SETTING

Lucas and Barro each formulate rational expectations models that explicitly formalize the role of information disparity. 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 extension allows the variance of relative prices to be related to the variance of the general price level--both being endogenous variables related to exogenous impulse variables. In the CW world individual producers cannot distinguish aggregate from relative price change. They observe changes in their own individual market price but do not know with certainty if these changes 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.

Hercowitz (1981, 1982) extends the model further by incorporating aggregate supply shocks and by allowing each market to have 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, and all supply effects are unanticipated.

Froyen and Waud (1982) derive supply functions for individual markets in the CW setting demonstrating that anticipated and unanticipated supply events, 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 on the output effects of supply changes.

In 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.<sup>1/</sup> 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.<sup>2/</sup> In the model presented below, these assumptions are relaxed.

### III. THE MODEL

Our model is a generalization of Hercowitz's. We assume that there are an infinite number of individual commodities with 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 markets  $(v=1, \dots, n)$  the  $v^{\text{th}}$  market supply equation is (all variables are expressed in logarithms)

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

where  $y_t$  is cyclical (nontrend) output,  $P_t(v)$  is the price observed in market  $v$  and known in the other  $j$  ( $j \neq v$ ) markets only with a one period lag, and  $P_t$  is the average price level across  $v$  markets.

The expectation of  $P_t$  formed by the agents of each market

$(\bar{E}P_t)$  is based on past information equally shared in all markets,

$P_{t-1}$ , and on their own market's currently observed price. The term

$\epsilon_t^s(v)$  is a market specific, relative supply shift term. The parameter

$\alpha^s(v)$  represents the market specific relative price elasticity of supply.

The introduction of the aggregate supply "shock" term,  $U_t$ , has been suggested elsewhere.<sup>3/</sup> The introduction of  $U_t$  in previous studies presumes, however, that all  $v$  markets react identically and with unitary elasticity to a change in  $U_t$ . The more realistic assumption introduced here is that there are market specific response elasticities, the  $\beta^s(v)$ s, to a given aggregate supply "event". Relaxing the assumption of identical, cross-market responses to an aggregate supply "event" greatly enhances the realism of the model and yields a more general relative price solution.

We further generalize the model by assuming that  $U_t$  is comprised of an anticipated and an unanticipated component. Thus, 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  $\xi_t$  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  $\beta^s(v)$ .<sup>4/</sup> In this world, 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 familiar form

$$(2) y_t^d(v) = -\alpha^d(v)[P_t(v) - \frac{EP_t}{V_t}] + (M_t - \frac{EP_t}{V_t}) + \epsilon_t^d(v)$$

where  $\alpha^d(v) > 0$  is the price elasticity of aggregate demand (assumed to be equal in all markets). Expected real money balances are

$M_t - \frac{EP_t}{V_t}$ , 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 represented by the term  $\epsilon_t^d(v)$ .

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

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

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

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

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



and

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

The outcome of solving this model for each market's relative prices is<sup>5/</sup>

$$(3) \quad P_t(v) - P_t = -\delta_1 (U_{t-1} + \xi_t) + \delta_2 \tilde{m}_t \\ - \delta_3 \tilde{u}_t + \delta_4 \epsilon_t(v)$$

where the  $\delta_i$  ( $i = 1, 2, 3, 4$ ) are defined in Appendix B. Equation (3) specifies that all anticipated and unanticipated aggregate supply events, unanticipated aggregate demand events and market specific demand and supply events cause individual market prices to diverge from the average price level. If we follow CW, Froyen and Waud, and Hercowitz and assume that supply elasticities are identical across markets, the  $\delta_1$  term equals zero and the anticipated aggregate supply event  $(U_{t-1} + \xi_t)$  disappears from the right-hand-side of equation (3).<sup>6/</sup> Thus, a test of the importance of the different supply elasticities assumption investigates the role of these anticipated aggregate supply factors in the relative price equation. Such a test is the central focus of this paper.

It would be interesting to directly test equation (3) across markets. Defining individual markets and finding data for market specific supply and demand shocks, however, is well beyond the scope of this paper. Instead, we sum squared values across markets to get a measure of aggregate relative price variability,  $S_t$ , where,

$$(4) \quad S_t = \sum_{v=1}^n (P_t(v) - P_t)^2.$$

Applying this summation to equation (3) suggests the simplified

$$(5) \quad S_t = S_t (S_t^\epsilon, S_t^u, S_t^m, S_t^\xi, C)$$

expression where the  $S^i$  ( $i = \epsilon, u, m, \xi$ ) refer to variances of unanticipated aggregated relative supply and demand variables, unexpected aggregate demand and supply variables, and the expected supply variable, respectively.<sup>7/</sup> Intuition suggests a positive relationship between  $S_t$  and any of the  $S^i$ s. That is, unanticipated supply and demand events as well as anticipated supply events create greater relative price dispersion. The particular way of defining relative price dispersion, equation (4), further implies that increases in the variance (squared values for zero mean variables) of each  $S^i$  causes an increase in  $S_t$ .<sup>8/</sup> The C term in equation (5) is a composite for all the covariances among the demand and supply events mentioned above.

Because the complete specification of (5) is complex, the hypothesized positive relationship between  $S_t$  and the  $S^i$ s in equation (5) is better illustrated using a simplified version of the model.

For illustrative purposes, assume that the only random variable is  $\tilde{m}_t$  and that no anticipated aggregate supply shocks exist; that is,

$$u_{t-1} + \xi_t = 0,$$

$$\tilde{u}_t = 0, \text{ and}$$

$$\sigma_u^2 = 0.$$

Using these assumptions, equation (3) can be written as

$$(3a) \quad P_t(v) - P_t = \tilde{m}_t \left[ \pi_3' \sigma_m^2 \left( \frac{1 - \lambda(v)}{\sigma_m^2 + \sigma_\epsilon^2} - v_1 \right) + (\lambda(v) - \lambda) \right] \\ + \epsilon_t(v) \left[ (1 - \lambda(v)) \left( \frac{\pi_3' \sigma_m^2}{\sigma_m^2 + \sigma_\epsilon^2} \right) + \lambda(v) \right]$$

where

$$\pi_3' = \lambda \sigma_m^2 V_1 / (\sigma_m^2)^2 V_1^2 - 2 \sigma_m^2 V_1 + 1 ,$$

$$\lambda(v) = 1 / \alpha^s(v) + \alpha^d(v) ,$$

$$\lambda = \frac{1}{n} \sum_{v=1}^n \lambda(v) ,$$

$$V_1 = \frac{1}{n} \sum_{v=1}^n (1 - \lambda(v)) / \sigma^2(v) , \text{ and}$$

$$\sigma_v^2 = \sigma_m^2 + \sigma_\epsilon^2 .$$

Squaring equation (3a) yields the aggregate measure of relative price variability

$$(4a) \quad (P_t(v) - P_t)^2 = \tilde{m}_t^2 [\cdot]^2 + \epsilon_t(v)^2 [\cdot\cdot]^2 \\ + 2 \tilde{m}_t \epsilon_t(v) [\cdot] [\cdot\cdot]$$

$$\text{where } [\cdot] = \pi_3' \sigma_m^2 \left[ \frac{1 - \lambda(v)}{\sigma_m^2 + \sigma_\epsilon^2} - V_1 \right] + (\lambda(v) - \lambda) ,$$

$$[\cdot]^2 = \pi_3'^2 (\sigma_m^2)^2 \left[ \frac{1 - \lambda(v)}{\sigma_m^2 + \sigma_\epsilon^2} - V_1 \right]^2 + (\lambda(v) - \lambda)^2 \\ + 2 \left[ \pi_3' \sigma_m^2 \left( \frac{1 - \lambda(v)}{\sigma_m^2 + \sigma_\epsilon^2} - V_1 \right) + (\lambda(v) - \lambda) \right] ,$$

$$[\cdot\cdot] = (1 - \lambda(v)) \left[ \frac{(\pi_3')^2 \sigma_m^2}{\sigma_m^2 + \sigma_\epsilon^2} \right] + \lambda(v) ,$$

and

$$[\cdot\cdot]^2 = (1 - \lambda(v))^2 \left[ \frac{\pi_3'^2 \sigma_m^2}{\sigma_m^2 + \sigma_\epsilon^2} \right]^2 + \lambda(v)^2 \\ + 2 \left[ (1 - \lambda(v)) \left( \pi_3' \sigma_m^2 / (\sigma_m^2 + \sigma_\epsilon^2) \right) + \lambda(v) \right] .$$

Note that  $\tilde{m}_t^2$  is merely  $S_t^m(v)$ . The effect on the  $v^{\text{th}}$  market of a rise in  $S_t^m(v)$  on its relative price squared is given by the expression

$$\frac{\partial \left( P_t(v) - P_t \right)^2}{\partial \left( S_t^m(v) \right)} = [\cdot]^2$$

From the definition of  $[\cdot]^2$  given above, except for the cross term in the expression for  $[\cdot]^2$ , this is clearly a positive partial effect. Thus, for any market, a rise in  $S_t^m(v)$  will induce an increase in  $(P_t(v) - P_t)^2$ . Aggregating across all markets, a rise in  $S_t^m$  causes an increase in  $S_t$  in equation (5).

#### IV. DATA

The relative price dispersion measure (S) 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.<sup>9/</sup> Second, the PCE represents a final goods' price which more closely matches the spirit of the theoretical model than, say, the wholesale price index (WPI).<sup>10/</sup> Finally, because we are concerned with the effects of demand and supply events on relative price behavior, a measure of price dispersion that represents only price movements is needed. Consequently, the fixed weight PCE 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 squared 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 each quarter to derive our time series of relative price dispersion. The eighteen components along with their respective weights that comprise the PCE index used to generate the price dispersion series are listed in Appendix C.<sup>11/</sup>

Before proceeding a final word about the data is in order. Because the model attempts to explain cyclical variability, all variables have been appropriately detrended for each sample period: once for the full sample period (1960/I to 1981/IV), and separately 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 are measures of "expected" events, and "unexpected" events are measured as the difference between predicted and actual movements.<sup>12/</sup>

## V. EMPIRICAL RESULTS

The outcome of empirically testing the hypothesis that expected and unexpected supply events have a significant influence on relative prices is reported in this section. The explanatory 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.<sup>13/</sup>

Measuring the supply variable is more problematic, since this variable ideally should measure only supply changes: measures such as real GNP may confuse supply and demand changes. Consequently, we follow Froyen and Waud by using the relative price of energy.<sup>14/</sup> 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. Thus, expected and unexpected changes in the relative price of energy are used as measures to capture supply events.<sup>15/</sup>

The empirical tests involve estimating equation (5) over the different time periods. To reiterate, our theoretical model posits that anticipated and unanticipated aggregate supply events affect relative price dispersion. Separating these effects, if this hypothesis is correct, should improve upon a 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.<sup>16/</sup> All equations are estimated using a first-order GLS autocorrelation correction procedure.<sup>17/</sup> The results for the 1960s admittedly are disappointing. 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  $\bar{R}^2$ s reported for each specification. These results suggest that during the 1960s 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: it reveals little variation around a constant value. Finally, the estimated coefficients on unanticipated demand are negative, a result that conflicts with theoretical expectations. In each case, however, they are not significantly different from zero.

The results for the 1970's are more supportive of the model: 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.

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 combined. Such restricted equations are reported in table 2. Again the model explains very little of the movements in relative price dispersion during the 1960s. During the 1970s, however, the equation achieves a high degree of explanatory power. There are several aspects of the results reported in

Tables 1 and 2 worth noting: First, the supply variable(SUP) 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(SUP) reduces the regression standard error by about 12 percent, from 20.002 to 17.707. An F-test to determine the significance of dichotomizing supply effects during the 1970's sample period yields a calculated F-value is 7.68, compared with a 5 percent critical value of 3.21. It also is 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 anticipated and unanticipated components.

Finally, the covariance of unanticipated demand and anticipated supply (DUSA) in Table 1 plays an important role as evidenced by the large t-statistic (4.26). The positive sign suggests that the coincident effect of high anticipated energy prices and a positive demand shock is more relative price dispersion. This finding suggests that a monetary policy that accommodates a relative rise in energy prices will increase the variance of relative prices.

## VI. THE LAGGED MODEL

Because anticipated supply events are a function of past supply events, the above results hide the explicit lag structure relating current relative price changes to supply events. We may investigate this



lag structure by using a simple model that specifies that the expected change in relative energy prices is expressed a distributed lag of past unanticipated relative energy price shocks; that is,

$$\lambda_t = \sum_{i=1}^N f_{t-i} \mu_{t-i}.$$

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

$S_t^\xi$  is replaced by a distributed lag on  $S_t^u$ .<sup>18/</sup> With this change we rewrite equation (5) as:

$$(6) S_t = S_t(S^e, S^m, \sum_{n=0}^N S_{t-n}^u, C_t).$$

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 (6) for the two periods are presented in table 3.<sup>19/</sup> The choice of lag length on the unanticipated supply variable was made by minimizing the regression standard error. These results confirm the model's inability to explain relative price dispersion during the 1960s. 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.

The temporal pattern of the effects of unanticipated supply (SU) 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.

Finally, it is interesting to compare the results for the equations in Table 3 to their counterparts in Table 1. 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 (6). In fact, this finding reinforces the notion that the contemporaneous expected supply measure is influenced by lagged values of unanticipated supply terms. Indeed, the closeness of fit between these two models indicates that this may well be the case during the 1970s.

## VII. CONCLUSION

We have 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 our theoretical model is that it introduces anticipated supply "events" into the supply function, unlike previous specifications of relative price changes which have included only actual or unanticipated supply events. Moreover, we have relaxed the restrictive assumption that there exists uniform supply elasticities across markets. These modifications yield a more general model where both anticipated and

unanticipated supply events affect the dispersion of relative prices in the economy suggesting that, even though supply changes may be fully anticipated by economic agents, they will increase the dispersion of prices.

Attempts to empirically capture the essence of the theoretical model were made 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. Extensions of the basic contemporaneous model also 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 results suggest that the impact of past supply changes peak and then diminish within only a few quarters.

Our findings have important policy implications since large, supply-induced price changes appear to be self-correcting within a relatively short time period. Using aggregate demand policies to quickly offset or reverse observed aggregate price change is not, therefore, the most appropriate remedy. The continued use of such policies lead to even more relative price dispersion as 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 substantial risk.

1/ Barro (1976) and Froyen and Waud (1982) do include an anticipated aggregate 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/ There are several steps involved in the derivation of equation (3). Because the basic methodology for deriving such an equation has been well developed in those studies cited above, we omit the intermediate steps in the text. These steps are reported in Appendix A.

6/ Appendix B shows that  $\delta_1 = \lambda(v) (\lambda^B / \lambda - \beta^S(v))$ . If all markets have identical supply shock elasticities, then  $\lambda^B$  equals  $\lambda \beta^S(v)$ . Consequently,  $\delta_1 = \lambda(v) \left( \frac{\lambda \beta^S(v)}{\lambda} - \beta^S(v) \right) = \lambda(v) (\beta^S(v) - \beta^S(v)) = 0$  which is the point made in the text.

7/ The difference between relative and aggregate effects may be confusing in equation (5). For example,  $S^e$  is a variance term representing the aggregation of relative excess demand shocks.

The term  $S^m$  is the variance of aggregate demand shocks.

Hercowitz (1982b) finds a proxy for  $S^m$  but in his empirical work subsumes the counterpart of  $S^e$  into the estimated constant term. While a strong theoretical distinction between  $S^e$  and  $S^m$  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  $S^e$ . 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 (5).

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

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

10/ Hercowitz (1982) uses a variable-weight version of the WPI.

11/ 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.

12/ 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). Of course, expectations can be proxied through more elaborate means: for example, the approach taken by Barro and Rush

(1980). To keep our results comparable to a similar study by Froyen and Waud and the other works in this area, we choose to retain the autoregressive modeling approach. Clearly, the use of other approaches is an avenue for further research.

13/ 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 (1981,1982), market demand equations are specified in terms of money.

14/ See Tatom (1981) for a description of the series.

15/ 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 S: 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, we also tried potential output 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, changes in full employment output may be viewed as supply dislocations which potentially affect the dispersion of relative prices. These tests revealed similar but slightly weaker vindication of the null hypothesis. These results are available upon request.

16/ 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.

17/ The necessity of the autocorrelation correction may indicate that the variances of the relative demand and supply disturbances ( $S^e$ ) in equation (5) 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 (1982).

18/ 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 (6) 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. In either case, one can argue that these specifications of anticipations are ad hoc. Although more work needs to be done in this area, such an extension is beyond the scope of our present study.

19/ 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.

# APPENDIX A

This appendix details the major steps involved in the derivation of equation (3). We begin with the equilibrium condition that sets  $y_t^s(v) = y_t^d(v)$ . Solving equations (1) and (2) for the market price results in:

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

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  $\pi$ 's are reduced form coefficients whose exact values will be determined below. The intuition of the model suggests that  $\pi_1, \pi_2$ , and  $\pi_3 > 0$ ;  $\pi_4, \pi_5$  and  $\pi_6 < 0$ . The expected price level is:

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

which can be rewritten as:

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

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

$$(6) \begin{aligned} \frac{E}{v} P_t &\equiv E(P_t | \Omega_{t-1}, P_t(v)), \\ \frac{E}{v} \tilde{m}_t &= E(\tilde{m}_t | \Omega_{t-1}, P_t(v)), \\ \frac{E}{v} \tilde{u}_t &= E(\tilde{u}_t | \Omega_{t-1}, P_t(v)). \end{aligned}$$



Using a projection theorem as developed by Sargent (1979, p. 327), the posterior expectations of  $m_t$  and  $u_t$  are:

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

where  $\phi_m$  and  $\phi_u$  are projection parameters. These expressions can be restated as:

$$(6b) \quad E_V m_t = g_t + \frac{\sigma_m^2}{\sigma_{(v)}^2} [\tilde{m}_t - \beta^S(v) \tilde{u}_t + \epsilon_t(v)]$$

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

where  $\sigma_{(v)}^2 = \sigma_m^2 + \sigma_\epsilon^2 + (\beta^S(v))^2 \sigma_u^2$ .

These equations show more explicitly the causes of the expectations of aggregate demand and supply events. The prior expectations ( $g_t$  and  $\xi_t$ ) 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  $\tilde{m}_t - \beta^S(v) \tilde{u}_t + \epsilon_t(v)$ ) from equation (3) by a ratio of variances. For example, if  $\sigma_m^2$  is large compared to  $\sigma_\epsilon^2 + (\beta^S(v))^2 \sigma_u^2$ , 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,  $\sigma_\epsilon^2$  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,  $E_V u_t$  and  $E_V p_t$ .

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

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

Substituting (7) into (3) yields:

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

Averaging over the densities  $\lambda(v)$ ,  $\epsilon_t(v)$  and  $\beta^S(v)$  we arrive at the average price level:

$$(9) \quad P_t = M_{t-1} (\pi_1 (1 - \lambda) + \lambda) + g_t (\pi_2 (1 - \lambda) + \lambda) \\ + U_{t-1} (\pi_4 (1 - \lambda) - \lambda^\beta) + \xi_t (\pi_5 (1 - \lambda) - \lambda^\beta) \\ + \tilde{m}_t (\pi_3 \sigma_m^2 V_1 - \pi_6 \sigma_u^2 V_2 + \lambda) \\ - \tilde{u}_t (\pi_3 \sigma_m^2 V_2 - \pi_6 \sigma_u^2 V_3 + \lambda^\beta)$$

where

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

$\beta^S$  " " " " " " " "  $\beta^S(v)$  ,

$\lambda\beta$  " " " " " " " "  $\lambda(v) \beta^S(v)$  ,

$V_1$  " " " " " " " "  $(1 - \lambda(v)) / \sigma_{(v)}^2$  ,

$V_2$  " " " " " " " "  $[1 - \lambda(v) \beta^S(v)] / \sigma_{(v)}^2$  ,

and

$V_3$  " " " " " " " "  $[(1 - \lambda(v))(\beta^S(v))^2] / \sigma_{(v)}^2$  .

Equation (9) must equal equation (4). This equality yield's the solution for the reduced-form parameters ( $\pi$ ):

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

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

$$\pi_3 = \frac{\lambda}{1 - \sigma_m^2 V_1} \left[ \frac{\sigma_u^2 V_3 + \sigma_m^2 \sigma_u^2 V_1 (V_2 - V_3)}{1 + \sigma_u^2 V_3 + \sigma_u^2 \sigma_v^2 V_2^2 - \sigma_m^2 V_1 - \sigma_m^2 \sigma_u^2 V_1 V_3} \right]$$

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

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

$$\pi_6 = \frac{\lambda [\sigma_m^2 (V_2 - V_1) + 1]}{(1 - \sigma_m^2 V_1) (1 + \sigma_u^2 V_3) + \sigma_u^2 \sigma_m^2 V_2^2}$$

The signs for the  $\pi_i$ s ( $i = 1, 2, 3, 4, 5, 6$ ) corroborate the intuition of the model, because it is clear that  $\pi_1, \pi_2 > 0$  and that  $\pi_4, \pi_5 < 0$ . The  $\pi_3, \pi_6$  parameters for  $m_t$  and  $u_t$  are not so directly signed and require some explanation. The complexity arises

because unanticipated aggregate shocks have several effects in the model. For example, an increase in  $\tilde{m}_t$

- i) directly increases  $y_t^d(v)$  and puts an upward pressure on prices in each market;
- ii) is incorporated in the posterior expectations of  $m_t$  and  $u_t$  as given by (6b);
- iii) the above is then translated into an increased posterior price expectation, as shown in (7); and
- iv) the rise in  $E_v P_t$  then has three effects on the supply and demand equations (1) and (2). Two of the effects cause an excess demand for goods and services and raise the price level. The third influence, a real balance effect, reduces aggregate demand and the price level.

If we assume that the real balance effect is dominated by the other two, then  $\pi_3 > 0$  and  $\pi_6 < 0$ .

Substituting these  $\pi_i$  values into equations (8) and (9) and subtracting (9) from (8) yields the expression for the relative price in market (v), referred to in the text as equation (3):

$$\begin{aligned}
 (10) \quad P_t(v) - P_t &= \left[ U_{t-1} + \varepsilon_t \right] \left[ \lambda(v) \frac{\lambda^\beta}{\lambda} - \beta^S(v) \right] \\
 &+ \tilde{m}_t \left[ \pi_3 \sigma_m^2 \left( \frac{1 - \lambda(v)}{\sigma(v)^2} - v_1 \right) - \pi_6 \sigma_u^2 \left( \frac{1 - \lambda(v)) \beta^S(v)}{\sigma(v)^2} - v_2 \right) + (\lambda(v) - \lambda) \right] \\
 &- \tilde{u}_t \left[ \pi_3 \sigma_m^2 \left( \frac{(1 - \lambda(v)) \beta^S(v)}{\sigma(v)^2} - v_2 \right) - \pi_6 \sigma_u^2 \left( \frac{(1 - \lambda(v)) (\beta^S(v))^2}{\sigma(v)^2} - v_3 \right) \right. \\
 &\left. + (\beta^S(v) \lambda(v) - \lambda^\beta) \right] \\
 &+ \varepsilon_t(v) \left[ (1 - \lambda(v)) \left( \frac{\pi_3 \sigma_m^2 - \beta^S(v) \pi_6 \sigma_u^2}{\sigma(v)^2} \right) + \lambda(v) \right].
 \end{aligned}$$

## Appendix B

This appendix presents the explicit definitions of the terms contained in equation (3). These are

$$\delta_1 = \lambda(v) \left[ \frac{\lambda^\beta}{\lambda} - \beta^S(v) \right] ,$$

$$\delta_2 = \pi_3 \sigma_m^2 \left[ \frac{1 - \lambda(v)}{\sigma^2(v)} - v_1 \right] + \pi_6 \sigma_u^2 \left[ \frac{(1 - \lambda(v)) \beta^S(v)}{\sigma^2(v)} - v_2 \right] + \left[ \lambda(v) - \lambda \right] ,$$

$$\delta_3 = \pi_3 \sigma_m^2 \left[ \frac{(1 - \lambda(v)) \beta^S(v)}{\sigma^2(v)} - v_1 \right] + \pi_6 \sigma_u^2 \left[ \frac{(1 - \lambda(v)) (\beta^S(v))^2 - v_3}{\sigma^2(v)} - v_3 \right] + \left[ \beta^S(v) \lambda(v) - \lambda^\beta \right] ,$$

and

$$\delta_4 = \frac{(1 - \lambda(v)) (\pi_3 \sigma_m^2 + \pi_6 \beta^S(v) \sigma_u^2)}{\sigma^2(v)} + \lambda(v) ,$$

where

$$\pi_3 = \left( \frac{\lambda}{1 - \sigma_m^2 v_1} \right) \left[ \frac{\sigma_u^2 v_3 + \sigma_m^2 \sigma_u^2 v_1 (v_2 - v_3)}{1 + \sigma_u^2 v_3 + \sigma_u^2 \sigma_v^2 v_2^2 - \sigma_m^2 v_1 - \sigma_m^2 \sigma_u^2 v_1 v_3} \right] ,$$

$$\pi_6 = \frac{\lambda [\sigma_m^2 (v_2 - v_1) + 1]}{(1 - \sigma_m^2 v_1) (1 + \sigma_u^2 v_3) + \sigma_u^2 \sigma_m^2 v_2^2} ,$$

$$\lambda(v) = 1/(\alpha^S(v) + \sigma^2(v)) ,$$

$$\lambda = \frac{1}{n} \sum_{v=1}^n \lambda(v) ,$$

$$\lambda^\beta = \frac{1}{n} \sum_{v=1}^n \lambda(v) \beta^S(v) ,$$

$$v_1 = \frac{1}{n} \sum_{v=1}^n [1 - \lambda(v)] / \sigma^2(v) ,$$

$$v_2 = \frac{1}{n} \sum_{v=1}^n [(1 - \lambda(v)) \beta^S(v)] / \sigma^2(v) ,$$

and

$$v_3 = \frac{1}{n} \sum_{v=1}^n [(1 - \lambda(v))(\beta^s(v))^2] / \sigma^2(v) .$$

APPENDIX C

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 <sup>1/</sup>	I/1960-IV/1969	I/1970-IV/1981
Constant	4.31 (6.05)	25.95 (2.32)
DU	-0.127 (1.53)	-0.219 (1.20)
SA	0.759 (0.45)	0.014 (1.90)
SU	0.021 (1.52)	0.042 (6.48)
DUSA	0.381 (0.60)	0.547 (4.26)
DUSU	-0.127 (2.21)	0.156 (1.34)
$\bar{R}^2$	0.038	0.759
SE	2.717	17.707
DW	1.94	1.89
$\hat{\rho}$	0.19	0.78

<sup>1/</sup> 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 <sup>1/</sup>	I/1960-IV/1969	I/1970-IV/1981
Constant	4.45 (7.07)	28.79 (2.78)
DU	-0.133 (1.62)	-0.438 (2.39)
SUP	.021 (1.45)	0.028 (5.38)
DUSUP	-0.116 (2.16)	0.419 (4.27)
$\bar{R}^2$	0.063	0.680
SE	2.683	20.002
DW	1.94	2.24
$\hat{\rho}$	0.20	0.72

<sup>1/</sup> DUSUP is the covariance between unanticipated demand and actual supply. See footnote to table 1 for other definitions.

Table 3  
Lagged Model

Variable <sup>1/</sup>	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

<sup>1/</sup> SUi (i = D, 1, 2, 3, 4) refers to contemporaneous and lagged unanticipated supply measures. See footnotes to table 1 for other definitions.

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