**Issues in the "Rockets and Feathers" Gasoline Price Literature**

Report to Federal Trade Commission

John Geweke, University of Iowa

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## 1. Preliminaries

(a) *Literature surveyed.* These notes synthesize the published "rockets and feathers" gasoline price literature. This literature addresses the question of whether there is a systematic tendency for downstream prices in the oil well-to-service station gasoline industry to respond to increases in upstream prices more rapidly than downstream prices respond to decreases in upstream prices. There are eighteen papers surveyed – the first eighteen in the References section of these notes. The survey excludes some marginally related papers, also indicated in the Refereces section, mainly having to do with the gasoline industry in Europe.

(b) *Focus.* There is a related literature in economic theory on possible connections between imperfect competition and asymmetric movements in price, some focussed on the gasoline industry in particular. Much of this literature exists within the papers surveyed here. These notes do not attempt to synthesize or evaluate this literature. This theoretical literature does not (yet) deliver implications that can be tested using available data.

(c) *Notation.* In what follows $x_t$ denotes an upstream price and $y_t$ a downstream price at time $t$. Whether a product price is upstream or downstream depends on the model: for example, wholesale rack price is downstream in its relation to crude oil price and upstream in its relation to retail gasoline price. The prefix $\Delta$ denotes finite backward difference, so that $\Delta x_t = x_t - x_{t-1}$. The superscripts $+$ and $-$ denote positive part and minus negative part, when applied to data, so that

$$(\Delta x_t)^+ = \begin{cases} \Delta x_t \text{ if } \Delta x_t > 0 \\ 0 \text{ if } \Delta x_t < 0 \end{cases} \quad \text{and} \quad (\Delta x_t)^- = \begin{cases} 0 \text{ if } \Delta x_t > 0 \\ \Delta x_t \text{ if } \Delta x_t < 0 \end{cases}$$

When applied to coefficients, e.g. $\beta_s^+$ or $\beta_s^-$, these superscripts simply indicate that the coefficients are different. The term $\varepsilon_t$ always denotes a disturbance in a linear stochastic equation that is serially uncorrelated with mean zero and variance $\sigma^2$, and is uncorrelated with all variables on the right-hand-side of the equation.

## 2. Types of models

(a) *Error correction models.* Most of the econometric models in this literature are elaborations of a simple error correction model (ECM) or partial adjustment price model, of the form

$$\Delta y_t = \gamma \left( y_{t-1} - \delta_0 - \delta x_{t-1} \right) + \varepsilon_t. \tag{1}$$

The "long run" or equilibrium relation between $y_t$ and $x_t$ is $y_t = \delta_0 + \delta_1 x_t$. The model (1) may be estimated directly. Alternatively, if the prices $x_t$ and $y_t$ are co-integrated, the long-run relation may be estimated separately and then inserted in (1) prior to estimation. (For details on the two-step procedure, see Greene [36]

Sections 19.5 and 20.4) Asymmetry in this model can be incorporated through either

$$\Delta y_t = \gamma_1 (y_{t-1} - \delta_0 - \delta x_{t-1}) + \gamma_2 (y_{t-1} - \delta_0 - \delta x_{t-1})^2 + \varepsilon_t \tag{2}$$

or

$$\Delta y_t = \gamma^+ (y_{t-1} - \delta_0 - \delta x_{t-1})^+ + \gamma^- (y_{t-1} - \delta_0 - \delta x_{t-1})^- + \varepsilon_t. \tag{3}$$

Asymmetry is indicated in (2) by $\gamma_2 \neq 0$ and in (3) by $\gamma^+ \neq \gamma^-$. (There are endless elaborations on incorporating asymmetry, but these are the two that have been employed in this literature.)

(b) *ECM with dynamics.* The dynamics in the simple ECM can be made richer by incorporating lagged differences on the right-hand-side of the equation.

1. The equation may add current and lagged upstream price changes, so that

$$\Delta y_t = \sum_{j=0}^{m} \beta_s \Delta x_{t-s} + \gamma (y_{t-1} - \delta_0 - \delta x_{t-1}) + \varepsilon_t. \tag{4}$$

   Asymmetry is introduced in this model by

$$\begin{aligned} \Delta y_t &= \sum_{j=0}^{m^+} \beta_s^+ (\Delta x_{t-s})^+ + \gamma^+ (y_{t-1} - \delta_0 - \delta_1 x_{t-1})^+ \\ &\quad + \sum_{j=0}^{m^-} \beta_s^- (\Delta x_{t-s})^- + \gamma^- (y_{t-1} - \delta_0 - \delta_1 x_{t-1})^- + \varepsilon_t \end{aligned} \tag{5}$$

   although some studies keep $\gamma^+ = \gamma^-$ while permitting $\beta_s^+ \neq \beta_s^-$.

2. The equation may also add lagged downstream price changes, so that

$$\Delta y_t = \sum_{j=1}^{k} \alpha_s \Delta y_{t-s} + \sum_{j=0}^{m} \beta_s \Delta x_{t-s} + \gamma (y_{t-1} - \delta_0 - \delta_1 x_{t-1}) + \varepsilon_t. \tag{6}$$

   Asymmetry is introduced in this model by

$$\begin{aligned} \Delta y_t &= \sum_{j=1}^{k^+} \alpha_s^+ (\Delta y_{t-s})^+ + \sum_{j=0}^{m^+} \beta_s^+ (\Delta x_{t-s})^+ + \gamma^+ (y_{t-1} - \delta_0 - \delta_1 x_{t-1})^+ \\ &\quad + \sum_{j=1}^{k^-} \alpha_s^- (\Delta y_{t-s})^- + \sum_{j=0}^{m^-} \beta_s^- (\Delta x_{t-s})^- + \gamma^- (y_{t-1} - \delta_0 - \delta_1 x_{t-1})^- + \varepsilon_t \end{aligned} \tag{7}$$

   although again some studies keep $\gamma^+ = \gamma^-$ while permitting $\alpha_s^+ \neq \alpha_s^-$ and $\beta_s^+ \neq \beta_s^-$.

(c) *Erroneous specifications.* Some forms are equivalent. For example (1), (4) and (6) are all special cases of

$$y_t = \sum_{j=1}^{k} \alpha_s y_{t-s} + \sum_{s=0}^{m} \beta_s x_{t-s} + \varepsilon_t. \tag{8}$$

The interpretation of the coefficients is different, but it is easy to see how they match up. For example Borenstein et al. [8] and EIA ([11] Model 1, p 94) formulate their models in this way. So long as one takes care with unit root issues—and these generally do not arise in testing for asymmetry—this formulation does not present any problems. However there are two formulations in this literature that are inconsistent with (1), (4) and (6). One is

$$\Delta y_t = \sum_{s=0}^{m} \beta_s \Delta x_{t-s} + \varepsilon_t \tag{9}$$

utilized by Karrenbrock ([2]), Duffy-Deno [7] and GAO [5]. The difficulty, here, is that $y_t$ will wander away from $x_t$ with no tendency to return: there is no equilibrium mark-up $y_t - x_t$. (The error correction models, by incorporating $y_{t-1} - \delta_0 - \delta_1 x_{t-1}$ coupled with $\delta_1 = 1$, prevent this.) The second formulation is

$$\Delta y_t = \sum_{s=0}^{m} \beta_s x_{t-s} + \varepsilon_t. \tag{10}$$

utilized in Peltzman's simple model ([13], p 474) and EIA ([11] Model 2, p 95). (Peltzman and EIA also use other models that do not suffer from this problem.) In this formulation there is either no equilibrium price of the upstream product (if $\sum_{s=0}^{m} \beta_s \neq 0$) or infinitely many equilibrium prices (if $\sum_{s=0}^{m} \beta_s = 0$).

3. **Defining or identifying "up" and "down"**. The rockets and feathers literature is motivated by (i) the common anecdotal observation that retail gasoline prices rise faster than they fall, which leads to the political importance of the question; and (ii) various economic models that have two distinct regimes, of which the best known is that of Green and Porter [35]. Both motivations suggest two, or at most a small number of regimes.

   (a) Error correction models with asymmetry have not two, but many regimes. In (5) one must know the most recent upstream price change and $\max(m^+, m^-)$ lagged upstream price changes in order to deduce which of $2^{\max(m^+,m^-)+1}$ possible combinations of coefficients apply in the determination of the current period's downstream price in the model. Given the lag lengths used in this literature (typically from 1 to 4) and the rapidity with which price changes reverse direction (for example see [1], Figure 1, p 213; or [14], Figure 1, p 56) there are many combinations of coefficients that apply. While it may be more appropriate to interpret the $2^{\max(m^+,m^-)+1}$ combinations as an approximation to a nonlinear asymmetric model, it is also the case that these models do not incorporate the primitive notion of two or even a small number of states.

   (b) In (2) and (3) the interpretation in terms of two regimes is much more distinct. However, the misspecification of these models in excluding short-term dynamics is clear in this literature, and they were applied only in early studies.

   (c) The GAO study includes interviews with industry participants ([5], p 72). These discussions may be interpreted as identifying the relevant states as the Cartesian product of rising and falling prices, on the one hand, and whether the price change is expected to be temporary or permanent, on the other. While it might be rash to take this formulation literally, it suggests a small number of discrete states.

(d) The only fully articulated model used to develop an econometric specification in the literature I surveyed is that of Eckert [14]. His model employs focal point pricing in a duopoly retail gasoline market. There are exactly two regimes in this model.

(e) The modern econometric literature of the past fifteen years includes a rich and growing variety of models involving states that are unobserved, but for which there may be observed covariates that make each state more or less probable. One of the earliest and best known is Hamilton's Markov regime-switching model [37]. There is a substantial amount of recent work with these models that is directly relevant to the rockets and feathers question, including work by Chib [25] and Martins *et al.* [38]. My survey indicates a lack of awareness of these potentially useful tools.

(f) These methods can be combined with threshold models in a way that richly generalizes the key idea in the study of Godby et al. [12]; see [33] and [38]. A by-product of this work would be identification of "up" and "down" states, if they really exist.

(g) While the approaches in 3e and 3f are promising, I ignore them in the rest of this survey because they have not been applied to the rockets and feathers question to date.

4. **Measuring asymmetry in markup**. Many papers in this literature review previous work. Quantitative findings in the literature tend to be summarized in a number of dimensions. In my view one of these is by far the most important, and is useful in summarizing findings.

   (a) *Amount asymmetry.* Most of the literature interprets estimated models by using them to answer the question, "What is the difference in downstream price response to a one-time, $x$-unit permanent increase in upstream prices and a one-time, $x$-unit decrease in upstream prices?" With symmetric response, the responses would be mirror images of one another, the only difference being sign.

      1. Some of this literature has been concerned with *amount asymmetry*, defined as asymmetry in the new equilibrium values of upstream prices. The question does not arise in error correction models, because the results are forced to be the same. Thus, one sees this question posed only in models that depart from the ECM approach, like (9) or (10).
      2. Amount asymmetry is implausible even beyond the circumstances in which ECMs are usually applied, i.e., cointegrated upstream and downstream prices. In particular, even if these prices were stationary, amount asymmetry would imply that upstream and downstream prices would tend to drift farther and farther apart if, under asymmetry, downstream prices respond faster on the upswing than on the downswing. Margins would be ever-widening, and would widen faster the greater the volatility in upstream prices.

(b) *Pattern asymmetry.* The literature is also concerned with pattern or timing asymmetry. In the case of the asymmetric ECM (5) this is a straightforward computation, setting all of the disturbances $\varepsilon_t$ to zero. Given a hypothetical history that has $x_t = x_1^*$ for $t < t_1$ and $x_t = x_2^*$ for $t \geq t_2$, find the corresponding $y_t$ by repeated application of (5). In the case of the asymmetric ECM (7) the problem is more complicated; see point 4e below.

(c) *Price and markup dynamics.* Borenstein et al. [8] have focussed on the cumulative difference in margins, in response to a one-time shock to downstream price. The conceptual experiment is that $\Delta x_t = 0$ for all $t \neq 0$ and $\Delta x_0 = h$. To illustrate the concept consider the specific case of (5)

$$\Delta y_t = \beta^+ (\Delta x_t)^+ + \gamma^+ (y_{t-1} - x_{t-1} - \delta)^+ + \beta^- (\Delta x_t) + \gamma^- (y_{t-1} - x_{t-1} - \delta)^- ,$$

the disturbance term $\varepsilon_t$ being suppressed since we are interested in expected impact on $y_t$. The thrust of the asymmetry literature is that in the presence of asymmetry,

$$0 \leq \beta^- \leq \beta^+ < 1, \tag{11}$$
$$-1 < \gamma^- \leq \gamma^+ < 0, \tag{12}$$

with the middle weak inequality being strict in at least one of (11) or (12). From (11) upward changes in upstream prices may be reflected instantaneously in downstream prices more fully than are downward changes in upstream prices. From (12) when downstream prices are above equilibrium and hence falling (other things equal) they may be moving toward equilibrium more slowly than when downstream prices are below equilibrium and hence rising (other things equal). Then if $\Delta x_0 = h > 0$,

| $t$ | $x$ | $\Delta x$ | $\Delta y$ | $y - \delta$ | $y - x - \delta$ |
|---|---|---|---|---|---|
| $-1$ | 0 | 0 | 0 | 0 | 0 |
| 0 | $h$ | $h$ | $h\beta^+$ | $h\beta^+$ | $h\left(\beta^+ - 1\right)$ |
| 1 | 0 | $-h$ | $h\left[-\beta^- + \left(\beta^+ - 1\right)\gamma^-\right]$ | $he_2^+$ | $he_2^+$ |
| 2 | 0 | 0 | $h\gamma^+ e_2^+$ | $h(1+\gamma^+)e_2^+$ | $h(1+\gamma^+)e_2^+$ |
| 3 | 0 | 0 | $h(1+\gamma^+)e_2^+$ | $h(1+\gamma^+)^2 e_2^+$ | $h(1+\gamma^+)^2 e_2^+$ |
| $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ |
| $t$ | 0 | 0 | $h(1+\gamma^+)^{(t-2)} e_2^+$ | $h(1+\gamma^+)^{(t-1)} e_2^+$ | $h(1+\gamma^+)^{(t-1)} e_2^+$ |
| $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ |
| Limit | 0 | 0 | 0 | 0 | 0 |
| Sum | $h$ | 0 | 0 | $h\left[\beta^+ - e_2^+/\gamma^+\right]$ | $h\left[\left(\beta^+ - 1\right) - e_2^+/\gamma^+\right]$ |

where $e_2^+ = \beta^+ - \beta^- + \left(\beta^+ - 1\right)\gamma^- > 0$ . The total impact on downstream price is

$$\sum_{s=0}^{\infty} (y_t - \delta) = h\left[1 - \frac{\beta^+ - \beta^-}{\gamma^+} + \frac{\left(\beta^+ - 1\right)\left(\gamma^+ - \gamma^-\right)}{\gamma^+}\right] > h \tag{13}$$

whereas the total impact on margin,

$$h\sum_{s=0}^{\infty} (y_t - x_t - \delta) = h\left[-\frac{\beta^+ - \beta^-}{\gamma^+} + \frac{\left(\beta^+ - 1\right)\left(\gamma^+ - \gamma^-\right)}{\gamma^+}\right] > 0 \tag{14}$$

but may be less than or greater than $h$.

On the other hand if $\Delta x_0 = -h < 0$,

| $t$ | $x$ | $\Delta x$ | $\Delta y$ | $y-\delta$ | $y-x-\delta$ |
|---|---|---|---|---|---|
| $-1$ | 0 | 0 | 0 | 0 | 0 |
| 0 | $-h$ | $-h$ | $-h\beta^-$ | $-h\beta^-$ | $h\left(1-\beta^-\right)$ |
| 1 | 0 | $h$ | $h\left[\beta^+ + \left(1-\beta^-\right)\gamma^+\right]$ | $he_2^-$ | $he_2^-$ |
| 2 | 0 | 0 | $h\gamma^? e_2^+$ | $h\left(1+\gamma^?\right)e_2^+$ | $h\left(1+\gamma^?\right)e_2^+$ |
| 3 | 0 | 0 | $h\left(1+\gamma^?\right)e_2^+$ | $h\left(1+\gamma^?\right)^2 e_2^+$ | $h\left(1+\gamma^?\right)^2 e_2^+$ |
| $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ |
| $t$ | 0 | 0 | $h\left(1+\gamma^?\right)^{(t-2)} e_2^+$ | $h\left(1+\gamma^?\right)^{(t-1)} e_2^+$ | $h\left(1+\gamma^?\right)^{(t-1)} e_2^+$ |
| $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ |
| Limit | 0 | 0 | 0 | 0 | 0 |
| Sum | $h$ | 0 | 0 | $h\left[-\beta^- - e_2^-/\gamma^?\right]$ | $h\left[\left(1-\beta^-\right) - e_2^-/\gamma^?\right]$ |

where $e_2^- = \beta^+ - \beta^- + \left(1-\beta^-\right)\gamma^+$ may be either positive or negative, and hence the occurrence of $\gamma^?$ in expressions for periods $t = 3, 4, \ldots$. The total impact on downstream price is

$$\sum_{s=0}^{\infty}\left(y_t - \delta\right) = h\left[-1 - \frac{\beta^+ - \beta^-}{\gamma^?} + \frac{\left(1-\beta^-\right)\left(\gamma^? - \gamma^+\right)}{\gamma^?}\right] > -h \qquad (15)$$

and could even be positive. The total impact on margin is

$$\sum_{s=0}^{\infty}\left(y_t - \delta\right) = h\left[-\frac{\beta^+ - \beta^-}{\gamma^?} + \frac{\left(1-\beta^-\right)\left(\gamma^? - \gamma^+\right)}{\gamma^?}\right] > 0. \qquad (16)$$

(d) *Markup return to volatility (MURV).* The sum of the effects of a positive shock ($\Delta x_t = h$) and a negative shock ($\Delta x_t = -h$) of equal value on price is the same as the sum of their effects on margin. The sum is positive in each case, as comparison of (13)-(16) immediately shows. If $\gamma^- = \gamma^+ = \gamma$ then $MURV = -2h\left(\beta^+ - \beta^-\right)/\gamma$; if not the expressions are more complicated but straightforward to compute given parameter values. *The primary effect of asymmetry in markup relations is to produce a systematic relationship between the volatility of upstream prices and the size of the downstream markup.* MURV captures this relationship. It expresses the fraction of upstream price volatility, measured as $E\left(\Delta x_t \mid \Delta x_t > 0\right) = E\left(\Delta x_t \mid \Delta x_t < 0\right) = E\left(\left|\Delta x_t\right|\right)$, that is captured in increased downstream margins and (equivalently) reflected in downstream prices. For example, if MURV is 0.4 and $E\left(\left|\Delta x_t\right|\right)$ increases from 1.5 cents to 2 cents, then $E\left(y_t\right)$ and $E\left(y_t - x_t\right)$ will increase by 0.2 cents.

(e) *Incorrect impact analysis given a lagged dependent variable.* The relevant real-world experiment consists not of equal offsetting shocks, but rather an unending succession of shocks to upstream price. So long as there is no asymmetry in the response of $y_t$ to lagged values of itself (e.g., $\gamma^+ = \gamma^-$ in the example in point 4c) this distinction is unimportant: effects of successive shocks are strictly additive and the analysis in points 4c and 4d is exact. The effect of such asymmetry is to make the impact of change in the volatility of $x_t$ on markup a nonlinear function that involves not only the volatility of upstream prices, but also the volatility of the shock $\varepsilon_t$ in the markup equation for downstream prices. I have not investigated the extent of this nonlinearity. Given asymmetry in response to lagged values of $y_t$, as occurs in the widely applied model (7), the only practical way to assess any response of downstream to upstream price changes or volatility is through a full dynamic simulation of the model. Many of the papers surveyed carry out simulation experiments to assess downstream response. While the documentation of these experiments is sketchy, it appears that they have all proceeded by suppressing the shock $\varepsilon_t$; this is inappropriate and leads to potentially misleading inferences.

(f) *MURV's reported in the literature.* The following calculations are are approximate, based on reading graphs in some cases; no study provides enough information to approximate a standard error for these estimates. I have included only those studies that indicate that the long run elasticity of $y_t$ with respect to $x_t$ is approximately 1.0. Frequency is important because $E(|x_t|)$ increases as the time elapsed between observations increases; therefore, one would expect MURV to be smaller for greater frequencies. The table supports the fact that studies differ widely in their assessment of the existence and importance of the "rockets and feathers" phenomenon.

| Study | Channel | Frequency | MURV |
|---|---|---|---|
| Karrenbrock[2] | Wholesale→Retail | Monthly | 0.39 |
| Shin[6] | Crude→Wholesale | Monthly | -0.10 |
| Borenstein et al.[8] | Crude→Retail | Biweekly | 1.38 |
| Balke et al.[10] | Crude→Wholesale | Weekly | 1.98 |
| Eckert[14] | Wholesale→Retail | Weekly | 0.44 |
| Bettendorf et al.[16] | Wholesale→Retail | Weekly | 0.15 |

5. **Asymmetry in markup versus asymmetry in price**. The "rockets and feathers" literature has been concerned with asymmetry in the markup relationship of downstream to upstream prices, to the exclusion of modelling upstream prices. One does not even encounter simple univariate time series models, symmetric or asymmetric, for upstream prices. Without modeling upstream prices, one has no answer to the question of whether (much less why) downstream prices are asymmetric.

   (a) This focus seems somewhat misplaced in the context of the political issue of retail gasoline price asymmetry. The consumer observes retail prices, not markups. She may have some awareness of upstream prices, but the main issue is that retail prices seem to rise faster than they fall. Thus models that are capable of producing a description of, or a verdict about, asymmetry in downstream prices would be relevant and interesting. Asymmetry in the markup relation interacts with asymmetry in upstream prices in producing asymmetry in downstream prices; in principle it is possible for asymmetry in the markup relation to absorb as well as amplify asymmetries in upstream prices. Such work would be straightforward, using "off the shelf" data and methods.

(b) The focus on markup is motivated at least in part by the possibility that imperfect competition in downstream markets may account for asymmetry. Articulating this idea in a well-developed theoretical model that will also yield an econometric specification for the data is a challenging task.

    1. The "rockets and feathers" literature has identified downstream oligopoly focal point pricing (Borenstein et al. [8], p324; Eckert [14], pp 61-68), midstream inventories and utilization (Borenstein et al.[8], p 327; GAO [5], pp 68-69) and search in downstream markets (Borenstein et al. [8], p 328; Lewis [18] pp 6-16) as possibilities. As Borenstein et al. ([8], p 329) emphasize, no single one of these features will account for asymmetry (or lack of it) on its own. Moreover individual models do not readily yield implications for observed data; Eckert [14] appears to have advanced as far as anyone, but links between theory and empirical work are loose even there.
    2. For the foreseeable future, developments in theory and empirical work are likely to continue in parallel with no strong links between them. With no compelling structure emerging from economic theory, the empirical work is likely to continue to employ reduced form models. It is natural for this work to focus on asymmetry in price as well as asymmetry in markup.

6. **Causality, feedback and endogeneity**. This literature utilizes estimated relations between upstream and downstream prices to trace out the impact of shocks to the former on the latter. There is a nearly unquestioned assumption that the estimated relations are structural with respect to this sort of intervention: that is, when upstream prices change exogenously, the estimated relations reliably trace through an impact on downstream prices.

    (a) It is possible, indeed likely, that shocks to downstream prices may also impact upstream prices. This fact is occasionally mentioned, often with the observation that downstream markets are local and small whereas the market for crude oil is international and huge. Occasionally there are conventional Hausman tests for endogeneity; for example see the discussion in Borenstein et al.( [8] pp 316-317). A key problem is that while downstream markets are small and local, they are not independent. They are subject to common macroeconomic shocks like recessions that reduce demand for gasoline and other petroleum products.

    (b) The only study that has addressed this question systematically is Balke et al. [10], and their results are disconcerting. They utilize a ten-year sample of weekly data on spot oil, and spot, wholesale and retail gasoline prices. Utilizing conventional Granger causality tests on pairs of upstream and downstream prices they find that with the exception of crude oil and spot gasoline, each upstream price causes each downstream price. But, in addition, each downstream price (including spot gasoline) causes crude oil price.

    (c) Bi-directional causality and feedback are issues only if the objective is to isolate the impact of shocks with economic interpretations, for example shocks to supply and distribution. This is the case if the focus is on markup relations. The simpler question of whether prices at various points in the distribution chain are symmetric or asymmetric does not require a structural model and can be addressed by standard multivariate time series methods like vector autoregressions, appropriately modified to permit asymmetry.

(d) In the investigation of asymmetry in structural relations like markups in the supply chain, there are several well-established tools that could be used to further investigate complications due to feedback, and to isolate the structural relations of interest.

1. Conventional simultaneous equations methods identify structural relations by means of excluded variables. On the supply side, GAO ([5], Appendix II) has found that refinery capacity utilization rates, crude oil stocks, and wholesale gasoline stocks are significant in predicting downstream prices. On the demand side, conventional measures of economic activity and seasonal indicators may play corresponding roles; however, none of the surveyed studies has explore this possibility.
2. The macroeconomics vector autoregression literature has used restrictions on dynamics to identify relations of interest, of which the most common are the absence of instantaneous feedback, or the enforcement of long run neutrality (summed effects of zero) in other relationships.
3. Feedback decomposition (Geweke [31]; Froeb and Geweke [29]) provides a useful interpretation of mutual feedback between prices in a multivariate context. Applications of this method have found, for example, that feedback from monetary growth to price price inflation is a long run phenomenon, whereas feedback from output growth to monetary growth is mainly seasonal (Geweke [32]). Analogous findings for upstream and downstream prices, if they exist, would help to evaluate the interpretation of estimated relationships as structural markup equations.

7. **Multiple levels of pricing**. Many of the studies surveyed employ several prices in the distribution chain, sometimes as many as five. Yet without exception they examine bivariate relations one by one.

(a) On the simple grounds of econometric efficiency alone, it would be preferable to estimate these relationships simultaneously. In most situations estimates will have smaller variance if the relations are regarded as a system of equations, like seemingly unrelated regressions. Even in the special cases where there is no gain in estimation efficiency, tests of the hypothesis of symmetry will be more powerful. Prime examples in which a multiple-equations approach would have provided more power are the multi-level pricing models in the GAO study [5] and the international comparisons in Galeotti et al. [17].

(b) A system of equations is the vehicle of choice in which to examine the universally maintained assumption in this literature that in the markup relation a downstream price is a function of a single upstream price. Sometimes this price is the one immediately upstream; some studies examine a downstream price as a function of alternative upstream prices, but do so individually.

1. The hypothesis that a downstream price is affected by only one upstream price is very strong, and likely to be rejected. The picture of asymmetry that would emerge when downstream prices depend on several upstream prices might be very different.
2. If, on the other hand, a downstream price is affected by only the immediate upstream price in a structural markup equation (as opposed to a reduced form equation) then such a restriction could be very powerful in isolating structural markup equations.

(c) A system of equations is the natural point of incorporation for futures (and perhaps options) data; see point 9a below.

8. **Aggregation issues**. Every empirical study chooses time periods (monthly, weekly, or daily) for data, and a geographic area (local, regional, or national) for downstream prices.

(a) *Aggregation over time.* The issue of aggregation over time is especially troublesome in most of these studies, because they have been carried out in asymmetric error correction models as described in point 2.

1. In a linear, symmetric model the case for using data at the finest available level of time disaggregation is compelling. That is especially the case when, as here, at least two variables (lagged $y_t$ and lagged $\mathrm{x}_t$) appear on the right side of the equation, the variables have strong comovements, and feedback is occurs on a daily basis; for theory and examples see Geweke [30].
2. In a linear, asymmetric model of the kind most popular in this literature the problem is much more difficult. Suppose, for the sake of illustration, that the appropriate markup model is of the form (7) with "$t$" indicating weeks. Then only a weekly model will get the dynamics even approximately right. (In the symmetric case, there are approximation theorems that would apply for monthly data [30]; here, there are not.) This problem emerges in this literature, nowhere more clearly than in the study of Bachmeir and Griffin [15] that comments on Borenstein et al. [8]; both used the model (7). The latter study used weekly data and found evidence of asymmetry. The former used daily data and did not. The reason is that it is impossible to reconstruct the weekly model as a special case of the daily model, and (from the perspective of a presumed weekly model) the daily price fluctuations are mainly "noise" that do very little to separate weeks into periods of rising and periods of falling prices.
3. In latent variable models of the kind described in points 3e and 3f, above, these problems do not arise. In these models a relatively small number of periods are linked to covariates in a way that is estimated, rather than presumed for data at a certain level of time aggregation as it is in the asymmetric ECM's favored in this literature and described in point 2.

(b) *Aggregation over space.* The dynamics of retail prices relevant to both the formal economics literature and the political problem are those in local markets. Yet, most studies have used national averages of retail prices because they are easier to acquire, and are sometimes thought to be more representative of retail prices.

1. Duffy-Deno [7] and Eckert [14] study retail gasoline prices in Salt Lake City, Utah (1989-1993) and Windsor, Ontario (1989-1994) respectively. Prices in Windsor show pronounced "rocket and feather" behavior (mean increases about 2.5 times mean decreases, but 2.5 times as many weeks with increases as decreases) whereas the those in Salt Lake City are symmetric; compare [7], Figure 1, p 87 and [14], Figure 1, p 56. In the Windsor data, price increases of a week followed by smaller decreases for two or three weeks are fairly common.
2. Such contrasts create a problem and an opportunity. The problem is that retail price behavior like that in Windsor and other cities will be obscured in national, or perhaps even regional, weekly data, unless the run-ups take place on the same weeks in all cities. This seems unlikely, given the Salt Lake City retail prices in the same time period. The opportunity is that contrasting retail price dynamics in different local markets could be very informative for both the empirical facts of markup asymmetries, and the economics underlying such behavior. No such work appears in this literature, perhaps because the data requirements are substantial.

9. **Related series**. This literature utilizes oil and gasoline prices at different levels, almost to the complete exclusion of other data. Yet it also provides strong indication of other data, much of it readily available, that would be useful in understanding asymmetric pricing in the gasoline industry.

(a) *Futures and derivatives data*

1. From its interviews with industry decision-makers, GAO ([5], p 72) identified periods of rising and falling upstream prices, and perceptions of whether these increases would be transitory or permanent, as determinants the response of downstream prices. The formal economics literature makes the same link, though in more precise if model-dependent ways. Futures prices constitute an ideal indicator of whether or not price changes are thought to be transitory or permanent, and would be prime candidates as covariates indicating different pricing regimes in a latent variable model. This line of investigation is especially promising because it involves essentially "off the shelf" data, models, and software.
2. Oil and gasoline derivatives provide further opportunities. First, GAO has also identified uncertainty about prices, especially price decreases, as a factor in downstream pricing. Derivatives (options) prices provide an indication of expected future volatility through the Black-Scholes pricing relations. Second, both futures and derivatives data provide conditional distributions that models like those in point 2 seek to capture: for example, systematic asymmetries in the conditional distribution of future prices, as a function of recent market price behavior, will be indicated by these series. This would provide yet another line of attack on asymmetry.

(b) *Spot vs. contract prices*. Most of this literature utilizes spot wholesale prices, yet the wholesale market is dominated by contract sales. GAO ([5], footnote 14, p 101) speculates that contract prices respond more slowly than spot prices, but provides no supporting arguments or references. Contract prices are linked to spot prices, but not perfectly so. Asymmetries that exist are not large, and spot-contract spreads may have sizes and dynamics similar to asymmetries. The literature has not investigated this point; I do not know if contract price data or the equivalent information required to do so, is available on reasonable terms.

(c) *Other data*. Point 6(d)1 above has indicated that capacity, inventory and utilization rates, as well as demand-side macroeconomic variables, have a potentially important role to play in identifying markup relations.

10. **Stability and robustness of asymmetric markup pricing**. An illuminating perspective on the "rockets and feathers" literature is that it finds that given the option of linear relationships in the markup equation that differ depending on whether prices are rising or falling, in many circumstances standard econometric procedures reject a single relationship that is the same for rising as for falling prices. Yet there has been little attention to whether the asymmetric relation is itself stable and a reliable indicator of the way downstream prices will follow upstream prices in the future.

    (a) Both upstream and downstream prices are characterized by a very small fraction of observations that account for the bulk of all changes. In more technical terms, price changes have outliers that are much larger than would would find in a normal distribution. Earlier papers, for example Bacon ([1], Figure 1, p 213) provide data plots showing these changes. Manning [3] reports that his findings about asymmetry are sensitive to a few outliers, but in general the subsequent literature has not examined the impact of these very large changes.

        1. Estimates in this literature are, without exception, least squares or close variants. The sensitivity of least squares estimates to outliers is well known and documented. Conventional Bayesian and non-Bayesian robust estimators are readily available and are less sensitive to outliers.
        2. It could well be the case that market downstream responses to upstream outliers (say, upstream price increases of more than 10% over a few weeks) cannot be described by the same model as more routine price changes. The outlier events tend to dominate the political questions (witness the Gulf War impetus for the GAO report) whereas routine pricing dominates the consideration of the formal economics literature. It would be unfortunate if econometric results, driven by outlying price changes, were taken as the stylized facts that the economics literature seeks to explain. Testing the hypothesis that the same model pertains in periods of extreme and normal upstream price volatility is a standard procedure that can easily be carried out.

    (b) Testing for stability over time is a standard part of econometric specification testing, but this is rarely done in the "rockets and feathers" literature; for an exception see Manning [3]. The petroleum markets have evolved over time in ways that suggest stability of downstream markup pricing relations over periods of many years may be questionable. GAO ([5], p 96) reports that the flow of information to market participants improved in the late 1980's and early 1990's due to increased activity in futures markets and use of computer-based pricing services. Karrenbrock [2] cites the changing mix of gasoline grades. Given the existence of long swings in upstream prices that sometimes take years to complete, testing for stability over time would help in sorting out the impacts of rising versus falling upstream prices and secular changes due to the evolution of technology.

11. Brief comments on individual papers, in chronological order

    (a) Bacon, 1991[1]. Wholesale and retail prices, biweekly, UK, 1982-1990. This is a standard partial adjustment model, with a quadratic term added to incorporate asymmetry. The evidence for asymmetry is marginal and is likely driven by the large drop in upstream prices in 1986 and the spike in prices in 1989.

    (b) Karrenbrock, 1991[2]. Wholesale and retail prices, monthly and weekly, US, 1983-1990. The model specification is (9), which is untenable in the long run.

    (c) Manning, 1991[3]. Crude and retail prices, monthly, 1973-1988, UK. The paper utilizes a general-to-specific modelling strategy for an ECM that leads to a long run relation in which the elasticity of retail with respect to crude prices is only 30%. Most of the coefficients are eliminated in the modelling exercise, leading to an overstatement of significance in those that remain. Asymmetry is barely significant, but there is good reason not to trust the results.

    (d) Norman and Shin, 1991[4]. Crude oil, wholesale and retail prices, monthly, US, 1982-1990. The model specification is (2). The coefficient of the quadratic term is insignificant in all relations. The usual diagnostics (such as those for serial correlation) are missing, making it difficult to evaluate the work.

    (e) GAO, 1993[5]. Crude oil, wholesale and retail prices, plus additional covariates (utilization rates, capacity and inventory), weekly, US, 1984-1991. This study has an unparalleled level of institutional detail and facts about the gasoline industry of potential relevance to asymmetric pricing. Unfortunately all the econometrics is carried out with first differences and no error correction terms, and is therefore untenable for the reasons given in point 2c with respect to (9). After all the work it was disappointing to find no hypothesis tests, and it is difficult to link the discussion to the formal results.

    (f) Shin, 1994[6]. Crude oil prices a weighted average of retail product prices, and wholesale gasoline prices, monthly, US, 1986-1992. The model specifications are (9) and a partial adjustment model with a quadratic term. The study finds no evidence of asymmetry.

    (g) Duffy-Deno, 1996[7]. Wholesale rack and terminal prices, and retail prices, weekly, all in Salt Lake City, 1989-1993. The model used is (10) and is therefore seriously compromised for reasons discussed in point 2c. The results are not credible.

    (h) Borenstein et al., 1997[8]. Crude oil, wholesale, terminal and retail prices, semi-monthly, US, 1986-1992. The models used are of the forms (7) and (8). The specification tests are perhaps the best in this literature. Results are presented only in graphical form and provide only approximate confidence intervals for response patters; there are no formal tests of asymmetry.

(i) Reilly and Witt, 1998[9]. Crude oil and retail prices, monthly, UK, 1982-1995. The work is done in the context of an ECM, in which the long run response coefficient on crude oil price is 0.58. This paper presents the results of a general-to-specific modelling exercise in which many variables were eliminated. The paper finds asymmetries. However, there is every indication that the results have been skewed by the modelling exercise.

(j) Balke et al., 1998[10]. Crude, wholesale, spot wholesale, and retail prices, weekly, US, 1987-1996. The study is unique in carrying out a systematic set of feedback tests, described above in point 6b. Unfortunately the key equation (6) in the paper is garbled and I was unable to understand exactly what the model is. They utilize models in both levels and error correction form, but the two are not comparable because the combinations of "up" and "down" regimes are not the same in the two forms.

(k) EIA, 1999[11]. Crude, spot, pipeline, rack, and retail prices, weekly, Chicago, 1992-1998. The sutdy's Model 2 incorporates (9), with all of the attendant problems discussed in point 2c. It finds asymmetry in some relations, mostly those with retail price as the downstream variable. Beyond the problems with the Model 2 specification the study provides no indication of routine checking for specification error.

(l) Godby et al., 2000[12]. Crude oil and retail prices, weekly, 13 Canadian cities, 1990-1996. This study utilizes an error correction model with only two regimes. Regime switching takes place according to a threshold model, and the threshold variable is the change in the price of crude oil. The work is nicely carried out. It finds very little evidence of asymmetry.

(m) Peltzman, 2000[13]. This is an ambitious study of asymmetry in downstream markup price relations utilizing over 200 industry pairs. There are serious difficulties in the way the data were collected, the model specification, and the credibility of the results. This paper really has no bearing on the "rockets and feathers" issue in gasoline pricing.

(n) Eckert, 2002[14]. Wholesale rack and retail prices, weekly, Windsor, Ontario, 1989-1994. The study utilizes a standard error correction formulation. The results are credible. He finds asymmetries, but the net effect on MURV is negligible. There are no formal tests, but it's fairly clear that MURV would not be significantly different from zero.

(o) Bachmeier and Griffin, 2003[15]. This paper is presented as a comment on Borenstein et al., 1997. It uses essentially the same data but at a daily rather than a semimonthly frequency. In contrast with the earlier paper, this one finds no evidence for asymmetry. The reason is undoubtedly the fact that any asymmetry in response is not due to a differential response to price changes that take place over periods as short as one day.

(p) Bettendoft et al., 2003[16]. Wholesale and retail prices, weekly, Netherlands, 1996-2001. Study utilizes a conventional error correction model. The paper is unique in using five separate sets of weekly data, one each for prices recorded on the five business days of each week. The study finds asymmetries for Mondays, Thursdays and Fridays, but not for Tuesdays and Wednesdays. The MURV's depart significantly from zero only on the Mondays.

(q) Galeotti et al., 2003[17]. Crude, wholesale and retail prices, weekly, Italy, France, Spain, Germany and UK, 1985-2000. The study utilizes standard error correction models and finds little evidence of asymmetry, but could have used more powerful tests as discussed above in point 7a. The paper describes results following a bootstrap procedure; both the discussion of the procedure and the presentation of these results are incomprehensible.

(r) Lewis, 2003[18]. Wholesale and retail prices, weekly, San Diego, 2000-2001. The study utilizes a two-regime model, based on whether the implicit error in the equilibrium equation is positive or negative. The study rejects symmetry, but presents few formal test results.

# References


[1] Robert W. Bacon. Rockets and feathers: the asymmetric speed of adjustment of UK retail gasoline prices to cost changes. Energy Economics (1991) 211-218.

[2] Jeffrey D. Karrenbrock. The behavior of retail gasoline prices: symmetric or not? Federal Reserve Bank of St. Louis, July/August 1991, 19-29.

[3] D.N. Manning. Petrol prices, oil price rises and oil price falls: Some evidence for the UK since 1972. Applied Economics 23 (1991) 1535-1541.

[4] Donald A. Norman and David Shin. Price adjustment in gasoline and heating oil markets. American Petroleum Institute Research Study #060, August 1991.

[5] General Accounting Office. Energy security and policy: Analysis of the pricing of crude oil and petroleum products. GAO/RCED-93-17, March, 1993. (134 pp)

[6] David Shin. Do product prices respond symmetrically to changes in crude prices? OPEC Review, Summer 1994, 137-157.

[7] Kevin T. Duffy-Deno. Retail price asymmetries in local gasoline markets. Energy Economics 18 (1996) 81-92.

[8] Severin Borenstein, A. Colin Cameron and Richard Gilbert. Do gasoline prices respond asymmetrically to crude oil price changes? The Quarterly Journal of Economics 112 (1997) 305-339.

[9] Barry Reilly and Robert Witt. Petrol price asymmetries revisited. Energy Economics 20 (1998) 297-308.

[10] Nathan S. Balke, Stephen P.A. Brown, and Mine K. Yucel. Crude oil and gasoline prices: An asymmetric relationship? Federal Reserve Bank of Dallas Economic Review (First Quarter 1998) 2-11.

[11] Energy Information Administration. Price changes in the gasoline market: Are Midwestern gasoline prices downward sticky? DOE/EIA-0626, February 1999. (55 pp)

[12] R. Godby, A.M. Lintner, T. Stengos, and B. Wandschneider. Testing for asymmetric pricing in the Canadian retail gasoline market. Energy Economics 22 (2000) 251-276.

[13] Sam Peltzman. Prices rise faster than they fall. The Journal of Political Economy 108 (2000) 466-502.

[14] Andrew Eckert. Retail price cycles and response asymmetry. Canadian Journal of Economics 35 (2002) 52-77.

[15] Lance J. Bachmeier and James M. Griffin. New evidence on asymmetric gasoline price responses. The Review of Economics and Statistics 85 (2003) 772-776.

[16] L. Bettendorf, S.A. van der Geest, and M. Varkevisser. Price asymmetry in the Dutch retail gasoline market. Energy Economics 25 (2003) 669-698.

[17] M. Galeotti, A. Lansa, and M. Manera. Rockets and feathers revisited: An international comparison on European gasoline markets. Energy Economics 25 (2003) 175-190.

[18] Matt Lewis. Asymmetric price adjustment and consumer search: An examination of the retail gasoline market. University of California-Berkeley working paper, November 2003. (55 pp)

[19] M. Asplund, R. Eriksson, and R. Friberg. Price adjustment by a gasoline retail chain. Scandinavian Journal of Economics 102 (2000) 101-121.

[20] Stephen P.A. Brown and Mine K. Yucel. Gasoline and crude oil prices: Why the asymmetry? Federal Reserve Bank of Dallas Economic and Financial Review, Third quarter 2000, 23-29.

[21] Mark French. Asymmetry in gasoline price changes. BOGFRS August 1991 draft paper.

[22] Gebhard Kerchgassner and Kunt Kubler. Symmetric or asymmetric price adjustments in the oil market: An empirical analysis of the relations between international and domestic prices in the Federal Republic of Germany, 1972-89. Energy Economics 14 (1992) 171-185.

[23] K. Hendricks. Analysis and opinion on retail gas inquiry. Independent study prepared for the Director of Investigation and Research, Competition Bureau, Canada (1996).

[24] A. Lanza. Speed of adjustment and market structure: a study of gasoline market in Germany. Oxford Institute for Energy Studies, Energy Economics Study N. 14.

[25] S. Chib. Estimation and comparison of multiple change-point models. Journal of Econometrics 86 (1998) 221-241.

[26] S. Cook. Nonsymmetric error correction revisited. Applied Economics Letters 6 (1999), 467-470.

[27] S. Cook, S. Holly and P. Turner. DHSY revisited: the role of asymmetries. Applied Economics 31 (1998) 775-778.

[28] S. Cook, S. Holly, and P. Turner. The power of tests for non-linearity: the case of Granger-Lee asymmetry. Economics Letters 62 (1999) 155-159.

[29] L. Froeb and J. Geweke. Long run competition in the U.S. aluminum industry. International Journal of Industrial Organization 5 (1987) 67-78.

[30] J. Geweke. Temporal aggregation in the multiple regression model. Econometrica 46(1978) 643-662.

[31] J. Geweke. The measurement of linear dependence and feedback between multiple time series. Journal of the American Statistical Association 77 (1982) 304-324

[32] J. Geweke. Causality, exogeneity, and inference. Invited paper, Fourth World Congress of the Econometric Society, in D. Hildenbrand (ed.), Advances in Econometrics, 209-236. Cambridge: Cambridge University Press, 1983.

[33] J. Geweke and N. Terui. Bayesian threshold autoregressive models for nonlinear time series. Journal of Time Series Analysis 14 (1993) 441-455.

[34] C.W.J. Granger and T.H. Lee, Investigation of production, sales and inventory relationships using multicointegration and non-symmetric error correction models. Journal of Applied Econometrics 4 (1989) S145-S159.

[35] E.J. Green and R.H. Porter. Noncooperative collusion under imperfect price information. Econometrica 52 (1984) 87-100.

[36] William H. Greene. Econometric Analysis. Prentice Hall, 2003, Fifth edition.

[37] J.D. Hamilton. A new approach to the economic analysis of non-stationary time series and the business cycle. Econometrica 57 (1989) 357-384.

[38] M. Martens, P. Kofman and TCFA Vorst. A threshold error-correction model for intraday futures and index returns. Journal of Applied Econometrics 13 (1998) 245-263.