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Dynamic Adjustment in Monthly Consumer Demands for Meats

Michael K. Wohlgenant and William F. Hahn

This paper focuses on the nature of dynamic adjustment in monthly consumer demands for beef, pork, and chicken. Estimates with monthly data can differ from those with longer data periods. This is because habit formation relative to inventory adjustment decreases as the time interval decreases (Sexauer). With short time periods such as a month, inventory demand tends to dominate demand for use. If inventory demand is more elastic in the short run, the total elasticity of demand can increase as the time interval is shortened. As shown by Pasour and Schrimper, the relative importance of inventory demand with respect to the length of the adjustment period is an empirical question, and its importance can vary from commodity to commodity. This paper presents estimates of monthly consumer demands for meats and examines the role of inventories and habits on the estimated short-run demand elasticities.

The State Adjustment Model and Consumer Demand for Meats

The basic model used in this study is the Houthakker-Taylor (HT) state adjustment model. Past behavior is embodied in a state variable, encompassing both stocks held by consumers and habits formed by past consumption. The model has two equations: a short-run demand function and a stock depreciation equation.

A logical specification of the HT model for the i th meat commodity is

$$(1) \quad X_i(t) = \alpha_i + \beta_i S_i(t) + \gamma_{ib} P_b(t) + \gamma_{ip} P_p(t) + \gamma_{ic} P_c(t) + \gamma_{im} M(t), \text{ and}$$

$$(2) \quad S_i(t) = \frac{dS_i(t)}{dt} = X_i(t) - \delta_i S_i(t),$$

where $i = b, p, c$ (beef, pork, chicken); X_i is per capita demand for the i th meat commodity at t ; S_i is

the state variable of the i th commodity; P_i is the real (deflated) price of the i th commodity at t ; and M is per capita real consumer income. Equation (2) specifies that stocks depreciate at a declining geometric rate over time.

If the inventory effect predominates, the coefficient, β_i , should be negative. That is, the larger the physical stock, the smaller will be the consumer's demand at t . Conversely, if habits predominate, the larger the (psychological) stock of habits and the greater will be the demand at time t .

With very short time periods (e.g., monthly), almost any commodity can be considered a durable which provides a stream of services over time. A major reason households hold stocks is the high opportunity cost of the consumer's shopping time (Sexauer, p. 131). Households also may hold inventories for speculative reasons (Pasour and Schrimper). For example, with a price special on pork, consumers might find it advantageous to purchase more pork now and store for later consumption.

The state variable in equation (1) is unobservable, but can be eliminated with equation (2). Since these two equations are formulated in continuous time, it is necessary to approximate them by discrete time for estimation. Following Houthakker and Taylor (chap. 1) or Philips (chap. 6), the estimating equation for each meat commodity has the form

$$(3) \quad X_{it} = [1 - \frac{1}{2}(\beta_i - \delta_i)]^{-1} \{ \alpha_i \delta_i + \gamma_{ib}(1 + \frac{1}{2}\delta_i) \Delta P_{bt} + \gamma_{ip}(1 + \frac{1}{2}\delta_i) \Delta P_{pt} + \gamma_{ic}(1 + \frac{1}{2}\delta_i) \Delta P_{ct} + \gamma_{im}(1 + \frac{1}{2}\delta_i) \Delta M_t + \gamma_{ib} \delta_i P_{bt-1} + \gamma_{ip} \delta_i P_{pt-1} + \gamma_{ic} \delta_i P_{ct-1} + \gamma_{im} \delta_i M_{t-1} + [1 + \frac{1}{2}(\beta_i - \delta_i)] X_{it-1} \}, \text{ or}$$

$$(4) \quad X_{it} = A_{i0} + A_{i1} \Delta P_{bt} + A_{i2} P_{bt-1} + A_{i3} \Delta P_{pt} + A_{i4} P_{pt-1} + A_{i5} \Delta P_{ct} + A_{i6} P_{ct-1} + A_{i7} \Delta M_t + A_{i8} M_{t-1} + A_{i9} X_{it-1} + V_{it},$$

where V_{it} is a random disturbance term.

The reduced-form coefficients in (3) are restricted since the structural parameter, δ_i , is over-identified. A unique estimate of δ_i is obtained if the following restrictions hold:

$$(5) \quad \begin{aligned} A_{i1} &= A_{i2} A_{i7} / A_{i8}, \\ A_{i3} &= A_{i4} A_{i7} / A_{i8}, \text{ and} \\ A_{i5} &= A_{i6} A_{i7} / A_{i8}. \end{aligned}$$

The unique solutions of δ_i and β_i using the reduced-form parameters are

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$$(6) \quad \delta_i = 1/(A_{i7}/A_{i8} - \frac{1}{2}) \text{ and} \\ \beta_i = \delta_i + 2(A_{i9} - 1)/(1 + A_{i9}).$$

Unique solutions for α_i , γ_{ib} , γ_{ip} , γ_{ic} , and γ_{im} are then obtained by substituting δ_i and β_i from (6) into A_{ij} 's in (4).

The short-run derivatives of per capita demand with respect to prices and income are given by the γ_{ij} 's and γ_{im} in (1). The long-run derivatives are obtained by setting each S_i in (2) equal to zero and substituting the results into (1) to yield

$$(7) \quad X_i = \frac{\alpha_i \delta_i}{(\delta_i - \beta_i)} + \frac{\gamma_{ib} \delta_i P_b}{(\delta_i - \beta_i)} \\ + \frac{\gamma_{ip} \delta_i P_p}{(\delta_i - \beta_i)} + \frac{\gamma_{ic} \delta_i P_c}{(\delta_i - \beta_i)} + \frac{\gamma_{im} \delta_i M}{(\delta_i - \beta_i)}.$$

For $\delta_i \neq \beta_i$, the long-run demand derivatives are the price and income coefficients. If habit persistence dominates, the long-run elasticities will be larger than the short-run elasticities. Conversely, if inventory behavior is dominant, the short-run elasticities will be larger.¹

Empirical Analysis of Demand for Meats

The demand equations were estimated with monthly data over the period January 1965 through June 1979. Eleven monthly intercept dummy variables were included in each regression equation to account for seasonal shifts in demand. Data on quantities and retail prices of beef and pork were obtained from the *Livestock and Meat Situation*, while data for chicken came from the *Poultry and Egg Situation*.² Monthly data for disposable personal income are not available, so monthly personal income data from *Business Statistics* were used with a proportionality factor to estimate values for disposable personal income for months in between the published quarterly values.³ Quantities and income were in per capita terms, while prices and per capita income were deflated by the consumer price index.

Estimation Procedure

The main problem in estimating the HT model is serial correlation. If disturbance terms are included in the structural equations (1) and (2), then the disturbance in the estimating equation (4) will be autocorrelated. This will generate inconsistent as well as inefficient estimates since a lagged dependent variable appears in the specification.

Application of Durbin's asymptotic test to the residuals of the unrestricted models indicated there was serial correlation in the beef and pork equations but none in the chicken equation.⁴ Autocorrelation and partial autocorrelation functions of the residuals of the beef and pork equations were calculated to identify tentatively the order of the autoregressive process of the residuals.⁵ Since these sample correlations are inconsistent when a lagged dependent variable appears in the specification, each model was first fitted by the instrumental variable technique suggested by Fuller (pp. 429–47). A close study of these correlation functions indicated that either a second- or third-order process would closely approximate the disturbance process of each model. Therefore, each model was first fitted with correction for third-order serial correlation, and the significance of ρ_3 was tested. In each case, the parameter, ρ_3 , was insignificant. Thus, each model was fitted assuming the disturbance process was

$$(8) \quad V_t + \rho_1 V_{t-1} + \rho_2 V_{t-2} = U_t,$$

where U_t is independently and identically distributed with zero mean and constant variance.

Each model in (3) is nonlinear in the parameters and was estimated with Hartley's modified Gauss-Newton method. The beef and pork models also were estimated subject to the error process in (8) and the parameter restrictions in (5). Since there was no indication of serial correlation in the chicken equation, it was estimated assuming V_t to be distributed as U_t .

Since a single-equation approach was used here, some simultaneity questions might arise. However, because meat supplies vary more than demand for meats, the demand equations can be estimated with single-equation methods without serious simultaneity problems. In addition, Heien, testing for the exogeneity of retail meat prices using the causality test of Sims, found that the data are generally consistent with this specification.⁶

Discussion of the Econometric Results

Estimates of the unrestricted and restricted models for the three meat commodities are reported in table 1.

For chicken meat, the unrestricted results indi-

¹ With monthly data, these magnitudes are not strictly long-run elasticities. With quarterly and annual data we might expect to observe larger elasticities because more time is permitted for households to respond to a given price or income change.

² The per capita quantity values were based on carcass, rather than retail, weight. The proportionality factor for converting from carcass to retail weight was relatively constant over the sample period considered.

³ The proportionality factor used in the conversion was the ratio of disposable personal income to personal income for that quarter.

⁴ The Durbin-H statistic could not be calculated because it entailed taking the square root of a negative number.

⁵ It is entirely possible that the true model could be a moving average or mixed ARMA (autoregressive-moving average) process. However, it is frequently the case in applications that such processes can be approximated well by a low order autoregressive process (e.g., Gallant and Goebel). To simplify the estimation procedure, this is the approach taken in this paper.

⁶ As Heien (p. 15) points out, considerable controversy surrounds Sims's causality test. Also, broiler results indicate independence rather than one-way causality between retail and wholesale prices. Nevertheless, the beef and pork results are consistent with the specification employed here—causality running from the wholesale to the retail level.

Table 1. Estimates of the Reduced-Form Parameters of the State Adjustment Model

Variable Statistics	Model					
	Beef, X_b		Pork, X_p		Chicken, X_c^a	
	Unrestricted	Restricted	Unrestricted	Restricted	Unrestricted	Restricted
ΔP_b	-0.0741 (0.0112) ^b	-0.0492	0.0186 (0.0066)	0.0509	0.0078 (0.0073)	
P_{b-1}	-0.0109 (0.0032)	-0.0173 (0.0033)	0.0142 (0.0020)	0.0114 (0.0017)	0.0054 (0.0026)	0.0056 (0.0025)
ΔP_p	0.0338 (0.0125)	0.0296	-0.0854 (0.0079)	-0.0840	0.0015 (0.0090)	
P_{p-1}	0.0149 (0.0033)	0.0104 (0.0033)	-0.0311 (0.0034)	-0.0307 (0.0031)	0.0011 (0.0028)	0.0009 (0.0027)
ΔP_c	-0.0331 (0.0141)	-0.0484	0.0209 (0.0084)	0.0189	-0.0147 (0.0082)	
P_{c-1}	-0.0378 (0.0068)	-0.0170 (0.0053)	0.0045 (0.0042)	0.0069 (0.0029)	-0.0228 (0.0063)	-0.0230 (0.0063)
ΔM	12.300 (8.7884)	18.851 (5.1933)	5.5273 (5.2553)	5.2098 (1.7046)	2.8347 (4.6096)	
M_{t-1}	3.8418 (1.6206)	6.6237 (1.6831)	1.4750 (0.7789)	1.9035 (0.6775)	12.1047 (1.5136)	12.091 (1.4943)
X_{t-1}	0.6162 (0.0448)	0.6097 (0.0508)	0.4954 (0.0392)	0.5023 (0.0399)	0.0660 (0.0821)	0.0682 (0.0807)
ρ_1	0.5611 (0.0743)	0.4634 (0.0723)	0.6623 (0.0757)	0.6259 (0.0760)		
ρ_2	0.2947 (0.0639)	0.2311 (0.0641)	0.3359 (0.0647)	0.3083 (0.0653)		
R^2	0.80	0.78	0.84	0.83	0.84	0.84
σ^2	0.1406	0.1528	0.0541	0.0558	0.0350	0.0357

Note: X_i ($i = b, p, c$) is per capita quantity of i th meat commodity purchased (lb./person); P_i is deflated price of the i th meat commodity ($\$/lb.$); and M is per capita deflated disposable personal income (\$1000/person); monthly intercept values are not reported but can be obtained from the senior author.

^a Parameter estimates of the flow adjustment model where coefficient estimates pertain to average price and income levels.

^b Values in parentheses are the estimated standard errors.

cate that the estimated stock depreciation parameter, δ , is outside the range required for stability ($|\delta| < 2$). Houthakker and Taylor (chap. 2) encountered this situation, and showed that when $1/\delta = 0$, the estimating equation reduces to a discrete version of the continuous time-flow adjustment model. Following Houthakker and Taylor (chap. 2), the discrete version of this model can be written as

$$(9) \quad X_{ct} = [\Psi/(1 + \frac{1}{2}\Psi)](\alpha_c + \gamma_{cb}\bar{P}_{bt} + \gamma_{cp}\bar{P}_{pt} + \gamma_{cc}\bar{P}_{ct} + \gamma_{cm}\bar{M}_t) + [(1 - \frac{1}{2}\Psi)/(1 + \frac{1}{2}\Psi)]X_{ct-1} + V_{ct},$$

where Ψ is the coefficient of adjustment parameter ($\Psi > 0$), $\bar{P}_{bt} = \frac{1}{2}(P_{bt} + P_{bt-1})$, etc. This specification is identical to equation (3) when the restrictions in (5) hold and $A_{c7}/A_{c8} = \frac{1}{2}$. In this case, however, γ_{ij} 's are long-run rather than short-run price and income slopes. Estimates of equation (9) for chicken are in the last two columns of table 1.

Unrestricted and restricted estimates of each model are reported in table 1. For each commodity, the restricted model is tested against the unrestricted with the likelihood ratio test (Gallant). This

test statistic is based on a minus twice the logarithm of the likelihood ratio, which follows the chi-squared distribution with degrees of freedom equal to the number of independent restrictions tested. It is computed as $(n)\ln(\hat{\sigma}^2/\hat{\sigma}^2)$, where n is the number of observations (171 for beef, pork; 173 for chicken), $\hat{\sigma}^2$ is the estimated disturbance variance under the null hypothesis, and $\hat{\sigma}^2$ is the estimated disturbance variance under the alternative hypothesis. The computed values for beef, pork, and chicken are 13.97, 6.22, and 1.73, respectively. For beef and pork this statistic has 3 degrees of freedom, and for chicken it has 4 degrees of freedom. The critical value for beef and pork at the 5% significance level is 7.81, while the critical value for chicken is 9.49. Thus, we believe that the pork and chicken data are consistent with the hypothesized demand specifications. However, the test statistic for beef is larger than the critical value, causing us to doubt that the state adjustment model is adequate.

Structural estimates of the state adjustment model for beef and pork, and the flow adjustment model for chicken are presented in table 2. For beef

Table 2. Structural Parameter Estimates of the State and Flow Adjustment Models

	Structural Parameter Estimate						
Commodity	δ	β	Ψ	γ_b	γ_p	γ_c	γ_m
Beef	0.4263 (0.1077)	-0.0586 (0.1023)		-0.0504 (0.0104)	0.0303 (0.0085)	-0.0495 (0.0156)	19.3048 (5.9918)
Pork	0.4471 (0.0601)	-0.2155 (0.0662)		0.0339 (0.0053)	-0.0914 (0.0106)	0.0205 (0.0081)	5.6679 (1.9120)
Chicken			1.7500 (0.1415)	0.0060 (0.0099)	0.0010 (0.0061)	-0.0246 (0.0362)	12.9545 (17.8299)

Note: The structural parameter estimates for beef and pork correspond to the state adjustment model in equations (1) and (2), while the structural parameter estimates for chicken correspond to the flow adjustment model in equation (9). Standard errors of the parameter estimates (the values in parentheses) were calculated from formulas for the asymptotic variance for a function of random variables (e.g., Goldberger, p. 124).

and pork, the depreciation coefficient, δ , suggests stability. Both own-price parameters are negative, and both income parameters are positive. The results indicate that beef and pork are substitutes. However, the relationship between chicken and the other two commodities is less clear.

For both commodities the monthly stock adjustment coefficient, β , is negative, indicating that inventory behavior predominates. For pork, the stock coefficient estimate is highly significant, indicating that inventory adjustment is an important short-run feature of consumer behavior.

The stock adjustment coefficient estimate for beef, although negative, is insignificant. Since the state adjustment model was statistically rejected as well, we doubt the adequacy of this specification for beef. One reason this model might be too restrictive is that the consumption data also include lower quality, manufacturing beef, an important commodity in fast food chains. Since beef demand in fast food outlets is likely quite different from choice beef demand for home consumption, it is not surprising that the state adjustment is too restrictive for all beef purchased, and the inventory effect is found to be less important for beef than pork. More

detailed analysis is required before any firm conclusions can be drawn about monthly purchase behavior for beef.

A popular model in dynamic analysis of consumer demand is Nerlove's partial adjustment model. For the i th meat commodity, this model is

$$X_{it} = \eta(\alpha_i + \gamma_{ib}P_{bt} + \gamma_{ip}P_{pt} + \gamma_{ic}P_{ct} + \gamma_{im}M_t) + (1 - \eta)X_{it-1},$$

where η is the partial adjustment parameter. Observe that this specification is the same as equation (3) when the restrictions in (5) hold and $A_{i7} = A_{i8}$. This model is, therefore, appropriate if $\delta = 2$ (Houthakker and Taylor, chap. 2). The calculated t -values for beef and pork under the null hypothesis ($H_0: \delta = 2$) are -14.61 and -7.44, respectively. Thus, in each case, we decisively reject the partial adjustment model in favor of the state adjustment model.⁷

⁷ We have not tested for the partial adjustment model in chicken since the flow adjustment model already constrains the parameter as $1/\delta = 0$.

Table 3. Price and Income Elasticities of the Dynamic Models of Demands for Meats

	Elasticity with Respect to			
	Price of Beef	Price of Pork	Price of Chicken	Per Capita Income
Beef				
1. Short run	-0.49	0.23	-0.20	0.51
2. Long run	-0.43	0.20	-0.17	0.45
Pork				
1. Short run	0.60	-1.25	0.15	0.27
2. Long run	0.40	-0.84	0.10	0.18
Chicken				
1. Short run	0.08	0.0	-0.14	0.49
2. Long run	0.18	0.02	-0.30	1.06

Note: The elasticities are computed at the sample means. The values of per capita purchases for beef, pork, and chicken are 9.43, 5.18, and 3.09. The mean prices for these three meats are 91.27, 71.06, and 37.29. Mean per capita income is 0.25.

Implications

Price and income elasticities are presented in table 3. For beef and pork, where inventory behavior predominates, the short-run price and income elasticities are larger in absolute value than their long-run values. The response to either a change in price or income is more elastic in the short run than the long run because households can vary their stocks as well as their consumption. With pork, the own-price elasticities indicate that demand is relatively price elastic in the short run but relatively inelastic when enough time has elapsed for full adjustment to occur. The results indicate more short-run price responsiveness for pork, but about the same for beef as in past studies using monthly data (Myers and Havlicek). For chicken, we find that demand is more elastic in the long run than in the short run. The long-run income elasticity of demand is larger than expected. However the standard error of the income variable is quite large, table 2.

These results have implications for short-run retail price behavior. Many believe that retail prices remain relatively stable in the short run because of retail pricing policies (e.g., Heien). However, the beef and pork results indicate that household inventory adjustment may be important. The predominance of inventory behavior means that demand is more price elastic within a given month than over a longer period. Thus, we should observe less short-run price variability for a given change in supply because demand is relatively more elastic.

In summary, this analysis emphasizes the role of time on measured demand elasticities of meats. For pork, the results indicate inventory adjustment dominates consumption habits, implying demand is more elastic when monthly data are used. The results for chicken are consistent with the flow adjustment model, suggesting the predominance of consumption habits and less demand responsiveness in the short run. Although the beef demand estimates indicate inventory adjustment predominates, this effect is not significant, and the state adjustment model seems too restrictive. Perhaps more refined data and modeling techniques can give additional insight into monthly demand for this commodity.

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[Footnotes]

⁶ **Markup Pricing in a Dynamic Model of the Food Industry**

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