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Testing Structural Change and Estimation of U.S. Demand for Meat

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Abstract

The hypothesis of structural changes in U.S. meat demand is tested in the Rotterdam demand system using a fluctuation test developed by Ploberger, Krämer, and Kontrus. Structural changes in U.S. meat demand are identified over three periods. The revised Singh-Ullah estimation procedure for seemingly unrelated regressions with random coefficients (SURRC) is more efficient than Zellner's SUR in estimating U.S. meat demand. The results show that structural changes have significant effects on demand elasticities for beef and pork, and have mainly affected expenditure elasticity for poultry.

Key words: demand system, meat demand, structural change, fluctuation test, random coefficient estimation.

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Analysis of structural change in U.S. meat demand has been considerable interest for agricultural economists over the last decade. Some studies assumed that there is one structural change at a known point in time (Braschler, 1983; Eales and Unnevehr, 1993). However, the break point and the duration of structural change are usually not known precisely. To overcome these difficulties, many studies used the time-varying parameter approach to investigate structural change in U.S. meat demand (Chavas, 1983; Dahlgran, 1987; Moschini and Meilke, 1984, 1989). In those studies, structural changes were assumed to occur over one period or were assumed to be permanent after they happened. Ignoring the possibility of structural changes occurring over more than one period or imprecisely choosing the break point may affect the reliability of the test for structural change and result in inefficient estimation of the meat demand model.

The objectives of this paper are to detect structural changes in U.S. meat demand using the fluctuation test developed by Ploberger, Krämer, and Kontrus (PKK test) and to estimate the U.S. meat demand using random coefficient estimation. Since the performance of the well-known linear approximation of the Almost Ideal Demand System (LA/AIDS) was found to be questionable by Buse, a complete Rotterdam demand system for U.S. meat demand is estimated using the revised Singh-Ullah estimation procedure for the seemingly unrelated regression with random coefficients (SURRC).

The next section of the paper presents the Rotterdam demand system. The third section highlights the PKK fluctuation test for structural change in U.S. meat demand. The fourth section describes the estimation procedure and the data used in this study. The fifth section discusses the results. The last section contains the summary and conclusions drawn from this study.

The Rotterdam Demand System

The Rotterdam demand system, first introduced by Theil (1965) and Barten (1966), is used to estimate U.S. meat demand. Following Keller and Van Driel (1985), the basic equations of the Rotterdam model in differentials are defined as

$$w_i Dq_i = \mu_i D\left(\frac{m}{P}\right) + \sum_j^n \pi_{ij} Dp_j , \tag{1}$$

where Dx stands for the total differential of $logx$, $Dx = d(logx)$, w_i is the budget share, p_j and q_i are prices and quantities, m is total expenditure, μ is the marginal budget share, P is the Divisia price index, which is implicitly defined by

$$DP = \sum_i^n w_i Dp_i , \tag{2}$$

π_{ij} is the so-called Slutsky coefficient, and $i, j = 1, \ldots, n$ refer to commodities.

The parametric demand restrictions of Equation (1) are

$$\sum_i^n w_i = 1, \quad \sum_i^n \mu_i = 1, \quad \sum_i^n \pi_{ij} = 0 ; \tag{3}$$

$$\sum_j^n \pi_{ij} = 0 ; \tag{4}$$

$$\pi_{ij} = \pi_{ji} ; \tag{5}$$

where Equations (3), (4), and (5) represent the adding-up, homogeneity, and Slutsky symmetry restrictions, respectively.

According to Theil (1975), the Rotterdam model of Equation (1) is converted into a model of finite changes. Assume that for each finite time period, $t = 1, \ldots, T$, the information on prices and quantities and other information derived from these two variables are available. Define

$$\overline{w}_t = (w_{t-1} + w_t) / 2 , \tag{6}$$

$$\overline{D}x_t = \log x_t - \log x_{t-1}, \quad t = 1, \ldots, T . \tag{7}$$

After adding disturbance term ϵ_{it}, the finite-change of the Rotterdam model can be expressed as follows using a local quadratic approximation:

$$\overline{w}_{it} \overline{D} q_{it} = \mu_i \overline{D} \left(\frac{m_t}{P_t} \right) + \sum_j^n \pi_{ij} \overline{D} p_{jt} + \varepsilon_{it} . \tag{8}$$

The expenditure and price elasticities for the Rotterdam model can be obtained from the parameter estimates as follows:

$$\eta_i = \mu_i / \overline{w}_i , \tag{9}$$

$$e^{*}_{ij} = \pi_{ij} / \overline{w}_i , \tag{10}$$

$$e_{ij} = \pi_{ij} / \bar{w}_i - \bar{w}_j \eta_i , \qquad (11)$$

where $\bar{w}_i$ is the budget share at sample mean, η_i denotes the expenditure elasticity, and e^*_{ij} and e_{ij} represent the compensated and uncompensated price elasticities, respectively.

The PKK Fluctuation Test for Structural Change

Unlike most previous tests for structural change, the PKK fluctuation test does not require that the possible change points be known. This test is directly based on successive parameter estimates rather than on recursive residuals as in the well-known CUSUM and CUSUM of squares tests by Brown *et al.* (1975). The PKK test is more powerful against many local alternatives than the CUSUM and CUSUM of squares tests (Ploberger *et al.* 1989, P. 312-14). The PKK test examines for structural change at all points in the sample from period $K+1$ through T.

The departure points of the PKK test are the successive OLS parameter estimates as

$$\beta^{(t)} = (X^{(t)\prime}X^{(t)})^{-1}X^{(t)\prime}Y^{(t)}, \quad t = K, \ldots, T. \qquad (12)$$

The basis of the PKK test is that if the OLS estimate of any coefficient varies by more than a specific amount, as the number of observations used to estimate it changes from $K+1$ to T, the null hypothesis of constant parameters is rejected for that model and data set. More precisely, the test rejects the null hypothesis whenever there is excessive fluctuation in the quantities defined as

$$\|\beta^{(t)} - \beta^{(T)}\|_\infty = \max_{i=1,\ldots,K} |\hat{\beta}_i^{(t)} - \hat{\beta}_i^{(T)}|, \tag{13}$$

where $\|\cdot\|_\infty$ denotes the maximum norm.

The test statistic is

$$S^{(T)} = \max_{t=K,\ldots,T} \frac{t}{\hat{\sigma}T} \|(X^{(T)\prime}X^{(T)})^{1/2}(\hat{\beta}_i^{(t)} - \hat{\beta}_i^{(T)})\|_\infty, \tag{14}$$

where

$$\hat{\sigma} = [\Sigma(y_t - x_t^{\prime}\hat{\beta}^{(T)})^2/(T-K)]^{1/2}. \tag{15}$$

Estimation Procedure and Data

The system of equations in (8) can be rewritten as

$$Y = X\beta + \epsilon \tag{16}$$

where X represents a MT x K ($K = \sum_{i=1}^{M} K_i$) block-diagonal matrix; M is the number of equations; K_i is the number of independent variables in each equation; and Y, β, and ϵ are vectors of respective orders MT x 1, K x 1, and MT x 1.

Under the common assumption of a classical regression model that the regression coefficients remain constant over sample observations and $E(\epsilon_{it}, \epsilon_{jt'}) = \sigma_{ij}$ if $t = t'$, and zero otherwise, Zellner's (1962) seemingly unrelated regression (SUR) estimator for Equation 16 is consistent and asymptotically efficient. However, if the model is one with random coefficients, Zellner's SUR estimation may be viewed as imposing zero restrictions on unobserved random disturbance terms of coefficients and, thus, introducing a kind of misspecification in the model. Under this circumstance, a random coefficient estimation approach may be more preferable to deal with the structural change problems.

Extending Zellner's SUR and modifying the Hildreth-Houck (1968) estimation procedure, Singh and Ullah (1974) proposed a consistent and asymptotically more efficient estimation procedure to estimate the seemingly unrelated regressions with random coefficients (SURRC). This estimator is consistent and has the same asymptotic normal distribution as Aitken's generalized least squares. Singh and Ullah also proved that the SURRC estimator is asymptotically more efficient than Zellner's SUR estimator when the true model is one with random coefficients. However, if we impose any restrictions across equations, e.g., symmetry restriction in the Rotterdam demand system, X in Equation (16) will become a nonblock diagonal matrix. In this case, the regular Singh-Ullah procedure cannot be directly applied to estimate Equation (16) with such restrictions. In this study, we modified the Singh-Ullah procedure to estimate SURRC with across-equation restrictions.

First, the homogeneity and symmetry restrictions were imposed in Equation (16). Then, the whole system was estimated as one equation using the procedures proposed by Hildreth and Houck (1968) and Zellner's SUR. This is similar to using Zellner's SUR to estimate Equation (16) with restrictions. The estimation procedure can be viewed as a revised Singh-Ullah procedure for the estimation of SURRC with across- equation restrictions.

The Rotterdam demand system was estimated by using quarterly data on U.S. meat consumption and retail prices from the first quarter of 1960 to the fourth quarter of 1993. Three meat items (beef and veal, poultry and turkey, and pork) were included in the study.

Consumption and retail prices of beef and veal, and pork were obtained from the *Livestock and Meat Situation* (USDA). Consumption and retail prices of poultry and turkey were collected from the *Poultry and Eggs Situation* (USDA). Before estimating the model, data on consumption and expenditure of each type of meat were converted to per capita terms, and the prices were deflated by Consumer Price Index (CPI). Data on U.S. population and CPI were obtained from the *Statistical Abstract of the United States* (U.S. Department of Commerce). The average expenditure shares of meat consumption in the study period are 0.520, 0.234, 0.233, and 0.013 for beef and veal, pork, poultry, and turkey, respectively. Since the expenditure share for turkey is not significant, poultry and turkey are combined as poultry. In this study, demand for these three meats is assumed to be weakly separable with all other goods.

Empirical Results

To detect structural change for U.S. meat demand, we performed the PKK fluctuation tests on each equation of (8) and the whole demand system. The test results for structural change are reported in Table 1. Given the critical values of the PKK fluctuation test by Ploberger *et al.*, the null hypothesis of constant coefficients is rejected for each equation and for the demand system at the 99% confidence level, providing strong evidence of structural changes in U.S. meat demand over the period from 1962 through 1993. The PKK tests indicate that poultry demand equation experienced the most significant structural change during the study period, followed by pork demand. Structural change in U.S. beef demand was the least significant among the three meat demand equations.

To investigate the structural change over the sample period, the test statistics of each time period were plotted against time in Figure 1. The points above the line of critical value denote structural changes. The results indicate that all three demand equations experienced structural change during the study period.

To examine occurrences of structural changes over time, the whole sample is divided into five different periods according to the PKK test statistics over the sample period (Figure 1). In the first period (1962-1973), structural change occurred only in pork demand between 1967 and 1969. No structural changes were found in beef and poultry demands during the time period. Like most studies, significant structural changes were found in poultry and beef demand equations in the mid-1970s. Structural changes also occurred in pork demand from 1978 to 1981. However, these changes were not permanent and were abrupt in 1981. Structural changes occurred again from early 1983 to 1987 for poultry demand and from the third quarter of 1983 to the end of 1985 for beef demand (the fourth period). Structural changes in the second period (1974-1981) were more significant and lasted longer than those in the fourth period (1983-1987). Pork demand did not show any structural changes during the fourth period. There were no structural changes in the third and fifth periods.

With the strong evidence of structural change in U.S. meat demand, the Rotterdam model for U.S. meat demand was estimated by using the modified Singh and Ullah's SURRC estimation procedure. The homogeneity and symmetry restrictions were imposed in the estimation. The equation for poultry was dropped because of the adding-up condition for the model.

The coefficient estimates obtained from the SURRC procedure are presented in Table 2. Also shown are Zellner's SUR estimates for comparison. For both estimations, all the expenditure parameters differ significantly from zero at the 0.05 level. The own-price parameters, except that for poultry, are negative and statistically significant. The SURRC estimation procedure provides smaller standard errors of the estimates than does Zellner's SUR procedure (Table 2). The gain in efficiency for the SURRC estimator suggests that a random coefficient regression approach is more appropriate in estimating the Rotterdam demand system for U.S. meat demand with structural change.

The estimated expenditure and Marshallian price elasticities of the Rotterdam demand model, using the SURRC procedure, were calculated at the sample mean of expenditure share for the whole sample period and each of the five time periods (Table 3). Most demand elasticities are statistically significant at the 95% confidence level. The changes of expenditure shares over the five time periods illustrate an increasing poultry consumption and a decreasing beef consumption over the last three decades. Own-price elasticities are negative, and expenditure elasticities are positive for all meat classes. Beef and pork are close substitutes. The response of beef consumption to pork price is small, but pork consumption is sensitive to beef price. Beef and pork are complements of poutry. Demand for poultry meat is more inelastic with respect to price, but more elastic to expenditure than demand for the other two meat items.

Structural changes in U.S. meat demand are also reflected in the estimated elasticities. Expenditure elasticities for poultry demand in the second and fourth periods are less elastic than those in the periods before the structural change, while its own-price elasticities are inelastic and remain unchanged after the second period. This implies that structural changes have more income effects than price effects in U.S. poultry demand. Decreasing expenditure elasticities of poultry demand imply that poultry has become a necessity in U.S. meat demand. Own-price and expenditure elasticities for beef in the second and fourth periods are more elastic than those in the periods before structural changes and also have shown increasing trends across the five periods. The cause for structural changes in beef consumption is not clear, but beef consumption has become more sensitive to expenditure and price over the sample period. There is no significant trend for the change of expenditure elasticity of pork demand over the five periods. However, its own-price and expenditure elasticities in the two periods with structural change since mid-1970s are almost the same or more elastic than those in the two periods without structural changes.

Summary and Conclusions

This paper presents a new test to identify structural change in U.S. meat demand. The results provide strong evidence of structural changes in U.S. meat demand over the sample period. Significant structural changes in U.S. meat demand are identified over three periods (1967-1969, 1974-1981, and 1984-1987). Most previous studies have found structural changes occurred from the mid-1970s to early 1980s. Our findings provide further information about time paths of structural change in U.S. meat demand.

Since the PKK fluctuation test suggests structural changes in U.S. meat demand, the revised Singh and Ullah procedure for estimation of seemingly unrelated regressions with random coefficients (SURRC) was applied to estimate the Rotterdam demand system with random coefficients for U.S. meat demand. The empirical results indicate that the revised SURRC procedure to estimate the Rotterdam demand model for U.S. meat demand has led to smaller standard errors of estimated coefficient than those from the Zellner's SUR procedure. The gain of efficiency suggests that a random coefficient model is more suitable to estimate the Rotterdam model for U.S. meat demand with structural changes.

To examine the effect of structural changes on consumer behavior over the time periods, the elasticities from SURRC over the five different periods were estimated based on structural changes in U.S. meat demand. The results indicate significant effects of structural changes on both expenditure and own-price elasticities for beef and pork demands. Structural changes in poultry demand have mainly affected its expenditure elasticity, while the effect on its own-price elasticity was not significant over the sample period.

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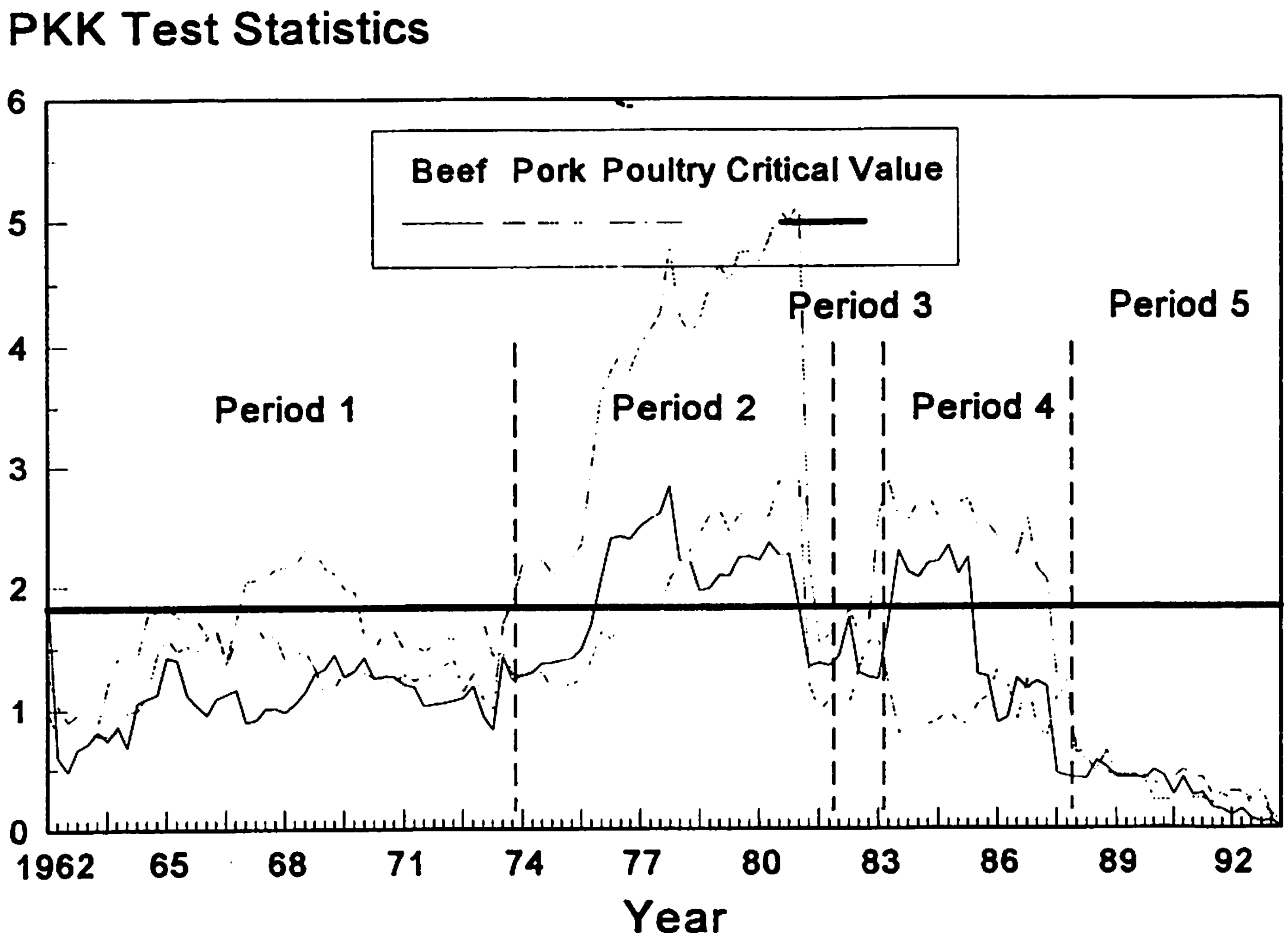

Figure 1. Structural Changes in U.S. Meat Demand, 1962-1993

Table 1. The PKK Tests for Structural Change in U.S. Meat Demand (1961-93)

Meat	Test Statistics	DF	Critical Value* ($\alpha = 0.01$)
Beef	2.84	4	1.83
Pork	2.89	4	1.83
Poultry	5.15	4	1.83
System	7.77	8	1.92

* The critical value of the test is given by Ploberger, Krämer, and Kontrus (1989).

Table 2. Coefficient Estimates of the Rotterdam Model for U.S. Meat Demand (1960-93)

Meat	i	Beef π_{i1}	Pork π_{i2}	Poultry π_{i3}	Expenditure μ_i
			SURRC		
Beef	1	-0.1296*	0.1442*	-0.0146	0.4807*
		(0.0258)	(0.0217)	(0.0133)	(0.0539)
Pork	2		-0.1440*	-0.0003	0.1780*
			(0.0242)	(0.0151)	(0.0644)
Poultry	3			0.0149	0.3393*
				(0.0173)	(0.0681)
			Zellner's SUR		
Beef	1	-0.1237*	0.1387*	-0.0150	0.4767*
		(0.0271)	(0.0225)	(0.0142)	(0.0584)
Pork	2		-0.1425*	0.0038	0.1780*
			(0.0249)	(0.0160)	(0.0681)
Poultry	3			0.0112	0.3454*
				(0.0188)	(0.0768)

* Indicates significance at 5% level.
Standard errors are enclosed within parentheses ().

Table 3. Estimated Expenditure and Marshallian Price Elasticities from SURRC at the Sample Mean

Meat	Beef	Pork	Poultry	Expenditure Share
		The Entire Sample Period (1960.I - 1993.IV)		
Beef	-0.7266*	0.0573	-0.2430*	0.5269
	(0.0698)	(0.0499)	(0.0349)	
Pork	0.2083	-0.7870*	-0.1801*	0.2372
	(0.1634)	(0.1258)	(0.0889)	
Poultry	-0.8201*	-0.3422*	-0.2761*	0.2359
	(0.1614)	(0.0953)	(0.0991)	
Expenditure	0.9123*	0.7588*	1.4384*	
	(0.1023)	(0.2714)	(0.2886)	
		The First Time Period (1960.I - 1973.IV)**		
Beef	-0.7097	0.0331	-0.1730	0.5660
Pork	0.1631	-0.7337	-0.1216	0.2611
Poultry	-1.2228	-0.5294	-0.2513	0.1729
Expenditure	0.8496	0.6922	2.0035	
		The Second Time Period (1974.I - 1981.II)**		
Beef	-0.7287	0.0799	-0.2713	0.5241
Pork	0.2354	-0.8557	-0.2244	0.2137
Poultry	-0.7646	-0.2890	-0.2807	0.2622
Expenditure	0.9202	0.8447	1.3343	
		The Third Time Period (1981.III - 1982.IV)		
Beef	-0.7238	0.0576	-0.2356	0.5332
Pork	0.2049	-0.7907	-0.1776	0.2361
Poultry	-0.8510	-0.3503	-0.2745	0.2307
Expenditure	0.9018	0.7634	1.4758	
		The Fourth Time Period (1983.I - 1987.II)**		
Beef	-0.7468	0.0849	-0.3253	0.4902
Pork	0.2635	-0.8527	-0.2517	0.2150
Poultry	-0.6387	-0.2579	-0.2873	0.2948
Expenditure	0.9872	0.8409	1.1840	
		The Fifth Time Period (1987.III - 1993.IV)		
Beef	-0.7585	0.0755	-0.3477	0.4674
Pork	0.2667	-0.8168	-0.2460	0.2271
Poultry	-0.5766	-0.2581	-0.2899	0.3055
Expenditure	1.0307	0.7961	1.1246	

* Indicates significance at 5% level.
Asymptotic standard errors are enclosed within parentheses ().
** Denotes the period with structural change in U.S. meat demand.