Price Formation and Food Safety in U.S. Meat Demand: A Semi-flexible Normalized Quadratic Inverse Demand System

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Introduction

Food contamination is a growing concern in the United State of America (US) and worldwide. Impacts of major outbreaks or isolated events (such as the recent Bovine Spongiform Encephalopathy (BSE) case in the US) on consumer demand and inverse demand relationships and international trade for meat products are key to understanding immediate market impacts and subsequent market recovery (Piggott and Marsh, 2003). The focus of the current research is to investigate the own- and cross-commodity effects of public food safety information on retail price formation for beef, pork, and poultry using an inverse demand system.

Examining the impact of food safety information reported in the media and product recall information on demand for food and agricultural markets has been a topic of considerable interest to economists, e.g. Piggott and Marsh (2003), Marsh, Schroeder, and Mintert, Brown (1969), Johnson (1988), Smith, van Ravenswaay and Thompson (1988), van Ravenswaay and Hoehn (1991), Robenstein and Thurman (1996), Lusk and Schroeder (2000), McKenzie and Thomsen (2001), Thomsen and McKenzie (2001), Dahlgran and Fairchild (1987). Public information pertaining to food safety and health concerns through the media have previously been shown to affect demand, e.g., van Ravenswaay and Hoehn (1991), Smith, van Ravenswaay and Thompson (1988), and Dahlgran and Fairchild (1987). Several of these studies have been concerned with the U.S. meat market and analyzing how public information concerning health information and product recalls impact futures markets and publicly traded companies. For example, Dahlgran and Fairchild (1987) found that adverse publicity about salmonella contamination of chicken depressed demand for chicken, but the effects were small (less than 1%), with consumer's soon forgetting this adverse publicity and reverting back to previous consumption levels.

Previous studies have investigated the impact of food safety on meat demand using a single-index for food safety information. For instance, Burton and Young (1996), as well as Burton, Young and Cromb (1999), focused on the effects of food safety on meat demand in England using a single-index based on the number of newspaper articles generated about BSE. Piggott and Marsh (2003) developed a theoretical model of consumer response to publicized food safety information on meat demand with an application to U.S. meat consumption. Evidence was found for the existence of pre-committed levels of consumption, seasonal factors, time trends, and contemporaneous own- and cross-commodity food safety concerns. The average demand response to food safety concerns was small, especially in comparison to price effects, and to previous estimates of health related issues. This small average effect masked periods of significantly larger responses corresponding with prominent food safety events, but these larger impacts were short-lived with no apparent food safety lagged effects on demand.

The two major objectives addressed in the current study are to: (1) to study consumer price formation by specifying an inverse demand model and estimating own- and cross-price flexibilities among beef, pork, and poultry; and (2) to analyze the impacts of identified public food safety concerns on prices, and also spillover effects onto other meat types.

The remaining part of this paper is organized in the following manner. The modeling framework is presented in the next section. This is followed by the sections on data and the empirical model. Then, results are presented and discussed. The paper ends with a concluding remark.

Modeling Framework

A theoretically consistent inverse demand system can be derived from a specified distance function:

(1) $$D(U,q) = \left\langle \min_{\pi} \left\{ \pi^T q : V(\pi) \geq U \right\} \right\rangle$$

where π is a vector (nx1) of normalized prices ($\pi =$ p/m), **q** is nx1 vector of consumption quantities, **p** is a vector (nx1) of prices and **m** is group expenditure. Using Shephard's lemma, the above distance function can be differentiated with respect to **q,** to give the inverse Hicksian demand expressed thus:

(2) $$\pi^h(U,q) = \nabla_q D(U,q)$$

Substituting U=U(q) into the Hicksian at the optimum point gives an observable Marshalian demand:

(3) $$\pi(q) = \nabla_q D(U(q),q)$$

The Semi-Normalized Inverse Demand System (SNQIDS), unlike most of the widely used (for demand analysis) functional forms (IAIDS, Inverse Rotterdam, Translog) that give concavity locally, maintains concavity globally at a reference vector. It has been shown to be locally flexible and enables the easy imposition of all the demand regularity conditions without losing its flexibility (Holt and Bishop, 2002). As a second order (quadratic) function, it easily approximates consumer preferences and therefore enhances exact welfare estimation. The normalized quadratic distance function is specified explicitly as:

(4) $$D(U,q) = c^T q + [b^T q + \frac{1}{2}\left(\alpha^T q\right)^{-1} q^T Aq]U^{-1}$$

where α is a vector (nx1) of predetermined parameters and, **c** and **b** are vectors (nx1) of unknown parameters to be estimated, while **A** $=[a_{ij}]$ is a matrix (nxn) of unknown parameters to be estimated (i.e U(**q**) $= \frac{\left[b^T q + \frac{1}{2}(\alpha^T q)^{-1} q^T Aq\right]}{[1 - c^T q]}$). Differentiating the distance function with respect to **q** as stated above gives the compensated demand:

(5) $$\pi_i = c_i + [b_i + (\alpha^T q)^{-1} \sum_{j=1}^{n} a_{ij} q_j - \frac{1}{2}\alpha_i \left(\alpha^T q\right)^{-2} q^T Aq]U^{-1}$$

Substituting the utility function in eq. (5), the uncompensated demand function can be easily derived to give:

(6) $$\pi_i = c_i + \frac{\left[b_i + \left(\alpha^T q\right)^{-1} \sum_{j=1}^{n} a_{ij} q_j - \frac{1}{2}\alpha_i (\alpha^T q)^{-2} q^T Aq\right]}{\left[b^T\, q + \frac{1}{2}(\alpha^T q)^{-1} q^T Aq\right]}\left[1 - c^T q\right]$$

Rewriting (6), the estimated model in share form gives;

(7) $$w_{it} = c_i q_i + \frac{\left[b_i q_{it} + (\alpha^T q_t)^{-1} \sum_{j=1}^{n} a_{ij} q_{it} q_{jt} - \frac{1}{2}\alpha_i q_{it} (\alpha^T q_t)^{-2} q_t{}^T A q_t\right]\left[1 - c^T q_t\right]}{\left[b^T q_t + \frac{1}{2}(\alpha^T q)^{-1} q_t{}^T A_t\right]} + \nu_{it}$$

Here, w_{it} is the ith meat category's share in total consumption expenditure where i =1..3, t=1..71, c_i, α and b_i are parameters to be estimated, v_{it} is the error term, and the remaining notations are as defined above. The quantity data are normalized to give unit means; that is, $q^* = I_n$. This enhances the imposition of the required conditions, while α_i *is set* $=1/n$ where n=3. In all, the homogeneity and symmetry restrictions are imposed thus;

(8) $\alpha^T I_n = 1 \qquad (b') \quad c^T I_n = 0 \qquad (c') \quad AI_n = 0_n \; \textit{and} \; A = A^T$

Since consumers' access to information is rarely instantaneous and hardly perfect, the classical demand theory assumption is relaxed in this study by incorporating the lag of the food safety concern indexes variables in the above model. This enables the analysis of dynamic consumer behavior by allowing parameters characterizing these preferences (including quality) to be incorporated. While only few number of demand analysis on meat have used explicit dynamic parameterizations (Kesavan and Buhr, 1995; Holt and Goodwin, 1997; Piggot and Marsh, 2003) in this respect, most these studies used the Almost Ideal Demand system (AIDS) and the corresponding inverse model, IAIDS.

Also, Burton *et al*. (1999) argues that the use of dummy variables for a food safety event is limited by some methodological problems (discrete, time invariant nature of dummy variables and their attendant "step nature") and inefficient in describing a continuous and evolving trend like consumers' response to health information. Their use (i.e dummy variables) also leads to biased identification of transitory effects. On the other hand, news articles have been used for this purpose in several studies (Burton and Young, 1996; Burton *et al*., 1999; Piggot and Marsh, 2003). So, food safety information variables are introduced as the number of news articles that bear any food (meat) safety concern issue. This approach has the unique advantage of capturing the dynamics of information dissemination process, without the possible econometric problem of multi-collinearity between independent variables. In this way, the immediate short-term and lagged effects of the food safety information are both investigated.

Demographic variables are translated into equation 7 through the intercept term c_i as:

(9) $\tilde{c}_i = c_{i0} + c_{i1} * qtr_1 + c_{i2} * qtr_2 + c_{i3} * qtr_3 + c_{i4} tr_i + c_{i5} bf + c_{i6} pk + c_{i7} py$

where c_{i0} is pre-committed quantity of meat type i, c_{i1}, c_{i2}, c_{i3} are the coefficients of seasonal dummies for the first three quarters of the year, while c_{i4} is the coefficient of trend variable. In this form, no restriction is imposed on the seasonal, trend and food safety effect variables. This also allows the effect (in terms of seasonality and trend) to be tested. Therefore substituting $\tilde{c}_i$ in equation 7 we have;

(10) $$w_{it} = \tilde{c}_i q_i + \frac{\left[b_i q_{it} + (\alpha^T q_t)^{-1} \sum_{j=1}^{n} a_{ij} q_{it} q_{jt} - \frac{1}{2} \alpha_i q_{it} (\alpha^T q_t)^{-2} q_t{}^T A q_t \right] \left[1 - \tilde{c}^T q_t \right]}{\left[b^T q_t + \frac{1}{2} (\alpha^T q)^{-1} q_t{}^T A_t \right]} + \varepsilon_{it}$$

The food safety concern indices are similarly translated with c_{i5}, c_{i6} and c_{i7}, representing coefficients of beef, pork and poultry indexes respectively, while coefficients of lagged food safety indices for beef, pork and poultry are c_{i8}, c_{i9} and c_{ii0} respectively. The unrestricted model, is therefore the one containing all the demographic variables (i.e both contemporaneous and lagged food safety indices). Two restricted models are examined. One incorporates only a BSE index, while the other contains only contemporaneous (current) food safety indices for beef, pork, and poultry separately.

In line with several previous studies on meat demand (Eales and Unnevehr, 1988; Martin and Porter, 1985; Eales and Unneverhr, 1994; Kesavan and Buhr, 1995; Burton *et al*., 1999; Holt and Goodwin, 1997; Fousekis and Revell, 2002; Piggot and Marsh, 2003), meat is assumed to be weakly separable. With the model specified in the above stated manner, the poultry equation (one of the three equations) was deleted to avoid singularity of the covariance matrix. This procedure has no effect on whichever equation is dropped. So, the estimation was done on beef and pork and estimates for the poultry were recovered using the imposed regularity restrictions (homogeneity and symmetry). Estimating equation 7 gives the model without food safety effects, while the effects of the food safety variables are determined by estimating equation 10 (model with current and lagged food safety indexes). The iterated non-linear estimation in Shazam is used for estimation.

Data

The quantity data used are per capita disappearance data from United States Department of Agriculture (USDA), Economic Research Service (ERS) supply and utilization tables for beef, pork and poultry. The quarterly meat prices for beef, pork and poultry (chicken and turkey) were obtained from the same source. While the beef price is the average retail price of choice beef, the poultry price is the linear sum of the quarterly expenditures on chicken (average retail price of whole fryers) and quarterly expenditures on turkey (average retail price of whole frozen birds), divided by the sum of the per capita disappearance on chicken and turkey. The data span the quarterly period 1982(1)-1999(3). Food safety indices computed from fifty (50) English language newspapers (1982-1999) for each of the meat types were obtained from Piggott and Marsh (2003)[1].

[1] Academic version of Lexis-Nexis search tool and keywords like food safety or contamination, product recall, food borne disease etc were used by the authors to search for relevant articles with respect to the selected meat types (beef, pork, turkey and chicken).

Analysis and Discussion

A summary statistics of the entire data (excluding the binary variables) used is presented in Table 1 while fig 1 gives a graphical summary of the price data. From a relatively small number of articles in the study period (1982-1988), a significant increase is noticed in beef safety concern articles beginning in 1988 (Fig 2), coinciding with the reported BSE crisis in Europe. Beef shows the highest average number of articles (174.2) over the period, with a standard deviation of 24.5, while pork series shows the least (43.1 articles) and standard deviation of 46.9. Poultry series has a mean value of 153.0 articles and standard deviation of 135.7. Disease crisis on pork did not witness any dramatic increase like these until the second quarter of 1999 when there was the pork dioxin outbreak in Europe (Piggott and Marsh, 2003). Unlike the remarkable changes in quantity demand over the sample period, prices of the meat types have been relatively stable (Fig 1).

Preliminary estimation revealed existence of autocorrelation in the data. This was corrected using the Auto command in Shazam. Therefore, the estimated rho values are statistically significant (5% level) in all cases. Estimated parameters are as shown in Tables 2. All the three cases considered exhibited high predictive ability of over 0.89, as reflected by their respective R-squares shown in Table 2.[2] This shows that the model provides a good fit in explaining per capita consumption pattern of consumers over the study period. Over 90% of the variations in the data are explained in the unrestricted model (containing both contemporaneous and lagged variables). Also, all the seasonal variables were statistically significant at 5% level indicating that seasonality is an important factor in meat prices. While there is a negative effect on the price of pork

[2] As shown in Table 2, the unrestricted model, containing both lagged and contemporaneous variables however exhibited the highest R^2.

indicating that pork price falls for the first three quarters of the year relative to the fourth quarter, price of beef exhibits the opposite effect. This is consistent with the fact that more poultry meat is bought by the consumers during thanksgiving season and Christmas, relative to pork.

We incorporated and tested in the model both a single BSE index and sets of contemporaneous and lagged beef, pork, and poultry indices. Neither the BSE index for meat nor the contemporaneous indices were statistically different form zero in the two restricted models. However, the lagged safety indices of beef on beef (lbbf), and beef on pork (lpbf) were statistically significant at 5% level (Table 2). In line with *a priori* expectation, the own effect of the food safety index is negative, while the cross-effect (lagged safety index of beef on pork) is positive. For example, flexibility of the beef's lagged own index (lbbf) shows that a 100% increase in public food safety information on beef causes own price to fall by 0.08%. A similar increase in the publicized safety information on pork increases the price of beef by 0.04%. The small effects are in agreement with the findings of Piggott and Marsh (2003), where they found a small effects on quantity of meat demanded.

Price flexibilities (compensated and uncompensated) for the meat types (Table 2) exhibit the expected negative own price effects. All the flexibility estimates are lower than unity showing that all meat types are price inflexible to quantity changes. The cross flexibilities (compensated) estimates also show that each meat type is a net q-substitute for the other. These differ from the corresponding uncompensated estimates which are all negative, reflecting the scale effects in all cases. So, the uncompensated price flexibilities show that complementary relationship (i.e they are gross q-complements) exists among the meat types. For instance, in the unrestricted model (Table 2c), the compensated flexibilities for beef and pork show that a percentage increase in their respective quantities, causes own price to fall by 0.16 and 0.32%. On the other hand, the uncompensated flexibilities for the beef, pork and poultry indicate that a percentage increase in the quantities of pork, poultry and beef induces their cross prices to fall by 0.16, 0.11 and 0.39% respectively.

Estimates of the consumption scale flexibilities (Table 5) show that beef is a necessity good as indicated by the low estimates (scale flexibility < -1), while pork is (surprisingly) shown to be a luxury good. In all, the estimates show the changes in normalized prices brought about by a proportional change in all quantities (change in the scale of consumption). For instance, as the consumption of all goods increases by 1%, the marginal utility of beef consumption declines by proportionately less than 1% (0.99)%, while marginal pork consumption decreases by proportionately more than 1% (1.07) and in the unrestricted model. This shows that the price of pork is more responsive (flexible) to food expenditure changes than other meat types. The flexibility estimates are consistent with those reported by Holt and Goodwin (1997).

Conclusion

This paper investigates the impact of publicized food safety information on consumer price formation of meat (beef, pork, and poultry). Own- and cross-price flexibilities of the major meat types were also estimated. Using the SNQIDS model proposed by Holt and Bishop (2002), *preliminary results* show a statistically significant seasonal impact on meat price. *Preliminary analysis* also indicates that contemporaneous food safety concern information do not have statistically significant impacts on the price of meat, while some lagged food safety concerns are found to be significant.

These results are consistent with Piggott and Marsh in that market responses are small in comparison to quantity and scale factors. However, further work is needed to examine how food safety variables should be incorporated into the semi-normalized inverse demand system, before definitive conclusions can be reached.

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Fig 1

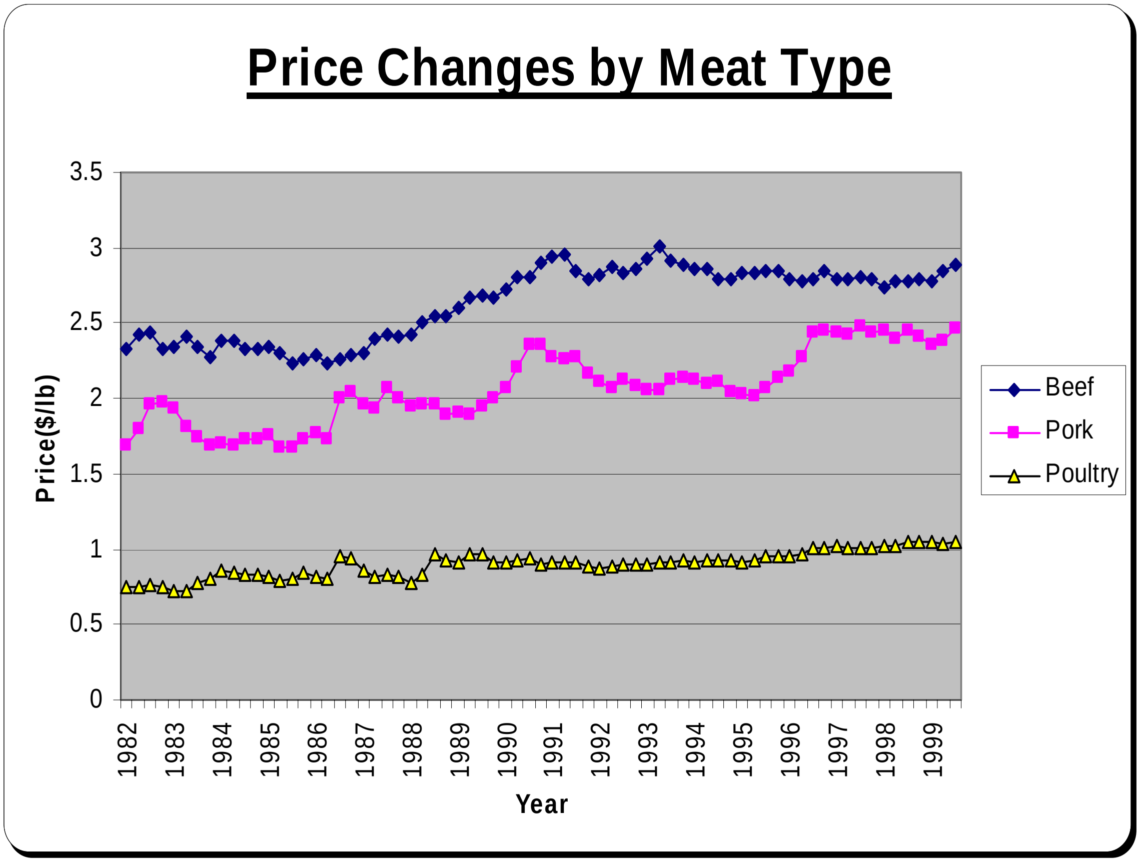
Price Changes by Meat Type
3.5
3
2.5
2
1.5
1
0.5
0
Price($/lb)
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
Year
Beef
Pork
Poultry

Fig 2

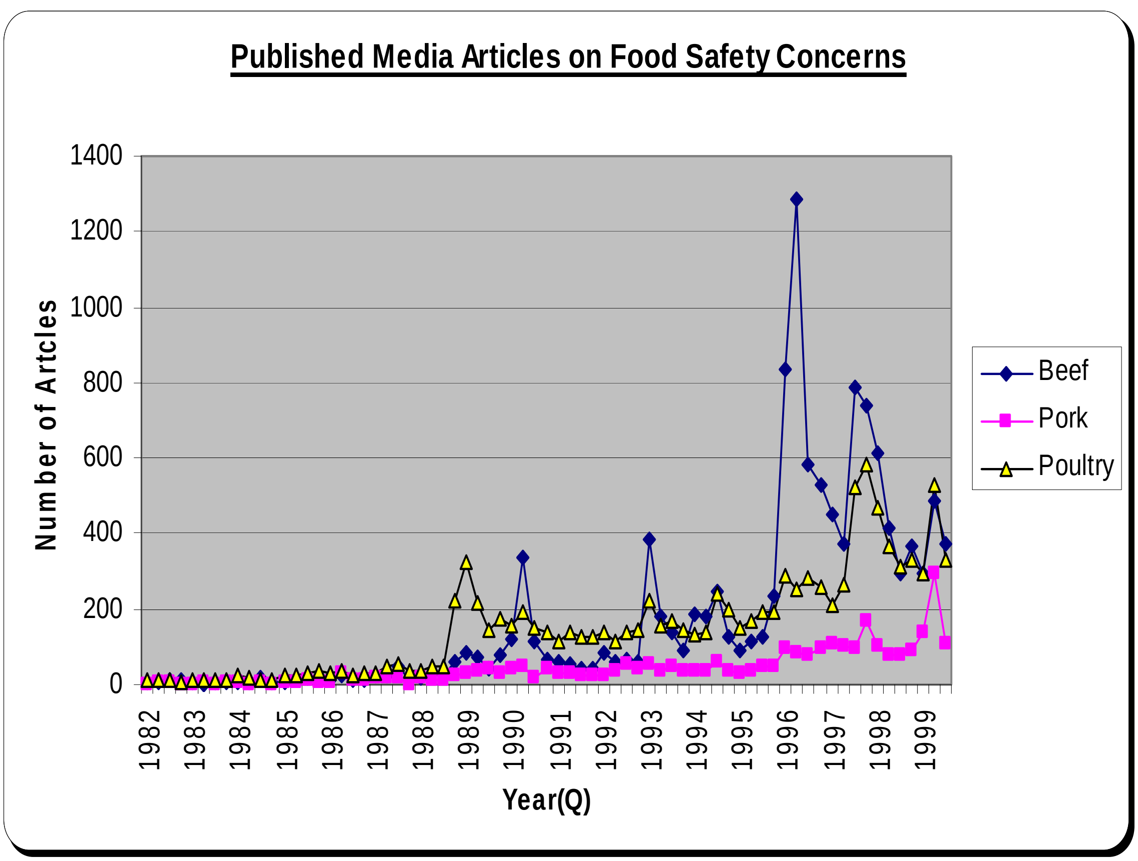
Published Media Articles on Food Safety Concerns
1400
1200
1000
800
600
400
200
0
Number of Artcles
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
Year(Q)
Beef
Pork
Poultry

Table 1 **Summary Statistics of Quarterly Data, 1982(1)-1999(1)**

VAR	N	MEAN	ST.DEV	VARIANCE	MINIMUM	MAXIMUM
TR	70	36.514	20.348	414.02	2	71
YEAR	70	1990.5	5.0983	25.993	1982	1999
QRT	70	2.5	1.1132	1.2391	1	4
QBEEF	70	17.687	1.4244	2.029	15.792	20.817
QPORK	70	12.711	0.68178	0.46483	11.334	14.329
QCHICK	70	15.731	2.2085	4.8776	11.69	19.547
QTURK	70	3.9061	1.2183	1.4844	1.9057	6.4494
QPOUL	70	19.637	2.9186	8.5182	14.243	24.767
PBF	70	264.22	23.864	569.48	222.73	300.4
PPK	70	207.17	23.945	573.35	167.83	248.07
PCK	70	87.987	9.9309	98.623	68.733	107.33
PTK	70	100.02	4.6226	21.368	90.8	109
PPY	70	0.9028	8.50E-02	7.23E-03	0.72105	1.0513
EXP	70	90.655	7.6504	58.529	78.191	106.84
BF_SHARE	70	0.51498	3.81E-02	1.45E-03	0.43265	0.58557
PK_SHARE	70	0.28954	1.45E-02	2.09E-04	0.26476	0.32122
PY_SHARE	70	0.19548	2.94E-02	8.66E-04	0.13293	0.24613
BF	70	176.59	245.89	60464	3	1283
PK	70	43.7	46.963	2205.5	0	292
PY	70	155.07	135.6	18389	6	582

Table 2 **FLEXIBILITY ESTIMATES**

	(a) with BSE index			b) with Contemporaneous Safety effects			(Restricted Model) c) With Lagged Safety Effects		
COMPENSATED									
	Beef Qty	Pork Qty	Poultry Qty	Beef Qty	Pork Qty	Poultry Qty	Beef Qty	Pork Qty	Poultry Qty
Price									
beef	-0.16511	0.133324	0.031791	-0.1572	0.130209	0.026992	-0.15735	0.127552	0.029799
pork	0.236717	-0.32297	0.086258	0.231187	-0.33242	0.10123	0.22647	-0.32311	0.096639
poultry	0.083604	0.127762	-0.21137	0.070984	0.149939	-0.22092	0.078366	0.14314	-0.22151
UNCOMPENSATED									
beef	-0.66415	-0.14774	-0.15797	-0.66136	-0.15374	-0.16471	-0.6689	-0.16056	-0.16472
pork	-0.3424	-0.64914	-0.13395	-0.33014	-0.64857	-0.11222	-0.32211	-0.63208	-0.11196
poultry	-0.37371	-0.12981	-0.38526	-0.39921	-0.11489	-0.39972	-0.39127	-0.12137	-0.40008

Table 3 **SCALE FLEXIBILITY ESTIMATES**

	With BSE	Contemp. Safety -Effects	Lagged Effects
Beef	-0.97073	-0.98069	-0.99508
Pork	-1.12651	-1.09191	-1.06711
Poulty	-0.88958	-0.91464	-0.91354

Table 4. Food Safety Effects

	Models with only Contemporaneous Effects	Model with Contemporaneous and Lagged Effects
bbf	-0.0001809	-0.0002001
bpk	-0.0001416	-0.0003086
bpy	0.0010722	0.0011864
lbbf		-0.0008254
lbpk		-0.0004170
lbpy		0.0009608
pbf	-0.0000642	-0.0000456
ppk	-0.0003401	-0.0001533
ppy	0.0005325	0.0003967
lpbf		0.0008843
lppk		0.0004104
lppy		-0.0009511