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Measuring the Welfare Impact of Asymmetric Price Transmission

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Several previous studies report that prices are asymmetrically transmitted across levels in US commodity markets, but the evidence about the economic magnitude of the phenomenon is limited. In this paper, we use estimated asymmetric error correction models (ECM) for producer, wholesale, and retail pork and beef prices to compute the compensating variation associated with asymmetric price transmission for US consumers. Overall, the phenomenon does not have a substantial impact—the expected welfare loss for the average US beef and pork consumer is about $1.10 per year, which is less than 1% of annual per–capita retail expenditures.

INTRODUCTION

Prices are said to be asymmetrically transmitted across market levels if the downstream (e.g., retail) prices respond to upstream (e.g., producer or wholesale) price increases and decreases at different rates. Over the past several years, researchers have reported statistically significant evidence of asymmetric price transmission in a broad range of commodity markets in the US and other countries. Although the findings are not uniform across studies, the typical pattern observed in the data indicates that wholesale or retail prices respond more quickly when producer prices are rising than when producer prices are falling. Despite the large amount of this statistical evidence, the behavioral origins of asymmetric price transmission are difficult to establish from a given set of data. Consequently, economists have proposed several plausible explanations, including asymmetric marketing costs (e.g., Blinder, Canetti,, Lebow, and Rudd, 1998), imperfect competition (Reynolds, 1982; Kovenok and Widdows, 1998), menu costs (Ball and Mankiw, 1994), production lags and inventory management practices (Blinder, 1982; Reagan and Weitzman, 1982), and search costs (Benabou and Gertner, 1993).

Given the large number of possible explanations, we cannot empirically identify the exact behavioral source of asymmetric price transmission for a particular market. However, we can use observed market outcomes to estimate the magnitude of the phenomenon in order to determine its economic significance. For example Borenstein, Cameron, and Gilbert (1997) and Bettendorf, Geest, and Varkevisser (2003) estimated the impact of the phenomenon on retail gasoline expenditures in the US and Dutch markets. Although this approach provides a rough measure of the impact of asymmetric pricing on consumers, we know that there are more appropriate measures of welfare impacts resulting from price changes. In this paper, we estimate the consumer welfare impact of asymmetric price transmission with compensating variation, which can be computed from Marshallian demand equations with the main algorithm proposed by Vartia (1983). To demonstrate, we estimate the annual per–capita and aggregate compensating variation in the US beef and pork markets, which have received considerable attention in the previous literature on asymmetric price transmission.

The remainder of the paper is organized as follows: in the next section, we present recent evidence of asymmetric price transmission in the US pork and beef markets. In section 3, we specify and estimate AIDS and Rotterdam models of the US retail meat demand system. In section 4, we review the properties of the compensated welfare measures and outline the method used to estimate the compensation variation associated with asymmetric price transmission. Concluding remarks appear in the final section.

EVIDENCE OF ASYMMETRIC PRICE TRANSMISSION: US PORK AND BEEF MARKETS

Several previous studies report evidence of asymmetric price transmission in many agricultural markets. The beef and pork markets have attracted a considerable amount of this attention because the products represent a relatively large share of consumer retail food expenditures. Also, the identity of the goods are largely preserved as the products move through the processing sector, so estimates of the cross–level price relationships are meaningful. The relevant literature for the pork and beef markets includes Abdulai (2002), Azzam (1999), Boyd and Brorsen (1985, 1988), Goodwin and Harper (2000), Goodwin and Holt (1999), Miller and Hayenga (2001), Schroeder (1998), Schroeder and Hayenga (1987), and Von Cramon–Taubadel (1998). The asymmetric price transmission phenomenon has also been addressed in the popular press, but the issue is typically associated with isolated incidents, especially when farm prices are historically low (see the New York Times article cited by Peltzman, 2002). For example, meat producers hae

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complained that retailers quickly increase meat prices as farm prices rise, but retail meat prices do not fall as quickly when farm prices drop. However, the statistical evidence presented in this literature indicates the phenomenon is not associated with isolated market events—— it occurs in more subtle yet pervasive ways as downstream prices respond to upstream price changes.

For purposes of this study, we use monthly price series from January, 1987, to December, 2003 (204 observations). The pork price series are trend stationary and the beef price series are cointegrated, so we use the following error correction (EC) models to represent the relationships across market levels for both markets.

$$\Delta R_t = \alpha_1 + \beta_{11}\Delta R_{t-1} + \beta_{21}\Delta R_{t-2} + \beta_{31}\Delta W_t + \beta_{41}\Delta W_{t-1} + \beta_{51}\Delta W_{t-2} + \beta_{61}\Delta R^+_{t-1} + \beta_{71}\Delta W^+_t + \beta_{81}\Delta W^+_{t-1} + \gamma_1(W_{t-1} - \upsilon_1 R_{t-1}) + \sum_{i=1}^{11}\delta_{i1}D_{it} + \varepsilon_{1t} \quad (1)$$

$$\Delta W_t = \alpha_2 + \beta_{12}\Delta W_{t-1} + \beta_{22}\Delta W_{t-2} + \beta_{32}\Delta F_t + \beta_{42}\Delta F_{t-1} + \beta_{52}\Delta F_{t-2} + \beta_{62}\Delta W^+_{t-1} + \beta_{72}\Delta F^+_t + \beta_{82}\Delta F^+_{t-1} + \gamma_2(F_{t-1} - \upsilon_2 W_{t-1}) + \sum_{i=1}^{11}\delta_{i2}D_{it} + \varepsilon_{2t} \quad (2)$$

Where $\Delta F_t = F_t - F_{t-1}$ is farm price difference and ΔF^+_t = max (0, ΔF_t) is the positive farm price difference. The same variable name rule also applies to the wholesale (W_t) and retail (R_t) price variables. The causal structure of the model is based on Granger's causality test and the block exogeneity test, and the number of lags is selected under the AIC and SBC criteria. Also, we note that these EC models include current variables on the righthand–side due to the relatively short span of time in which the prices are determined in all three market levels. Although this form of the EC model is not commonly used in the general time series literature, we adopt this specification following standard practice in the symmetric pricing literature. Accordingly, we estimate the parameters in Equations (1) and (2) with instrumental variable (IV) methods due to the endogeneity of the righthand–side variables.

The IV estimation results for the pork and beef models are presented in Tables 1 and 2. The primary test for asymmetric price transmission across market levels is based on the joint null hypotheses, H_0: $\beta_{71} = \beta_{81} = 0$ and H_0: $\beta_{72} = \beta_{82} = 0$, which are evaluated with Wald statistics (asymptotically chi–square (2) under H_0). The Wald statistic is 10.06 (p–value=0.0001) for the retail pork equation and 0.96 (p–value=0.3841) for the wholesale pork equation. The Wald statistic is 8.57 (p–value=0.0002) for the retail beef equation and 5.86 (p–value=0.0031) for the wholesale beef equation. Thus, the Wald test results indicate significant evidence of asymmetric price transmission from the farm to wholesale market levels for both pork and beef and from the wholesale to retail market in the beef market.

Tests for other forms of asymmetric price transmission may also be conducted with the EC models. For example, the present form of H0 represents short–term asymmetries in the price response across market levels. We also conducted test for asymmetric response in the error–correction components of (1) and (2), which reflects long–term asymmetric price transmission. The

Table 1. Estimated pork error correction models, 1987–2003

Coefficient	Retail–Wholesale equation			Wholesale–farm equation		
	Parameter estimate	t stat	p value	Parameter estimate	t stat	p value
α	–0.48254	–0.64	0.5214	0.940579	1.3	0.1951
β_1	–0.0175	–0.1	0.9166	1.474019	9.13	<0.001
β_2	0.201221	2.25	0.0254	–0.16928	–1.82	0.0706
β_3	0.229868	4.86	<0.001	0.219778	3.36	0.0009
β_4	–0.38553	–3.07	0.0025	0.117861	1.01	0.3133
β_5	0.163863	2.61	0.0098	–0.26385	–3.24	0.0014
β_6	0.164091	0.8	0.4272	–0.84287	–4.42	<0.001
β_7	0.124749	0.9	0.3699	0.209057	1.59	0.1129
β_8	0.314897	1.68	0.0937	–0.12939	–0.72	0.4708
γ	0.032385	1.9	0.0596	0.063573	2.66	0.0084
δ_1	0.421769	0.45	0.6514	–2.78712	–3.14	0.0019
δ_2	0.691707	0.81	0.4171	–1.91118	–2.12	0.0356
δ_3	0.020613	0.02	0.9822	0.964801	0.99	0.3254
δ_4	–2.03516	–2.29	0.0231	–0.29281	–0.34	0.7336
δ_5	0.663741	0.71	0.4758	–0.22277	–0.25	0.8054
δ_6	1.391776	1.45	0.1489	–0.56174	–0.6	0.5525
δ_7	0.299998	0.31	0.7583	–0.42981	–0.46	0.6464
δ_8	1.380823	1.5	0.1349	1.700018	1.88	0.0616
δ_9	–0.32281	–0.32	0.7492	3.806475	3.37	0.0009
δ_{10}	–0.69608	–0.75	0.4521	2.425258	2.68	0.0079
δ_{11}	–0.66584	–0.72	0.4706	2.896754	2.57	0.0111

System R^2 = 0.7031, n = 204

Table 2. Estimated beef error correction models, 1987–2003

Cofeficient	Retail–Wholesale equation			Wholesale–farm equation		
	Parameter estimate	t stat	p value	Parameter estimate	t stat	p value
α	–1.93806	–2.14	0.0334	0.90832	1.01	0.3143
β_1	0.182088	0.9	0.3696	2.097499	9.86	<.0001
β_2	0.039241	0.41	0.6858	0.113884	0.9	0.3717
β_3	0.262559	4.62	<.0001	0.169466	1.71	0.0885
β_4	–0.16014	–0.97	0.3353	–0.15543	–1.26	0.2097
β_5	–0.18267	–2.47	0.0144	–0.22728	–2.61	0.0097
β_6	–0.11826	–0.5	0.6157	–1.26769	–5.15	<.0001
β_7	0.46033	3.31	0.0011	–0.10206	–0.54	0.5905
β_8	0.156964	0.76	0.4502	0.135288	0.77	0.4403
γ	0.058761	2.72	0.0071	0.081116	1.89	0.061
δ_1	0.467866	0.4	0.6906	–0.55216	–0.49	0.6238
δ_2	1.310101	1.13	0.2587	–1.87023	–1.7	0.0915
δ_3	2.539119	2.21	0.0284	–0.71898	–0.65	0.5149
δ_4	4.126708	3.63	0.0004	1.187686	1.1	0.2735
δ_5	1.145974	1	0.3166	5.385242	4.86	<.0001
δ_6	1.323267	1.07	0.2862	3.122259	2.39	0.0179
δ_7	1.310608	0.98	0.3295	0.487108	0.38	0.7063
δ_8	2.802273	2.25	0.0254	2.168118	1.81	0.0713
δ_9	1.257448	1.03	0.3045	0.760616	0.66	0.5097
δ_{10}	1.26945	1.03	0.28	1.242116	1.11	0.2694
δ_{11}	4.604557	4.04	<.0001	–0.66081	–0.61	0.5426

System R^2 = 0.7185, n = 204

results of these tests were not statistically significant and agree with the evidence from Tables 1 and 2 that indicates the estimates of the current coefficients (β_{71} and β_{72}) have larger t–statistics than the lagged coefficients (β_{72} and β_{82}). These findings are also compatible with much of the previous empirical research on asymmetric pricing, which suggests that the phenomenon is largely due to short–term pricing decisions rather than long–term behavior.

QUANTITY RESPONSES TO ASYMMETRIC PRICE TRANSMISSION

To calculate the welfare effects of asymmetric price transmission, we also need to determine the quantity response to the monthly price changes. In this section, we describe our estimates of Almost Ideal Demand System (AIDS) and the Rotterdam demand models for US aggregate retail meat consumption. We use two distinct demand models in order to check the robustness of our welfare analysis. For purposes of this research, we model beef, pork and chicken consumption as a meat demand system. Although we are not primarily concerned with the poultry market for our study of asymmetric price transmission, poultry is an important component of US meat consumption. The estimated demand models are based on USDA quarterly data on beef, pork, and chicken prices and consumption from the first quarter of 1992 to the last quarter of 2001 (88 observations).

Although we would prefer to use monthly price and consumption data to match our asymmetric EC models from the previous section, monthly beef and pork consumption are not available for the full sample period. To overcome this problem, we use the interpolation method devised by Chow and Lin (1971) to estimate the missing monthly beef and pork consumption data based on the available quarterly consumption data plus monthly observations on a related series (slaughter quantities). The estimated regression model used to interpolate the consumption data is :

$$C_t = \alpha + \beta * t + \gamma_1 * S_t + \gamma_2 * S_{t-1} + \gamma_3 * S_{t-2} + \varepsilon_t \tag{3}$$

Where C is the meat consumption, S represents the meat slaughter, t is a trend variable, and ε is the error term. First, the monthly slaughter data are aggregated to quarterly observations, and the model is estimated from the quarterly slaughter and consumption data. Then, the model residuals are divided by three to estimate the monthly innovations in the consumption data. Finally, the fitted model and monthly residuals are used to interpolate the monthly consumption values from the monthly slaughter data. To check the validity of the constructed data set, we use the observed quarterly and estimated monthly consumption data to estimate the AIDS and Rotterdam demand systems (details provided below). The estimated demand elasticities are very similar under the quarterly and monthly models and are comparable to values reported in the meat demand literature. We conclude that the interpolated data are suitable for modeling aggregate consumer quantity response in the US retail meat markets.

The estimated AIDS model takes the following form:

$$w_i = \alpha_i + \sum_{j=1}^{3} \gamma_{ij} \ln p_j + \beta_i \ln(X/P) + s_{i1} D_1 + \ldots + s_{i11} D_{11} + \theta_i {*} t + \varepsilon_i \quad (4)$$

Where wi is the expenditure share for product i=1,…,3, the total expenditure is $X = p_b q_b + p_p q_p + p_c q_c$, and the price index is $\ln P = \sum_{i=1}^{n} w_i \ln p_i$. The expenditure shares sum to one, so we only need to estimate two of the three equations under the restrictions $\sum_{i=1}^{n} \gamma_{ij} = 0$ (homo geneity) and $\gamma_{ij} = \gamma_{ji}$ (symmetry). We also include a trend variable (t) and monthly dummy variables (D_1… D_{11}) to account for trend and seasonal effects. The estimated AIDS model parameters are reported in Table 3. To compute the welfare impact of asymmetric price transmission, we must compute the monthly quantity demanded conditional on prices and expenditures under the fitted AIDS model. Under the model in (4), we derive

Table 3. Parameter estimates for the AIDS demand models

Variable	Beef			Pork		
	Estimate	Standard error	t–ratio	Estimate	Standard error	t–ratio
Intercept	0.86019	0.07536	11.41	0.023071	0.04710	0.4899
$\ln P_{beef}$	0.19398	0.02429	7.986	–0.084265	0.01243	–6.780
$\ln P_{pork}$	–0.084265	0.01243	–6.780	0.10439	0.01059	9.853
$\ln P_{chick}$	–0.10972	0.02280	–4.812	–0.02012	0.01346	–1.495
$\ln (X/p)$	–0.18554	0.02811	–6.601	0.11750	0.01779	6.604
D_1	0.022186	0.005147	4.310	–0.024481	0.003256	–7.520
D_2	0.037397	0.004893	7.642	–0.034225	0.003095	–11.06
D_3	0.00034919	0.004932	0.0708	–0.013746	0.003123	–4.402
D_4	0.029654	0.005073	5.845	–0.025771	0.003213	–8.021
D_5	0.026981	0.004900	5.506	–0.044754	0.003103	–14.42
D_6	0.046518	0.005047	9.216	–0.051497	0.003195	–16.12
D_7	0.042815	0.004941	8.665	–0.043711	0.003129	–13.97
D_8	0.029839	0.005121	5.827	–0.034960	0.003243	–10.78
D_9	0.035711	0.005181	6.892	–0.027203	0.003277	–8.300
D_{10}	0.012987	0.005272	2.463	–0.012034	0.003339	–3.604
D_{11}	0.023622	0.004916	4.805	–0.0055931	0.003114	–1.796
Trend	–0.0027839	0.001519	–1.832	–0.0057833	0.0009366	–6.175
	$R^2 = 0.8167$			$R^2 = 0.8659$		

Table 4. Parameter estimates for the Rotterdam demand models

Variable	Beef			Pork		
	Estimate	Standard error	t–ratio	Estimate	Standard error	t–ratio
Intercept	–0.021157	0.01043	–2.028	0.0035066	0.004949	0.7085
$\Delta \ln P_{beef}$	–0.15078	0.1180	–1.278	0.090089	0.06295	1.431
$\Delta \ln P_{pork}$	0.090089	0.06295	1.431	–0.096913	0.05965	–1.625
$\Delta \ln P_{chick}$	0.060687	0.08442	0.7189	0.0068237	0.04186	0.1630
$\Delta \ln (Q)$	0.33340	0.03670	9.086	0.39241	0.01725	22.75
D_1	0.042854	0.009717	4.410	–0.029319	0.004622	–6.343
D_2	0.042017	0.008808	4.770	–0.017000	0.004188	–4.059
D_3	–0.019329	0.009012	–2.145	0.016962	0.004230	4.010
D_4	0.053518	0.009254	5.783	–0.018929	0.004359	–4.343
D_5	0.019379	0.008844	2.191	–0.023376	0.004228	–5.529
D_6	0.040622	0.009263	4.385	–0.013113	0.004443	–2.951
D_7	0.019052	0.008862	2.150	0.0023550	0.004275	0.5509
D_8	0.0069394	0.009050	0.7668	0.0040116	0.004327	0.9272
D_9	0.028588	0.008978	3.184	0.0017801	0.004219	0.4219
D_{10}	–0.0014863	0.008858	–0.1678	0.010538	0.004160	2.533
D_{11}	0.039099	0.008753	4.467	–0.0019668	0.004109	–0.4786
Trend	–0.00044245	0.002077	–0.2130	0.00050565	0.0009777	0.5172
	$R^2 = 0.7358$			$R^2 = 0.9080$		

$$q_i = (\alpha_i + \sum_{j=1}^{3} \gamma_{ij} \ln P_{ij} + \beta_i \ln(X/P) + s_{i1}*D_1 + \ldots + s_{i11}*D_{11}$$
$$+ \theta_p*t)*X/P_i \qquad (5)$$

For product i=1,…,3.

The Rotterdam meat demand model takes the form

$$\overline{w_{it}}(\Delta \ln q_{it}) = \sum_j \gamma_{ij} \ln P_{jt} + \beta_i \Delta \ln Q_t + s_{i1}D_{1t} + \ldots + s_{i11}*D_{11t}$$
$$+ \theta_i*t + \varepsilon_{it} \qquad (6)$$

Where $\overline{w_{it}} = (w_{it} + w_{it-1})/2$, $\Delta \ln p_{jt} = \ln(q_{it}/q_{it-1})$, and $\Delta \ln Q_t = \sum_j \overline{w_{jt}} \Delta \ln q_{jt}$, and the trend and seasonal dummy variables are defined as before. As with the AIDS model, we only have to estimate two of the three equations, and the restrictions $\sum_{j=1}^{3} \gamma_{ij} = 0$ (homogeneity) and $\gamma_{ij} = \gamma_{ji}$ (symmetry) are imposed. The estimated coefficients for the Rotterdam models of the pork and beef demand equations are reported in Table 4.

To derive the quantity of pork and beef demanded for the welfare analysis, we must solve the following nonlinear equation.

$$\delta_1*q*\ln q + \delta_2*q + \delta_3 q = \mu$$

Where $\delta_1 = p_i$, $\delta_2 = -p_i \ln p_{it-1}$, $\delta_3 = p_{it-1}*q_{it-1}*X/X_{t-1}$, and

$$u = 2*(\alpha_i + \sum_{j=1}^{3} \beta_{ij}(\ln p_{jt} - \ln p_{jt-1}) + \gamma_i \sum_{j \neq 1} \overline{w_{jt}} \Delta \ln q_{jt}$$
$$+ s_{i1}*D_1 + \ldots + s_{i11}*D_{11} + \theta_i*t/(1-\gamma_i)$$
$$+ p_{it-1}*q_{it-1}*X_t*\ln q_{it-1})/X_{t-1} \qquad (8)$$

The estimated AIDS and Rotterdam models are similar to those reported elsewhere in the literature. For example, the estimated own–price elasticities of pork demand are roughly the same in the AIDS and Rotterdam models. In contrast, the own–price elasticity of beef demand is inelastic in both models, but the magnitudes are –0.40 in the AIDS model and –0.66 in the Rotterdam model. For these reasons, we believe it is important to conduct the welfare analysis of asymmetric price transmission under more than one demand model specification.

COMPENSATED WELFARE MEASURES AND VARTA'S MAIN ALGORITHM

The primary tools used to evaluate the welfare impacts of price changes are consumer surplus, equivalent variation, and compensating variation. Consumer surplus (CS) measures the difference between buyers' willingness–to–pay and actual expenditure for a good. Consumer surplus can be computed from the estimated Marshallian demand structure and is convenient to use in applied economic research. However, consumer surplus does not account for the income effect of a price change, so it is an imperfect measure of the price change due to implicit changes in consumer utility.

Compensated welfare measures hold utility constant, and the two key compensated welfare measures are the equivalent variation (EV) and compensating variation (CV). To illustrate these concepts, we consider prices and incomes under a base scenario (p_0,m_0) and a new scenario (p_1,m_1). The equivalent variation (EV) is defined as the amount of money that must be added to the base scenario to make it equal in utility to the new scenario. EV may be directly defined as EV=e(p_0,u_1)– e(p_1,u_1), where e(p,u) is the expenditure function at prices p and utility u. EV may be implicitly expressed as V(p_0,m_0+EV)=V(p_1,m_1), where V(p,m) is the indirect utility function based on prices p and income m. The compensating variation (CV) is defined as the amount of money that must be taken away from the new scenario to compensate for the price change and leave the consumer at the original utility level. CV may be directly defined as CV=e(p_1,u_0)–e(p_0,u_0) or implicitly defined as V(p_0,m_0)=V(p_1,m_1–CV).

Figure 1 illustrates the differences between CS, EV and CV. Here, CV is the area $P_1^1 P_1^0 bc$ under the Hicksian demand curve compensated at the initial utility level, V(p_0,m_0). Similarly, EV is the area $P_1^1 P_1^0 ab$ under the Hicksian demand curve compensated at the new utility level, V(p_1,m_1). CS is the area $P_1^1 P_1^0 ac$ under the Marshallian demand curve. If the good is non–inferior (as in Figure 1), then CV ≥ CS ≥ EV. If the good is inferior, the directions of the inequalities in this expression are reversed. If there is no income effect, then CV= CS=EV. In general, income elasticities and the associated income effects for most products are relatively small, so the CS approximation to CV and EV may be reasonably close (Willig, 1976).

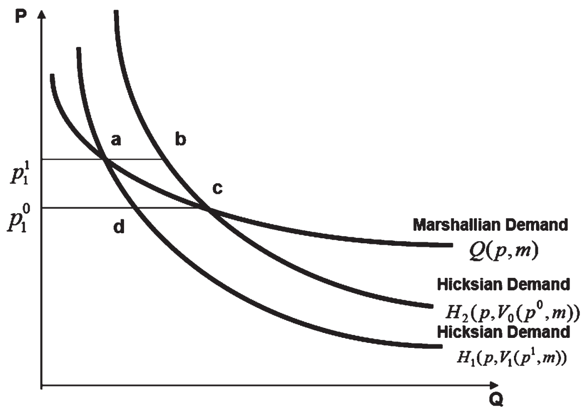

Fig. 1. Relationship among the Welfare Measures (CS, CV and EV).

Hausman (1981) derived an exact analytical expression for the CV from linear, log–linear, and quadratic demand functions. Alternatively, Varita(1983) derived efficient algorithms to calculate compensated welfare measures form Marshallian demand equations. Although the welfare measures must be iteratively computed, the welfare change between two equilibrium situations faced by consumers can be exactly determined for a general class of Marshallian demands. A detailed description of Vartia's main algorithm is provided in the appendix to this paper.

ESTIMATING THE COMPENSATING VARIATION DUE TO ASYMMETRIC PRICE TRANSMISSION

To calculate the welfare impact of asymmetric price transmission on retail consumers, we propose an algorithm based on the following steps:

1. Use fitted reduced form EC models to simulate monthly retail pork and beef price changes under symmetric and asymmetric price transmission
2. For the simulated retail price change, use the fitted demand model with Vartia's algorithm to compute the CV associated with the price change
3. Repeat the process by generating replicated draws from the price models, and save the estimated CV values

We then use the simulated distribution of CV estimates to evaluate the welfare impact of asymmetric price transmission in the US pork and beef markets.

The retail pork and beef price changes are simulated from the estimated reduce–form equations for the EC models.

$$\begin{aligned}\Delta Y_{it} = \eta_i &+ \lambda_{i1}\Delta F_{t-1} + \lambda_{i2}\Delta F_{t-2} + \lambda_{i3}\Delta W_{t-1} + \lambda_{i4}\Delta W_{t-2} \\ &+ \lambda_{i5}\Delta R_{t-1} + \lambda_{i6}\Delta R_{t-2} + \lambda_{i7}\Delta F^{+}_{t-1} + \lambda_{i8}\Delta W^{+}_{t-1} \\ &+ \lambda_{i9}\Delta R^{+}_{t-1} + \delta_{i1}D_1 + \ldots + \delta_{i11}D_{11} + \phi_{i1}\hat{\varepsilon}^{1}_{t-1} + \phi_{if2}\hat{\varepsilon}^{3}_{t-1} \\ &+ \mu_{it} \qquad (9)\end{aligned}$$

Where $\Delta Y_{1t} = \Delta F_t$, $\Delta Y_{2t} = \Delta W_t$, $\Delta Y_{3t} = \Delta R_t$, $\hat{\varepsilon}^{1}_{t-1}$ is the lagged residual from the farm–wholesale cointegrating regression, and $\hat{\varepsilon}^{3}_{t-1}$ is the lagged residual from the wholesale–retail cointegrating regression. The Shapiro–Wilk test for normality suggests that the reduced–form residuals are non–normal, and we bootstrap the residuals to generate the simulated retail price changes from the fitted reduced–form equations (9). Special care must be taken when simulating outcomes from second–order autoregressive (AR) models, and we follow the bootstrap steps outlined by Shao and Tu (1995, section9.3). Finally, we estimate the reduced–form equations under the restrictions $\lambda_{i7} = \lambda_{i8} = \lambda_{i9} = 0$ and use this fitted model to generate bootstrap outcomes under symmetric price transmission.

WELFARE SIMULATION RESULTS

The simulated monthly pork CV values for 2000 from the AIDS and Rotterdam demand models are based on 1000 replicated bootstrap samples, and the average CV outcomes and t–ratios are reported in Table 5. Also, we report the simulated CS values (by setting the income effect to zero) as a benchmark for comparison. For the average US pork consumer, the average CV ranges from 0 to 6 cents per month, and the results for the two demand models are very similar. Also, the CS estimates are very similar to the CV estimates, and this finding implies that the income effects in the pork market are small. More importantly, the welfare impact of asymmetric price transmission appears to be small relative to consumer expenditures on these goods. Based on current meat expenditures, the average US consumer spends $10

Table 5. Simulated CV and CS due to asymmetric price transmission for pork

Month	AIDS			Rotterdam		
	CV (CS)	sd	t–ratio	CV (CS)	sd	t–ratio
Jan, 2000	0.037 (0.037)	0.067 (0.067)	17.311 (17.303)	0.030 (0.030)	0.064 (0.064)	14.972 (14.973)
Feb, 2000	0.024 (0.024)	0.069 (0.068)	11.241 (11.229)	0.022 (0.022)	0.066 (0.066)	10.517 (10.517)
Mar, 2000	0.038 (0.038)	0.074 (0.074)	16.156 (16.149)	0.035 (0.035)	0.073 (0.073)	15.182 (15.181)
Apr, 2000	0.033 (0.033)	0.066 (0.066)	16.033 (16.026)	0.032 (0.032)	0.063 (0.063)	15.942 (15.942)
May, 2000	0.026 (0.025)	0.065 (0.065)	12.418 (12.406)	0.023 (0.023)	0.060 (0.060)	12.423 (12.423)
Jun, 2000	0.009 (0.009)	0.061 (0.061)	4.601 (4.586)	0.012 (0.012)	0.059 (0.059)	6.403 (6.403)
Jul, 2000	0.018 (0.018)	0.052 (0.052)	11.197 (11.186)	0.016 (0.016)	0.055 (0.055)	9.084 (9.085)
Aug, 2000	0.050 (0.050)	0.062 (0.062)	25.244 (25.249)	0.046 (0.046)	0.061 (0.061)	23.948 (23.948)
Sep, 2000	0.015 (0.015)	0.060 (0.060)	8.135 (8.122)	0.015 (0.015)	0.055 (0.055)	8.480 (8.480)
Oct, 2000	0.047 (0.047)	0.065 (0.065)	22.904 (22.901)	0.049 (0.049)	0.066 (0.066)	23.230 (23.229)
Nov, 2000	0.043 (0.043)	0.073 (0.073)	18.882 (18.874)	0.039 (0.039)	0.072 (0.072)	16.948 (16.948)
Dec, 2000	0.043 (0.043)	0.070 (0.070)	19.496 (19.485)	0.051 (0.051)	0.073 (0.073)	22.177 (22.177)

per month for pork, and the monthly CV due to price asymmetry in the pork market is less than 1% of the average pork expenditure.

To examine the sampling distribution of the CV estimates, we form the kernel density estimates (Figure 3 and 4) from the simulated CV outcomes for 2000, which represents the unconditional sampling distribution for the monthly CV. Also, we add the 12 monthly CV estimates to generate the simulated annual CV, and the associated kernel density estimates (Figure 5 and 6) represent the unconditional sampling distribution of the annual CV. First, we note that the AIDS and Rotterdam models yield very similar results for the monthly and annual outcomes. The average annual CV associated with asymmetric price transmission in the US pork market for 2000 is $ 0.38 per person under the AIDS model and $0.37 per person under the Rotterdam model, and the CS estimates are nearly identical. The estimated probability of consumer welfare loss, defined as the share of CV simulation outcomes greater than zero, is 0.668 for the AIDS model and 0.672 for the Rotterdam model in 2000.

Table 6 reports the average outcomes and t–ratios for the simulated monthly beef CV and CS estimates. The average CV (and CS) associated with asymmetric price transmission ranges from 1 to 9 cents per month for the average US beef consumer, and both demand models yield similar results. The average US consumer spends roughly $16 per month for beef, and the estimated monthly CV due to asymmetric price transmission in thisi market is less than 1% of the average monthly beef expenditure.

The kernel density estimates for the simulated monthly and annual beef CV estimates for 2000 are presented in Figure 7 and 8. As in the pork market, we find that the AIDS and Rotterdam models generate very similar results. The average annual CV in 2000 due to asymmetric price transmission in the retail beef market is $ 0.72 per person for the AIDS model and $0.73 per person for the Rotterdam model. The estimated probability of consumer welfare loss is 0.698 under the AIDS model and is 0.693 under the Rotterdam model. Finally, we note that the sum of the annual CV estimates from the US retail pork and beef markets is roughly $1.10 per person.

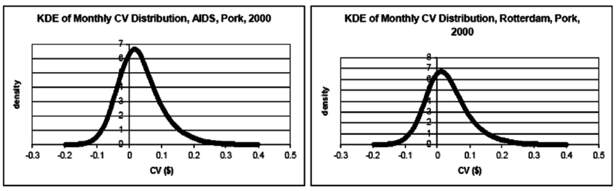

Fig. 2. Kernel density estimates of the monthly pork CV distributions.

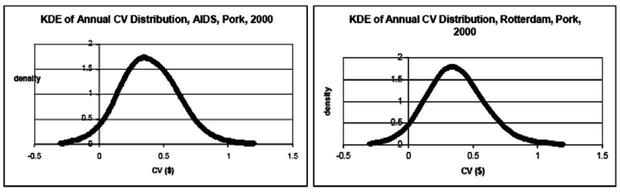

Fig. 3. Kernel density estimates of the annual pork CV distributions.

Table 6. Simulated CV and CS due to asymmetric price transmission for beef

Month	AIDS			Rotterdam		
	CV (CS)	sd	t–ratio	CV (CS)	sd	t–ratio
Jan, 2000	0.051 (0.051)	0.116 (0.116)	13.868 (13.851)	0.055 (0.055)	0.123 (0.123)	14.207 (14.207)
Feb, 2000	0.020 (0.020)	0.110 (0.110)	5.711 (5.690)	0.017 (0.017)	0.112 (0112)	4.770 (4.770)
Mar, 2000	0.060 (0.060)	0.106 (0.106)	17.874 (17.863)	0.059 (0.059)	0.109 (0.109)	17.203 (17.204)
Apr, 2000	0.066 (0.066)	0.109 (0.109)	19.145 (19.138)	0.067 (0.067)	0.110 (0.110)	19.245 (19.245)
May, 2000	0.061 (0.061)	0.105 (0.105)	18.236 (18.226)	0.068 (0.068)	0.115 (0.115)	18.579 (18.579)
Jun, 2000	0.066 (0.066)	0.119 (0.119)	17.469 (17.455)	0.056 (0.056)	0.110 (0.110)	16.176 (16.176)
Jul, 2000	0.058 (0.058)	0.104 (0.104)	17.690 (17.681)	0.059 (0.059)	0.107 (0.107)	17.388 (17.389)
Aug, 2000	0.081 (0.081)	0.112 (0.112)	22.905 (22.903)	0.085 (0.085)	0.121 (0.121)	22.060 (22.060)
Sep, 2000	0.073 (0.072)	0.107 (0.107)	21.502 (21.499)	0.067 (0.067)	0.102 (0.102)	20.891 (20.891)
Oct, 2000	0.055 (0.055)	0.112 (0.112)	15.533 (15.523)	0.060 (0.060)	0.112 (0.112)	17.032 (17.033)
Nov, 2000	0.058 (0.058)	0.106 (0.106)	17.330 (17.320)	0.058 (0.058)	0.109 (0.109)	16.899 (16.898)
Dec, 2000	0.076 (0.076)	0.103 (0.103)	23.260 (23.256)	0.077 (0.077)	0.099 (0.099)	24.650 (24.650)

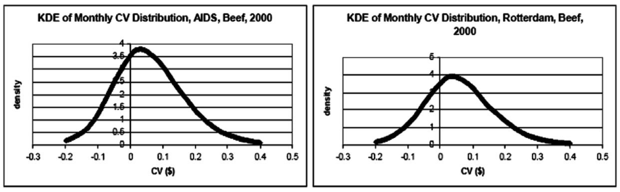

Fig. 4. Kernel density estimates of the monthly beef CV distributions.

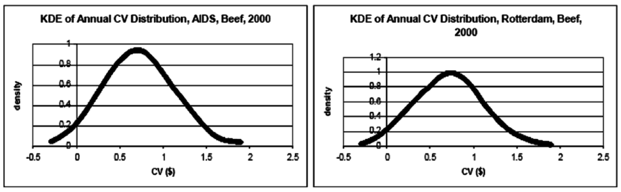

Fig. 5. Kernel density estimates of the annual beef CV distributions.

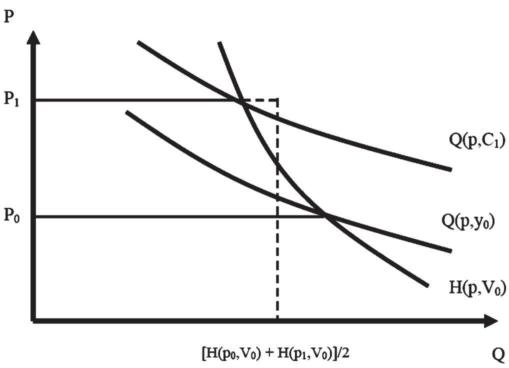

Fig. 6. Illustration of Vartia's Main Algorithm.

CONCLUDING REMARKS

Although the statistical evidence indicates that price are asymmetrically transmitted in the US pork and beef markets, the welfare impact on the average US pork or beef consumer is perhaps not economically significant. However, it is also important to note that the retail and wholesale sectors are highly concentrated. To the extent that asymmetric price transmission is due to market power, the potential excess profits for individual retails or wholesales may be very large. Assuming each pork and beef consumer loses ten cents each month due to asymmetric price transmission and the US population is 300 million, the aggregate loss is about $30 million per month, which may provide potentially large gains for a very limited number of retailers or wholesalers. For this reason, the impact of asymmetric price transmission on producer welfare is a key topic for future research in this area.

Other relevant future research directions include the distribution of welfare losses across the range of consumer incomes. Given that the share of income allocated to food expenditure is higher for low–income consumers, the welfare burden of asymmetric price transmission is potentially greater among this group. Also, we should examine the welfare implications of asymmetric price transmissions in other important markets, especially for gasoline and other energy products that represent a relatively large share of consumer expenditures. To the best of our knowledge, such research efforts have been very limited in number and scope, and our approach may serve as a useful basis for these research extensions.

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Appendix: Summary of Varitia's Main Algorithm

Vartia's main algorithm computes compensated income associated with a price change from initial price p0 by partitioning the price change into K steps, p0 < p1 <…< pK. The compensated income is iteratively computed for each step from the following expression.

$$C^m_k = C_{k-1} + 1/2(Q(p_k, C^{m-1}_k) + q_{k-1})(p_k - p_{k-1}) \quad \text{(A1)}$$

Here, C^m_k is compensated income for partition k and iteration m, Q is the Marshallian demand function, and qk–1 is the quantity from the previous step (k–1). The iterative computations for Ck continue for m steps until $|C^m_k - C^{m-1}_k|$ is less than some tolerance value. After convergence, we set $C_k = C^m_k$ and continue for all k=1,…, K. After step K, we compute the compensating variation as CV=Ck–y0, where y0 is initial income and Ck is the compensated income.

To graphically illustrate Vartia's main algorithm, we can compute the compensating variation from the partitioned price changes as $CV = \sum_{k=1}^{k} \Delta_k$ where $\Delta_k = e(p_k, V_0) - e(p_{k-1}, V_0)$. Under the Hicksian demand curve, the CV components may be computed as $\Delta_k = \int_{p_{k-1}}^{p_k} H(p, V_0)dp$, and the compensated income associated with the price change up to partition k is $C_k = y_0 + \sum_{j=1}^{k} \Delta_j$, and $CV = C_k - y_0$. Further, the integral expression for Δ_k may be estimated with the discrete approximation

$$\Delta_k \approx \frac{1}{2}(p_k - p_{k-1})[H(p_k, V_0) + H(p_{k-1}, V_0)] \quad \text{(A2)}$$

The associated discrete approximation to CV approaches the actual value as the number of partition components becomes asymptotically large and $K \to \infty$. In Figure 2, the approximation to Δ_k is represented by the area between prices p0 and p1 and to the left of the average quantity, [H(pk, V0)+H(pk–1, V0)]/2.

Although the Hicksian demand function is not directly observable, we can rely on the known identity $H(p, u) \equiv Q(p, e(p, u))$ to estimate Δ_k from the Marshallian demand function. In particular, we can replace H(pk, V0) with the Marshallian demand function evaluated at the compensated income for partition k, Q(pk, Ck). To compute the compensated income, we can restate (3) as

$$C_k - C_{k-1} \approx \frac{1}{2}(p_k - p_{k-1})[Q(p_k, C_k) + Q(p_{k-1}, C_{k-1})] \quad \text{(A3)}$$

And the objective of Vartia's Main Algorithm is to solve (4) for Ck conditional on Ck–1, pk–1, and pk. The algorithmic representation of (4) stated in (1) indicates that we iteratively search for the solution value of Ck until the algorithm converges and $|C^m_k - C^{m-1}_k|$ is negligibly small (i.e., the steps are indexed with m). Graphically, the Vartia algorithm shifts the Marshallian demand curve rightward in Figure 2 to reflect the income compensation, and the demand identity implies that the Marshallian deman curves intersect the Hicksian demand curve at the desired points if the income adjustment is correctly chosen. As the algorithm proceeds from one step to another, the compensated income value Ck is further adjusted in order to shift the Marshallian curves rightward and to iteratively build the estimate of CV.