Dynamic Economic Relationships among Danish Markets for Pork, Chicken, and Beef

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Traditionally, food demand is considered inelastic, and consumption volumes only sluggishly respond to price changes (Jensen and Toftkær 2002). Also, EU and U.S. food production is highly regulated through, for example, farm programs, environmental regulations, and trade barriers that further suggest food market inflexibility. The public has displayed an increasing interest in food safety in the wake of a 1985 U.S. salmonella outbreak that caused some 16,000 cases of illness, a 1995 British outbreak of Creutzfeldt-Jacob disease that claimed 10 lives, and Asian flu outbreaks that have claimed more than 140 lives since 2003 (USFDA 2004; USFDA n.d.; UNWHO 2006). Such events magnify interest by consumers, policy makers, agribusiness agents, and researchers on how food markets react to a shock, perhaps outbreak-induced, in one market. More specifically, such interested parties want to know the degrees to which such outbreaks influence quantities demanded and supplied for the affected market product and substitutes, elicit price responses, and change food costs. Such parties also want to know how quickly public confidence in a product market subject to such outbreaks can be re-established and the degree to which producers and consumers can and will switch to substitute products.

This paper examines the functioning of Denmark's three meat markets. For the first time, a VAR model provides results of use in answering the following five questions on how the markets dynamically operate and how they respond to and inter-react with price shocks from such outbreaks, as well as to other events:

- What are the reaction times with which the five respondent variables begin reacting?
- What are the directions/patterns taken by each respondent variable's impulses?
- What are duration times of each respondent variable's set of responses?
- What are the degrees of ultimate responses of each respondent variable?
- What are the strengths of causal interrelationships among the modeled variables?

Four sections follow. The first introduces the model and data; the next two provide answers to the five questions by analyzing the dynamic effects of price increases and the causal relationships between the variables, and the last section concludes.

The Econometric Model and Data

We specify, estimate, and simulate a quarterly VAR model of the following quantity and price variables covering Denmark's three meat markets: pork quantity (QPORK), pork price (PPORK), chicken quantity (QCHX), chicken price (PCHX), beef quantity (QBEEF), and beef price (PBEEF). VAR econometric procedures have been widely established and applied, and so are not recounted here. Readers are referred to Bessler (1984)'s seminal article and to this journal's prior research by Babula and Rich (2001) and Babula et al. (2004) for procedure details.

Considered a reduced-form framework, a VAR model is appropriately considered here because the six variables are stationary in logged levels (Babula et. al. 2004).[1] The VAR model posits each of the six variables as a function of three lags of itself and of three lags of the remaining five endogenous variables.[2] The data set covers the period of 1974:01–2004:04. Price data are farm prices, while quantities are the sum of Danish consumption and export (Statistics of Denmark 2006). Even though we use Danish prices, the fact that Denmark is a small, open economy which imports and exports large quantities of meat products implies a substantial correlation between world market prices and Danish prices. We estimated the model appropriately with ordinary least squares (Sims 1980 and Bessler 1984) and tested it for specification adequacy by applying Ljung-Box portmanteau and Dickey-Fuller unit root tests on the model's estimated residuals. Results strongly suggest that the model achieved literature-established standards of statistical adequacy.[3] We then simulated the model's impulse-response function under three shocks (increases in PPORK, PCHX, and PBEEF) and analyzed patterns of the model's forecast error variance (FEV) decompositions to answer the five above-posed questions. Information inherent in contemporaneously correlated current residuals was also utilized through imposition of a Choleski decomposition.[4]

Dynamic Effects of Price Increases

We simulated the impulse-response function under three experiments: increases in PPORK, PCHX, and PBEEF. The methods of shocking and simulating a VAR model's impulse-response function are well-known (Sims 1980; Bessler 1984). A one-time price shock equal to the long-run standard error of the shocked price's residuals was imposed.[5] We considered impulses that achieved statistical significance at the five-percent level.[6]

Imputed from answers to the five questions, Table 1 summarizes the dynamic effects of each shock on the five respondent variables: reaction time, direction of response, response pattern, durations, and

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[1] Dickey-Fuller and augmented Dickey-Fuller (DF, ADF) tests were applied to the logged levels of the 6 endogenous variables (Hamilton 1994). DF or ADF $T\tau$ values ranged from −4.5 through −5.5 for the three quantities. ADF $T\mu$ values ranged from −2.7 through −2.9 for the three prices. Following the arguments in Babula, Bessler, and Payne (2004), the 10-percent significance level is chosen. In that case, one rejects the null hypothesis of non-stationarity when the pseudo-T values are negative and have absolute values that exceed those of the relevant critical values of $T\mu = -2.58$ without a trend and $T\tau = -3.15$ with a trend. Hence evidence at the 10-percent levels suggests stationarity: cointegration is not an issue here and a levels VAR is justified.

[2] The three-order lag structure emerged from our application of the lag-selection procedure developed by Tiao and Box (1978). We also attempted to incorporate an array of binary variables to capture the effects of post-1973 European Community/Union enlargements, important Danish institutional and meat-market events, and apparent observation-specific outlier events. Ultimately, based on statistical-significance indicators of coefficient estimates, we included a time trend and a binary variable to capture the effects of each of the following events: the 1986 EU enlargement, the 1984 institution of Danish milk-production quotas, and the 1996:02 discovery of bovine spongiform encelopathy (BSE) in the United Kingdom. Quarterly centered seasonal variables were also included.

[3] Ljung-Box portmanteau or "Q" statistics generated by each equation's estimated residuals test the null hypothesis of model adequacy, with small Q-values below the critical chi-square value of 13.3 (three degrees of freedom, five-percent significance level), suggesting model adequacy. With the VAR model's six Q-values ranging from 0.35 to 0.96, evidence at the five-percent significance level was insufficient to reject the null hypothesis of model adequacy, suggesting that all six equations are adequately specified. We followed Granger and Newbold's (1986) recommendation not to rely solely on Q-values to discern model adequacy. Following Babula et al. (2004), we also tested estimated sets of residuals for a unit root with DF tests, with stationarity or absence of a unit root indicating specification adequacy. One rejects the DF null of nonstationary residuals when DF $T\mu$ values are negative and have absolute values above −2.89. Since the six DF $T\mu$ values ranged from −10.4 to −11.0, evidence at the five-percent significance level was sufficient in all cases to conclude that evidence supported adequate specification.

[4] The model's estimated residuals are likely contemporaneously correlated, and one must incorporate such information if impulse responses and FEV decompositions are to reflect observed patterns (Sims 1980; Bessler 1984). Following prior research we imposed a Choleski decomposition on the model's variance/covariance matrix for each of the three shocks in order to orthogonalize the innovation matrix such that the variance of the transformed innovations is identity (Bessler 1984). Each decomposition imposes an arbitrary Wold causal ordering on the modeled dependent variables. The general market variable ordering was chosen as follows based on the relative monetary importance of the three meat markets in the Danish economy: QPORK, PPORK, QCHX, PCHX, QBEEF, PBEEF, with the quantity and price variables reversed in each market for price shock-impulse-response simulations (Babula and Rich 2001). We chose the following orderings for the Choleski decompositions for the three simulations of price shocks: PPORK, QPORK, PCHX, QCHX, PBEEF, QBEEF for the simulated rise in PPORK; PCHX, QCHX, PPORK, QPORK, PBEEF, QBEEF for the simulated rise in PCHX; and PBEEF, QBEEF, PPORK, QPORK, PCHX, QCHX for the simulated rise in PBEEF.

[5] This translated into positive shocks of 10.7 percent for PPORK, 2.7 percent for PCHX, and 2.8 percent for PBEEF. The model is linear, so as to render the size of the shocks arbitrary (Babula and Rich 2001).

[6] We applied Kloek and Van Dijk's (1978) Monte Carlo simulation to generate Student t-values for each impulse response. In selected cases, impulses that emerged as statistically nonzero at significance levels of from six to eight percent were considered. Impulses with significance levels of 10 percent or more were considered statistically zero and not examined.

Table 1. Dynamic Quarterly Aspects of Impulse-Response Simulations.

	Reaction times (quarters)	Direction of responses	Response patterns	Response durations	Multipliers
Simulation 1: Increase in Danish pork price					
QPORK	2	decline	not relevant	1	-0.11
PCHX	0	increase	bell-shaped	7	+0.29
QCHX	NSSR	NSSR	NSSR	NSSR	NSSR
PBEEF	0	increase	not relevant	1	+0.13
QBEEF	NSSR	NSSR	NSSR	NSSR	NSSR
Simulation 2: Increase in Danish chicken price					
PPORK	0	increase	not relevant	1	+0.46
QPORK	NSSR	NSSR	NSSR	NSSR	NSSR
QCHX	0	decline	not relevant	1	-0.43
PBEEF	0	increase	not relevant	2	+0.26
QBEEF	1	increase	not relevant	2	+0.60
Simulation 3: Increase in Danish beef price					
PPORK	0	increase	bell-shaped	22	+0.71
QPORK	1	increase	bell-shaped	16	+0.10
PCHX	0	increase	bell-shaped	23	+0.42
QCHX	NSSR	NSSR	NSSR	NSSR	NSSR
QBEEF	NSSR	NSSR	NSSR	NSSR	NSSR

Notes: NSSR denotes no statistically significant response.

a response multiplier. The elasticity-like response multipliers illuminate the long-run average percentage change in a respondent variable per percentage change in the shocked variable (Babula and Rich 2001). Sign is important: a positive (negative) sign suggests that the respondent variable's reaction is in the same (opposing) direction as the shock. For example, a negative value of the multiplier of QPORK in response to an increase in PPORK reflects a net demand-driven decline over and above a positive supply response, such that the multiplier can at best be considered a lower-limit guide for the own-price elasticity of demand for pork.

Simulation 1: An Increase in Danish Pork Price

On average, each one-percent rise in Danish pork price elicits a decline of 0.11 percent in the market-clearing quantity. The negative sign on the multiplier suggests that the demand response dominates the supply response. The small absolute value of the response multiplier may reflect either an inelastic demand for pork in the world market or an elastic demand combined with a fairly elastic supply of Danish pork. QPORK responses take up to two quarters to begin responding and last for one quarter.

The positive PCHX and PBEEF multipliers suggest that consumers treat these two meats as substitutes for pork. Both prices rise "immediately" (i.e., within one quarter after the shock), with PCHX responding for nearly two years and ultimately rising 0.29 percent for each one-percent increase in pork price. Beef price increases more moderately (by 0.13 percent for each one-percent increase in PPORK) and for a shorter duration. The more modest PBEEF increase likely reflects the EU beef and veal support regime that has been in place since 1968. Originally, the regime involved domestic prices supported in times of surplus by

EU-financed purchases of beef off the market into intervention stores, and border protection via tariffs preventing the internal EU price from being undermined. Reforms of 1992 and 1999 reduced the role played by intervention storage, and the 2003 reform implied a decoupling of subsidy and volume of production. However, since the main part of the data set covers the period of domestic price support and border protection, it is to be expected that the price of beef is rather inelastic (Piccinini and Loseby 2001).

Simulation 2: An Increase in Danish Chicken Price

An increase in Danish chicken price elicits an immediate, one-quarter decline in QCHX of 0.43 percent for each one-percent rise in PCHX, with the negative reduced-form value again suggesting a dominance of negative demand over a positive supply response. The larger own-price elasticity of chicken demand than of pork demand may reflect that consumers are more willing to give up chicken consumption than pork consumption.

The positive PPORK and PBEEF multipliers reflect further evidence that consumers treat the three meats as substitutes. Both prices respond much less than unity to each percentage rise in PCHX, and for one to two quarters.

Not only is PBEEF affected by the increase in the price of chicken, but so too is the quantity: QBEEF increases 0.60 percent for each one-percent increase in PCHX. In Denmark, the production volume of beef is linked closely to the production volume of milk since the production of beef cattle is negligible. Hence, EU agricultural policy in terms of the national production quotas on milk governs the Danish production of beef. Therefore any change in QBEEF not ascribed to changes in the production quota most likely relates to changes in the import volume, and since almost 60 percent of total domestic beef consumption consists of imported beef, there is room for some variation here. Hence our results may suggest that Danish consumers view beef as a closer substitute for chicken than for pork because beef and chicken are perceived more as specialty meats than is pork, given the excessive consumption of pork in Denmark.

Simulation 3: An Increase in Danish Beef Price

Simulation 3's positive price multipliers of 0.71 for PPORK and 0.42 for PCHX reflect further evidence that consumers treat the three meats as substitutes. However, here the shock-induced rises in these two prices elicit immediate patterns of increases which last 22–23 quarters and are far more enduring than are the prior two simulations' price responses. Reasons for the PBEEF shock's more enduring effects may be two-fold. First, our sample included the 1995 British outbreak of Creutzfeld-Jacob disease that may have generated a longer-term substitution of pork and chicken because of a health-based fear of beef consumption. And second, since per-kg PBEEF substantially exceeds PPORK and PCHX in Denmark, there may be an income-based reason why consumers are more reluctant and slow to substitute back to the more costly beef products.

An increase in Danish beef price elicits no statistically discernible effect on the market-clearing quantity of beef, presumably due to the intervention system of the EU which implies that an eventual decrease in consumers' demand for beef is accompanied by EU-financed purchases of beef into intervention stores.

Causal Relationships

Analysis of FEV decompositions is a well-known accounting method for VAR model residuals. An endogenous variable's FEV is attributed to shocks in each endogenous variable, including itself. Analysis of FEV decompositions not only provides evidence of the simple existence of a causal relationship among variables but also illuminates the strength and dynamic timing of such a relationship. A variable is considered exogenous (endogenous) when large (small) proportions of its FEV is attributed to its own variation and small (large) proportions are attributed to other variables' variation at a particular (in this case, quarterly) time horizon (Bessler 1984). Decompositions of two or more variables may be added together at a horizon for a collective effect (Babula et al. 2004). Typically, a variable's FEV is more attributed to own-variation, and hence is exogenous, at shorter-run horizons, and tends to become more reliant on other endogenous variables at longer-run horizons (Babula, Bessler, and Payne 2004). Patterns of FEV decompositions are summarized in Table 2. FEV decompositions are more dynamically interesting for the prices, and are examined first. Patterns for the quantities follow.

Danish pork-price behavior is nearly exclusively attributed to own-variation at shorter-run horizons, when 98 percent of its FEV is self-attributed. Thereafter PPORK behavior becomes increasingly endogenous, and by Quarter 24, 57 percent of its behavior is self-attributed. In line with the response multiplier of PPORK in simulation 3 above, the next most important explanator of PPORK behavior appears to be PBEEF, which explains 23 percent of PPORK variation at longer-run horizons.

In the short run, PCHX is highly exogenous, but in the longer run it becomes far more endogenous than PPORK and BEEF: as little as 29 percent of PCHX variation is self-attributed in the long run, compared with 57 percent for PPORK and 68 percent for PBEEF. The following factors may explain the endogeneity of PCHX: the EU plays little role in supporting the sector financially; the reproduction cycle is fast, such that available chicken meat can increase rapidly; and the cost of feed is by far the most important aspect of chicken production. PCHX patterns of FEV decompositions reinforce evidence of strong consumer substitution among the three meats reflected by the impulse response results earlier. More specifically, the percentage of PCHX behavior explained by other-meat price variation is 20 percent for PPORK and 30 percent for PBEEF. These coincide with the statistically significant and enduring PCHX responses to PPORK increases in Simulation 1 and particularly to PBEEF increases in Simulation 3.

Danish beef-price behavior is highly exogenous, with 68 percent of its FEV self-attributed in the long run. As perhaps expected, QBEEF is the second most important explanator of beef-price behavior after own-variation, accounting for 16 percent of PBEEF variation at the longer-run horizons. The moderate but steady and time-enduring PCHX contributions to PBEEF behavior supports the PBEEF impulses generated by positive PCHX shocks in simulation 2. PPORK variation appears to contribute more to PBEEF behavior at the shorter-run horizons, which is consistent with the short and very mild influence that PPORK shocks had on beef price in Simulation 1.

The three quantities—QPORK, QCHX, and QBEEF—are all highly exogenous, with about 70 percent of behavior attributed to own-variation and modest own-price contributions explaining the variation in each.

Conclusions

Results generated by the reduced-form VAR model of Denmark's pork, chicken, and beef markets suggest that:

- Lower-limit guides for own-price elasticities of demand are −0.11 for pork and −0.43 for chicken,
- Consumers consider beef, pork, and chicken as substitutes for one another,
- Beef market shocks have more enduring impacts on pork and chicken markets than shocks in the latter two markets have on the beef market,
- Quantities are highly exogenous both in the short and long run,
- The price of chicken is much more endogenous than the prices of pork and beef.

We explain the results in terms of consumers' attitudes, the compositions of the quantity variables, and European farm policies, particularly those related to milk and beef production.

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Table 2. Decompositions of Forecast Error Variance.

	Percentage of forecast error variance explained by					
Variable and quarterly horizon	QPORK	PPORK	QCHX	PCHX	QBEEF	PBEEF
QPORK						
1	93.40	0.29	2.34	0.17	0.69	3.07
4	79.85	8.77	3.31	2.55	1.59	3.92
8	75.48	8.50	4.27	4.12	2.51	5.11
16	72.10	8.14	4.27	4.12	3.53	7.85
24	69.72	7.86	4.32	4.13	4.13	9.86
PPORK						
1	0.50	97.84	0.02	0.01	0.95	0.69
4	0.92	86.55	1.88	4.83	0.68	5.14
8	0.92	69.78	3.27	9.28	0.83	15.93
16	0.81	60.83	5.45	9.74	2.87	20.31
24	0.91	56.82	6.03	9.42	3.90	22.92
QCHX						
1	0.05	0.91	87.97	7.81	2.60	0.65
4	4.38	2.99	80.94	7.08	2.90	1.72
8	7.24	3.94	76.34	6.46	2.68	3.35
16	7.95	4.03	74.07	7.00	2.97	3.98
24	8.15	4.01	73.29	6.89	3.06	4.60
PCHX						
1	1.12	11.75	5.42	81.68	0.01	0.01
4	3.49	28.50	4.62	55.56	2.18	5.64
8	4.17	28.49	5.38	39.76	2.83	19.38
16	3.82	22.20	9.50	31.71	4.96	27.82
24	3.80	19.94	10.39	29.10	6.27	30.51
QBEEF						
1	5.39	0.64	1.17	6.21	86.59	0.01
4	7.98	1.89	1.49	12.06	76.53	0.05
8	8.40	2.36	1.74	11.84	75.11	0.55
16	8.71	2.48	1.96	11.78	74.43	0.64
24	8.75	2.48	2.01	11.77	73.35	0.64
PBEEF						
1	0.34	4.81	0.11	2.97	2.93	88.84
4	0.92	3.54	1.98	2.95	10.03	80.59
8	0.65	2.58	4.85	2.90	13.73	75.29
16	0.57	1.68	7.99	3.56	15.60	70.62
24	0.83	1.43	9.62	3.78	16.00	68.43

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