An Analysis of the Impact of Energy Price Escalations during the 1970s on Hawaii Beef Production and Prices

Roland K. Roberts, Gary R. Vieth and James C. Nolan, Jr.

A quarterly econometric model of the Hawaii beef production sector is estimated. Energy prices influence the model through Hawaii beef and feed prices which are a function of Mainland-to-Hawaii freight rates. Energy prices also influence the decision of whether to allocate feeder animals to feedlots or pasture. Through simulation, it was found that rapidly increasing energy prices after 1973 resulted in a 22 percent reduction in total Hawaii beef production. The composition of production also changed toward more grain fed and less grass fed beef. Given these results, other state and national beef modelers might find it useful to include energy prices in their models.

In this paper, a quarterly econometric model of beef production is used to study the impacts of rapidly increasing energy prices. The model is specific to Hawaii, but it includes some unique features and provides results that suggest important national and state implications. Unlike most econometric models of livestock subsectors (Arzac and Wilkinson; Baum, Safyurtlu and Purcell; Crom; Folwell and Shapouri; Freebairn and Rausser; Nelson and Spreen; Reutlinger), the Hawaii model includes the price of energy as a major determinant of beef production and prices. Energy prices influence beef production through the impact of freight rates on beef and feed prices. The Hawaii model uses state rather than national beef and feed prices to determine production. By including local rather than national prices in state or regional models, error from freight rate changes might be reduced, policy implications broadened, and additional energy price impacts captured. Energy prices also influence the model through their impact on cattle inventories and the decision of feeder cattle allocation to grain or grass finishing. Lasley suggests that fuel and energy costs are potentially important in farm production decisions. Yanagida and Conway (1980, 1981) recognize the direct influence of energy prices on production decisions, but they exclude the potential impact on the composition of beef production as energy prices influence placements on feed. The indirect impacts, which are possibly more important,[1] are also excluded.

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This research was supported by Western Regional Research Project W-145 and approved by the Hawaii Institute of Tropical Agriculture and Human Resources as Journal Series Number 2786. The authors are grateful to Peter Garrod of the University of Hawaii and Lloyd Garrett of the Hawaii Agricultural Reporting Service for their contributions in the early stages of this research.

[1] The direct energy price impacts on U.S. agriculture discussed by Carter and Youde come through price increases of energy-related farm inputs such as electricity, fuel, fertilizer, and chemicals. The in-

Western Journal of Agricultural Economics, 9(1): 90–105

Hawaii provides a unique setting for an impact analysis of energy prices on beef production. First, as a state it is an integral part of the United States market area. Beef is freely imported from the Mainland without restriction, and foreign beef exporters tend to view Honolulu as they would any other U.S. port (Schermerhorn *et al.*). Consequently, the analysis can be undertaken within a national context rather than at an international level. Second, Hawaii is located approximately 2,500 miles from the rest of the United States. This isolation leads to a richness of data in that freight costs are typically higher than in other states and more easily identified. Third, the methods of beef production in Hawaii are similar to those for the United States as a whole. The majority of Hawaii beef is produced in feedlots, while some steers and heifers are finished on grass. Finally, because of these features, Hawaii can be thought of as an extreme case. If energy prices are not influential in various aspects of Hawaii beef production, then they are less likely to have an impact on beef production in other states or regions of the United States.

The objective of this paper is to analyze the impacts of rapidly increasing energy prices during the 1974–80 period on Hawaii beef production and prices. There are three hypotheses formulated from the data presented in Table 1 and Figure 1 which relate to this objective. Table 1 shows that total Hawaii beef production increased sharply between 1953 and 1968, but demonstrated wide fluctuations and no upward trend thereafter. Similarly, the beef cow herd expanded from 71 thousand head in 1960 to a peak of 92 thousand head in 1969. The herd remained fairly constant until after 1976 when it declined substantially. Figure 1 shows the changes in the composition of beef production in Hawaii between 1969 and 1980. The trend toward a smaller percentage of grass fed relative to total steer and heifer beef production was reversed after 1974.[2] It is postulated that rapidly increasing energy prices after 1973 were a major cause of 1) the trend reversal shown in Figure 1, 2) the decrease in cow inventory after 1976, and 3) the lack of a continued upward trend in total Hawaii beef production during the 1970s. The authors recognize that there may have been other influences that contributed to changes in the structure of the Hawaii beef industry after 1973. For instance, higher relative feed costs and interest rates, and shifts in consumer preferences toward leaner beef might have influenced the change in the composition of Hawaii beef production and accentuated the decline in cow numbers.

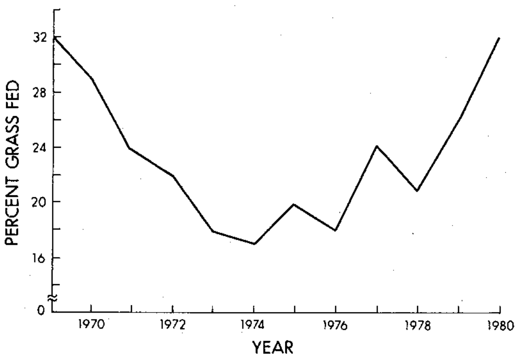

Figure 1. Hawaii Range Steer and Heifer Beef Production as a Percentage of Total Steer and Heifer Beef Production, 1969–80.

direct impacts originate from changes in general price levels and economic growth rates, induced by changes in energy prices.

[2] The disaggregation of steer and heifer beef production into grain and grass fed categories is based on actual data collected from slaughterhouse records by the Hawaii Agricultural Reporting Service. Grain fed steers and heifers are defined as animals fattened on grain or other concentrates which produce a carcass expected to grade good or better. Grass fed steers and heifers are defined as animals fattened primarily on grass and other roughage and may include some supplementary feeding of grain.

TABLE 1. Total Hawaii Beef Production and January 1 Beef Cow Inventory, 1953–80.

Year	Beef Production	Beef Cow Inventory	Year	Beef Production	Beef Cow Inventory
	(mil. lbs.)	(thou. head)		(mil. lbs.)	(thou. head)
1953	14.9	NA	1968	33.6	89
1954	17.9	NA	1969	31.4	92
1955	20.4	NA	1970	32.2	90
1956	21.4	NA	1971	34.0	89
1957	22.8	NA	1972	32.2	89
1958	24.0	NA	1973	31.0	90
1959	24.7	NA	1974	27.5	90
1960	25.0	71	1975	27.0	90
1961	25.7	73	1976	32.3	89
1962	24.3	73	1977	32.3	85
1963	26.3	75	1978	33.5	80
1964	26.2	79	1979	29.3	78
1965	26.0	85	1980	28.8	83
1966	29.2	87	1981	28.7	80
1967	31.3	87	1982	NA	80

NA—Not available.
Source: Hawaii Agricultural Reporting Service.

The Econometric Model

The quarterly econometric model of the Hawaii beef production sector estimated for this analysis is presented in Table 2 and symbol definitions are given in Table 3. The model considers both energy and feed costs, data limitations specific to Hawaii, and special characteristics of the Hawaii beef industry. For example, because of inadequate data on Mainland imports, the model excludes equations estimating consumer demand, and concentrates solely on Hawaii beef production. This does not reduce the usefulness of the model in studying producer response because local beef and feed prices are exogenously determined by Mainland supply and demand conditions and freight costs. Hawaii producers respond to these exogenous prices, allowing energy prices and freight rates to influence local beef production.

The Hawaii Agricultural Reporting Service estimates that 1980 beef imports from the Mainland United States and foreign sources (Australia and New Zealand) accounted for 53 and 16 percent of total Hawaii market supply, respectively.[3] However, imports to Hawaii from the Mainland were only 0.2 percent of Mainland production and Hawaii received only 1.3 percent of Australia and New Zealand beef exports to the entire United States (Schermerhorn *et al.*). The difference between Hawaii's demand for grain fed beef and local production of grain fed beef can easily be augmented by imports at the price for which Mainland beef can be sold on the Mainland plus freight costs. Similarly, Hawaii's demand for lower quality beef can be augmented by imports of foreign beef at the price in Australia and New Zealand plus freight costs. Hawaii's insignificance in the U.S. and international markets leads to the exogenous specification of prices in the model.

The United States is the world's leading producer and importer of beef, absorbing approximately one-third of the world beef trade. Evidence suggests that the United States is a price maker at the international level (Simpson, p. 1). Consequently, Hawaii prices of lower quality beef are dominated by Mainland prices via the Australia and New Zealand markets. This eliminates the need for the added complexity of using Australia and New Zealand prices to determine Hawaii cow and grass fed beef prices.

Because both the Mainland and Hawaii import lower quality beef from Australia and New Zealand, the process of arbitrage should lead to approximate equality between Hawaii and Mainland wholesale prices. Nevertheless, Mainland-to-Hawaii freight rates can have a substantial impact

[3] Mainland imported beef is of high quality and competes directly with production from Hawaii's feedlots. Foreign beef imports are of lower quality and compete with Hawaii's cow and grass fed steer and heifer beef.

TABLE 2. Estimated Equations and Identities of the Hawaii Beef Econometric Model.[a]

Equation Number		Equation
		I. Quarterly Freight Rate and Price Transmission Equations
1	TRANBQ	$= \underset{(.070)}{2.610} + \underset{(.0004)}{.002}\text{OILPQ} + \underset{(.005)}{.027}\text{TQ}$, $R^2 = .9926$, AUT, $\hat{\rho} = \underset{(.094)}{.784}$.
2	TRANFQ	$= \underset{(.612)}{14.385} + \underset{(.005)}{.018}\text{OILPQ} + \underset{(.052)}{.394}\text{TQ}$, $R^2 = .9879$, AUT, $\hat{\rho} = \underset{(.120)}{.607}$.
3	TRANFMQ	$= .25\text{TRANFQ} + .5\text{TRANFQ}(-1) + .25\text{TRANFQ}(-2)$.
4	HGFBPRQ	$= \underset{(1.477)}{-6.831} + \underset{(.020)}{.980}\text{LAGFBPRQ} + \underset{(.782)}{4.548}\text{TRANBQ}$, $R^2 = .9964$, DW $= 1.676$, OLS.
5	HNFBPRQ	$= \underset{(3.584)}{-4.770} + \underset{(.051)}{.362}\text{LAGFBPRQ} + \underset{(.056)}{.262}\text{LAGFBPRQ}(-1) + \underset{(1.965)}{4.343}\text{TRANBQ} + \underset{(.640)}{1.573}\text{D1Q} + \underset{(.713)}{1.518}\text{D2Q} + \underset{(.601)}{.041}\text{D3Q}$, $R^2 = .9882$, AUT, $\hat{\rho} = \underset{(.129)}{.516}$.
6	HCPRQ	$= \underset{(3.577)}{-14.725} + \underset{(.064)}{.227}\text{LACPRQ} + \underset{(.076)}{.412}\text{LACPRQ}(-1) + \underset{(.075)}{.175}\text{LACPRQ}(-2) + \underset{(.070)}{.131}\text{LACPRQ}(-3) + \underset{(1.702)}{5.120}\text{TRANBQ}$, $R^2 = .9870$, AUT, $\hat{\rho} = \underset{(.137)}{.425}$.
7	CFPQ	$= \underset{(.299)}{.535} + \underset{(.140)}{1.686}\text{USCPMQ} + \underset{(.012)}{.145}\text{TRANFMQ}$, $R^2 = .9747$, AUT, $\hat{\rho} = \underset{(.144)}{.360}$.
8	CFPIQ	$= \text{CFPQ}/10.56$.
		II. Annual Cattle Inventory and Calf Crop Equations
9	BCI	$= \underset{(25.386)}{8.754} + \underset{(.047)}{.114}\text{HGFBPR}(-1)/\text{CFPI}(-1) - \underset{(.010)}{.013}\text{OILP}(-1)/\text{CFPI}(-1) + \underset{(.242)}{.784}\text{BCI}(-1)$, $R^2 = .8561$, DH $= -.583$, OLS.
10	HI	$= \underset{(8.500)}{-10.528} + \underset{(.087)}{.449}\text{CC}(-1) - \underset{(.015)}{.623}\text{HGFBPR}(-1)/\text{CFPI}(-1) + \underset{(.003)}{.150}\text{OILP}(-1)/\text{CFPI}(-1) + \underset{(.094)}{.532}\text{HI}(-1)$, $R^2 = .8278$, AUT, $\hat{\rho} = \underset{(.253)}{-.568}$.
11	OHI	$= \underset{(3.106)}{-5.734} + \underset{(.070)}{.828}(\text{HI} - \text{HHDCR}) + \underset{(.009)}{.0008}\text{HGFBPR}(-1)/\text{CFPI}(-1) - \underset{(.001)}{.012}\text{OILP}(-1)/\text{CFPI}(-1)$,

TABLE 2. Continued.

Equation Number		Equation
		R^2 = .9660, AUT, $\hat{\rho}$ = −.499 .
		(.261)
12	HHBCR	= HI − OHI − HHDCR.
13	SI	= −8.705 + .465CC(−1) − .050HGFBPR(−1)/CFPI(−1)
		(10.312) (.122) (.022)
		− .007OILP(−1)/CFPI(−1) + .408SI(−1),
		(.005) (.151)
		R^2 = .8810, AUT, $\hat{\rho}$ = −.318 .
		(.310)
14	CC	= −34.757 + .899(BCI + DCI) + .784(HHBCR + HHDCR),
		(24.931) (.183) (.375)
		R^2 = .7275, AUT, $\hat{\rho}$ = −.426 .
		(.273)
		III. Quarterly Beef Production Equations
15	GFBPQ	= −4233.5 − 51.732TSOHIQ*D1Q − 57.630TSOHIQ*D2Q
		(1762.3) (23.447) (16.149)
		− 1.809TSOHIQ*D3Q + 103.50TSOHIQ
		(14.233) (22.84)
		+ 44.402TSOHIQ(−4)*D1Q + 221.42RSOHIQ*D1Q
		(20.727) (507.72)
		+ 1489.1RSOHIQ*D2Q + 31.939RSOHIQ*D3Q
		(537.33) (484.35)
		+ 2104.4RSOHIQ + 37.9HGFBPRQ(−1)/CFPIQ(−1)
		(905.65) (11.96)
		− 39.359HNFBPRQ(−1)/CFPIQ(−1) − 3.741OILPQ(−1)/CFPIQ(−1)
		(16.516) (1.634)
		− 18.067(HGFBPRQ(−1)/CFPIQ(−1) − HGFBPRQ(−2)/CFPIQ(−2))
		(6.237)
		+ 8.816(OILPQ(−1)/CFPIQ(−1) − OILPQ(−2)/CFPIQ(−2))
		(2.549)
		+ 972.86DM1Q + 593.36DM2Q − 253.64DM3Q
		(207.38) (195.4) (232.25)
		− 372.88WQ + 27.93TQ,
		(136.11) (17.248)
		R^2 = .9485, AUT, $\hat{\rho}$ = .563 .
		(.132)
16	NFBPQ	= −532.71 − .394TSOHIQ*D1Q + 4.233TSOHIQ*D2Q
		(365.55) (1.082) (.714)
		+ 2.110TSOHIQ*D3Q + 20.552TSOHIQ + 129.16RSOHIQ
		(1.037) (4.892) (108.25)
		− .087GFBPQ(−3) − 9.419HGFBPRQ(−3)/CFPIQ(−3)
		(.025) (2.438)
		+ 12.987HNFBPRQ(−3)/CFPIQ(−3) + .323OILPQ(−3)/CFPIQ(−3)
		(3.714) (.271)
		− 50.484WQ(−3) + 341.78DM3Q + .657NFBPQ(−1),
		(29.732) (66.416) (.073)
		R^2 = .9181, AUT, $\hat{\rho}$ = −.424 .
		(.144)

TABLE 2. Continued.

Equation Number		Equation
17	TSHBPQ	= GFBPQ + NFBPQ.
18	CBPQ	= 3317.0 − .769CIQ*D1Q + .934CIQ*D2Q (849.38) (.406) (.435) + .411CIQ*D3Q − 17.041CIQ (.371) (8.046) + 10.385(HCPRQ/CFPIQ − HCPRQ(−1)/CFPIQ(−1)) (3.642) − 5.067(HGFBPRQ/CFPIQ − HGFBPRQ(−1)/CFPIQ(−1)) (2.004) − 8.306TQ + 104.48WQ, (2.732) (42.360) R^2 = .6757, AUT, $\hat{\rho}$ = .361 . (.141)
19	BBPQ	= 36.171 + .046CBPQ + 44.798D1Q (64.666) (.038) (15.848) + 20.981D2Q + 31.276D3Q + .459BBPQ(−1), (15.920) (15.296) (.142) R^2 = .3190, DH = −.851, OLS.
20	TBPQ	= TSHBPQ + CBPQ + BBPQ.
		IV. Period Transition Identities
21	CFPI(L)[b]	$= .25 \sum_{t=1}^{4}$ CFPIQ(t).
22	HGFBPR(L)	$= .25 \sum_{t=1}^{4}$ HGFBPRQ(t).
23	OILP(L)	$= .25 \sum_{t=1}^{4}$ OILPQ(t).
24	CIQ(t = 1–4)	= BCI(L) + DCI(L).
25	TSOHIQ(t = 1–4)	= SI(L) + OHI(L).
26	RSOHIQ(t = 1–4)	= SI(L)/OHI(L).

[a] In the autoregressive equations (AUT), R^2 is viewed only as a measure of goodness-of-fit (Kmenta, p. 234). Numbers in parentheses below coefficients are estimated standard errors (asymptotic standard errors for AUT equations). Numbers in parentheses following variable names indicate lags.
[b] L refers to the current year and t refers to the quarter of that year.

on Hawaii cow and grass fed steer and heifer prices. First, even though little, if any, cow and grass fed unprocessed beef is imported from the Mainland, large unspecified quantities of lower quality processed beef are imported in the form of hamburger, and the like, by fast food restaurants and other enterprises. This also competes with locally-produced cow and grass fed steer and heifer beef. Second, a significant portion of the lower quality processed beef from the Mainland probably originates in Australia and New Zealand.

Exogenously determined prices greatly simplify estimation procedures. The matrix of endogenous variable coefficients is triangular and it is assumed that the industry can be represented by a recursive model structure (Johnston, p. 369). Con-

TABLE 3. Variable and Symbol Definitions.[a]

Variable or Symbol[b]	Definition
	Endogenous Variables
BBPQ	Bull beef production (dressed weight, 1,000 pounds).
BCI	Beef cow inventory (January 1, 1,000 head).
CBPQ	Cow beef production (dressed weight, 1,000 pounds).
CC	Calf crop (1,000 head).
CFPIQ	Cattle feed price index (1980 = 1.0).
CFPI	Cattle feed price index (annual average of CFPIQ).
CFPQ	Cattle feed price (paid by Hawaii ranchers, $/100 pounds).
CI	Beef plus dairy cow inventory (January 1, 1,000 head).
CIQ	Beef plus dairy cow inventory (January 1 inventory for each quarter of the current year, 1,000 head).
GFBPQ	Grain fed steer and heifer beef production (dressed weight, 1,000 pounds).
HCPRQ	Honolulu cow price (wholesale, all carcasses, utility, $/100 pounds).
HGFBPRQ	Honolulu grain fed beef price (wholesale, 500–900 pound carcasses, choice feedlot steers and heifers, $/100 pounds).
HGFBPR	Honolulu grain fed beef price (annual average of HGFBPRQ).
HHBCR	Heifers held for beef cow replacement (January 1st inventory, 1,000 head).
HI	Heifer inventory (January 1, 1,000 head).
HNFBPRQ	Hawaii grass fed beef price (dressed weight, steers and heifers, $/100 pounds).
NFBPQ	Grass fed steer and heifer beef production (dressed weight, 1,000 pounds).
OHI	Other heifer inventory, i.e., heifers not held for beef or dairy cow replacement (January 1, 1,000 head).
RSOHIQ	Ratio of steer to other heifer inventory (January 1 inventories for each quarter of the current year).
SI	Steer inventory (January 1, 1,000 head).
TBPQ	Total beef production (dressed weight, 1,000 pounds).
TRANBQ	Cost of transporting beef from the U.S. West Coast to Hawaii in containers ($/100 pounds).
TRANFQ	Cost of transporting animal feeds and feed ingredients from the U.S. West Coast to Hawaii in containers ($/ton).
TRANFMQ	Three-quarter-weighted-moving-average of TRANFQ (weights of 1/4, 1/2, and 1/4).
TSHBPQ	Total steer and heifer beef production (dressed weight, 1,000 pounds).
TSOHIQ	Steer plus other heifer inventory (January 1 inventories for each quarter of the current year, 1,000 head).
	Exogenous Variables
DCI	Dairy cow inventory (January 1, 1,000 head).
D1Q	Equals 1 in the first quarter and 0 otherwise.
D2Q	Equals 1 in the second quarter and 0 otherwise.
D3Q	Equals 1 in the third quarter and 0 otherwise.
DM1Q	Price freeze dummy, equals 1 for 1973(II)–1973(III).
DM2Q	Pre-trailer freight regulation dummy, equals 1 for 1976(I)–1977(II).
DM3Q	Post-trailer freight regulation dummy, equals 1 for 1978(IV)–1980(IV).
HHDCR	Heifers held for dairy cow replacement (January 1 inventory, 1,000 head).
LACPRQ	Los Angeles cow price (wholesale, 350–700 pound carcasses, utility, $/100 pounds).
LAGFBPRQ	Los Angeles grain fed beef price (wholesale, 600–700 pound carcasses, choice steers, $/100 pounds).
OILPQ	U.S. crude oil wholesale price index (1967 = 100.0).
OILP	U.S. crude oil wholesale price index (annual average of OILPQ).
TQ	Time, equals 1 in 1970(I) to 44 in 1980(IV).

TABLE 3. Continued.

Variable or Symbol[b]	Definition
USCPMQ	Three-quarter-weighted-moving-average of the average price received by U.S. farmers for corn (same weights as TRANFMQ, \$/bushel).
WQ	Weather dummy, equals 1 in quarters when droughts occurred.
	Other Symbols
R^2	One minus the ratio of the sum of squares residual to the sum of squares total (calculated from untransformed data for autoregressive equations).
DW	Durbin-Watson statistic.
DH	Durbin H statistic.
OLS	Ordinary least squares.
AUT	Autoregression procedure (Cochrane-Orcutt or grid search).
$\hat{\rho}$	Estimated first order autoregressive parameter.

[a] The data were obtained from the following sources: Hawaii Agricultural Reporting Service, *Statistics of Hawaiian Agriculture,* and worksheets; Hawaii Market News Service, *Honolulu Prices: Wholesale Eggs, Poultry, Pork, Beef, and Rice*; U.S. Department of Commerce, *Business Statistics 1977,* and *Survey of Current Business*; Matson Navigation Company, *Tariffs 14-B through 14-G*; Economics, Statistics, and Cooperative Service, *Agricultural Prices, Annual Summary*; California Federal-State Market News Service, *Livestock and Meat Prices and Receipts at Certain California and Western Area Markets*; National Weather Service, Honolulu, Hawaii, worksheets from Saul Price, Staff Meteorologist.

[b] Q at the end of a variable name denotes quarterly observations. All other variables are annual.

sequently, ordinary least squares, and Cochrane-Orcutt and grid search autoregression procedures were used to estimate the structural equations of the model, using quarterly and annual data for 1970 through 1980 (White). For those equations estimated as distributed lags, partial adjustment was assumed (Nerlove).[4] Estimated variances for autoregressive equations that included lagged dependent variables were calculated using Dhrymes' theorem 7.1 (pp. 199–201). Seasonal intercept shifting dummy variables were included in all quarterly equations, but retained only where they were found to be significant at the 5 percent level using an F test (Kmenta, pp. 414–15).

The structural equations and identities of the model are divided into three sections which determine Hawaii beef and feed prices, cattle inventories and beef production, and one section which interfaces annual cattle inventories with quarterly prices and production.

Equations 1 and 2 estimate beef (TRANBQ) and feed (TRANFQ) freight rates as a function of the U.S. crude oil (petroleum) wholesale price index (OILPQ), which is used as a proxy for energy prices. A time trend (TQ) is included to represent increases in transportation efficiency and other costs of transportation services. Equations 4–7 provide estimates of the Honolulu wholesale choice feedlot steer and heifer carcass price (HGFBPRQ), the Hawaii dressed weight grass fed steer and heifer price (HNFBPRQ),[5] the Honolulu wholesale utility cow carcass price (HCPRQ),[6] and

[4] Where lagged dependent variables were present with autocorrelation, a grid search technique was used to verify that the Cochrane-Orcutt procedure converged to a consistent estimator at the global maximum of the likelihood function. The grid search procedure (White) was accurate to the nearest one hundredth, still leaving a slight margin of error (Betancourt and Kelejian, p. 1076).

[5] A Honolulu wholesale price for grass fed steer and heifer carcasses is not available. Therefore, the state average dressed weight price received by farmers for grass fed steers and heifers is used. There is no analogous Mainland price. It is an advantage of the Hawaii data that steer and heifer prices are disaggregated by feedlot and grass feeding (Hawaii Agricultural Reporting Service).

[6] For simplicity, throughout the remainder of this paper HGFBPRQ and HNFBPRQ will be referred to as the Honolulu and Hawaii grain and grass fed beef prices, respectively, and HCPRQ will be referred to as the Honolulu cow price.

the Hawaii cattle feed price (CFPQ), all as functions of Mainland prices and freight rates. Equation 4 most closely fits the Mainland price plus freight cost model because of local pricing practices. Once a week the major Hawaii slaughterhouses call slaughterhouses in Los Angeles for price quotations. Hawaii prices of grain fed steers and heifers are based on these quotations plus a markup for freight costs. Pricing methods for Hawaii grass fed steer and heifer, and cow beef are not as well defined and Mainland price transmission via Australia and New Zealand is somewhat delayed because of the great distances involved. Lagged Mainland prices are included to capture price transmission delays. Hawaii feed costs also demonstrate lags in price transmission. Three-quarter moving averages are used in equation 7 to capture these delays and to avoid the problems of multicollinearity. The weighting scheme of equation 3 was assumed after preliminary regressions indicated that the influence of the one quarter lag was the strongest. All freight rate variables are significant at the 5 percent level and the R^2's are all over .97, suggesting that the Mainland price and freight rate variables provide a good fit to the Hawaii beef and feed price data.

Equation 8 simply converts the Hawaii cattle feed price (CFPQ) into an index with 1980 equal to 1.0 to be used as a price deflator in the remainder of the model. Deflating by the feed price is theoretically based on the zero degree homogeneity of derived input demand and commodity supply (Henderson and Quandt; Lau and Yotopoulos). A preferred deflator would be an index of prices paid by farmers for production inputs in Hawaii, but such an index does not exist. Instead of a U.S. average index, the Hawaii cattle feed price is used as the numeraire.

The absence of a "placements on feed" equation represents another significant departure from traditional or conventional beef models. It would have been more desirable to include placements on feed in the grain fed and grass fed beef production equations as did Arzac and Wilkinson, but data limitations precluded their estimation. Therefore, January 1 steer and heifer inventories were estimated to link the calf crop with beef production.

Equations 9–13 are inventory demand equations. Equation 9 estimates January 1 beef cow inventory (BCI) assuming partial adjustment. Normally, the feeder calf price would be included, but in Hawaii, ranchers typically retain ownership of their animals until the carcasses are marketed after slaughter. Consequently, live feeder and slaughter cattle prices are not available. The deflated Honolulu grain fed beef price (HGFBPR/CFPI) and the deflated U.S. crude oil wholesale price index (OILP/CFPI) lagged one year are used as proxies for the expected profitability of keeping a cow in the breeding herd (Jarvis; Nelson and Spreen; Reutlinger).

January 1 heifer inventory demand (HI) is estimated in equation 10 as a function of the calf crop (CC), the deflated U.S. crude oil wholesale price index (OILP/CFPI), the deflated Honolulu grain fed beef price (HGFBPR/CFPI), and HI all lagged one year. The theoretical signs of the coefficients for lagged OILP/CFPI and lagged HGFBPR/CFPI cannot be determined *a priori*. For example, energy prices influence HI through slaughter age in four ways. First, they influence the decision of whether to allocate feeder animals to feedlots or pasture. Over half of all grain fed cattle in Hawaii are transported between islands before they enter a feedlot (Schermerhorn *et al.*). Most are transported from the Island of Hawaii to the major feedlot on Oahu; a distance of approximately 200 miles, at a cost in 1981 averaging $14.23 per head for ocean freight (Hawaii Agricultural Reporting Service). Thus, an increase in energy prices this year would cause HI to increase next year, because of slower rates of gain as ranchers increase the proportion of their heifers allocated to grass.[7] Second, as with cows, higher energy prices reduce the expected profitability of retaining a heifer in the breeding herd (*ceteris paribus*). Thus, HI would decline as fewer heifers are held for replacement. Third, higher energy prices might encourage ranchers to change the method of producing calves from older cows to younger heifers. Most cows are slaughtered on the island of origin, so with higher energy prices the opportunity cost of retaining a cow would be reduced less than the opportunity cost of adding a heifer to the herd. Hence, older cows would be replaced by younger heifers. As more heifers are held for replacement, HI increases. Fourth, once a heifer is allocated to the feedlot or pasture, higher energy costs might be expected to reduce the slaughter age (Jarvis), causing HI to decline. The coefficient for OILP in equation 10 suggests that the positive effects outweigh the negative. The influences discussed above for OILP would be opposite for HGFBPR and indeed the coefficient for HGFBPR is negative in equation 10.

Equations 11 and 12 disaggregate beef heifers (HI-HHDCR) into heifers not held for replacement (OHI) and heifers held for beef cow replacement (HHBCR). The coefficient for (HI-HHDCR) in equation 11 suggests that on the average 17 percent of the beef heifers are held for replacement and 83 percent are held for future slaughter. OILP has a negative coefficient implying that for a given number of beef heifers, an increase in OILP will result in more heifers entering the replacement herd and less being held for slaughter. The opposite influence is evident for the Honolulu grain fed beef price (HGFBPR) but the coefficient is not significant at the 5 percent level.

Equation 13 determines January 1 steer inventory (SI) as a function of the same variables used to estimate heifer inventory. The coefficient for OILP is negative, though nonsignificant at the 5 percent level, perhaps because there is no analogous breeding herd replacement impact. The coefficient for HGFBPR has the same sign as in equation 10.

Finally, the annual calf crop (CC) is estimated as a function of the inventories of cows (BCI + DCI) and replacement heifers (HHBCR + HHDCR), completing Section II of the model.

Section III determines quarterly production of grain fed beef (GFBPQ), grass fed steer and heifer beef (NFBPQ), cow beef (CBPQ), and bull beef (BBPQ). Equation 15 estimates GFBPQ as a function of the January 1 inventory of steers plus heifers not held for replacement (TSOHIQ) and the ratio of steers to heifers not held for replacement (RSOHIQ). Dummy variables (D1Q, D2Q and D3Q) allow changes in their impacts among quarters. TSOHIQ represents the number of steers and heifers available for slaughter during the coming year, while TSOHIQ(-4) recognizes that some animals classified as steers and heifers on January 1 of the current year might not be slaughtered until the first quarter of the following year. This is especially true in Hawaii where many ranchers brand calves four times a year and usually consider them on their records as steers or heifers thereafter. RSOHIQ accounts for the fact that if steers constitute a larger proportion of the animals available for slaughter, beef production will be higher because of heavier carcass weights and faster growth rates of steers relative to heifers. Under this specification, prices are more important in the grain fed beef production equation than in previous studies (Arzac and Wilkinson;

[7] In Hawaii some ranchers produce only grass fed steers and heifers, others concentrate solely on feedlot production, with the remainder marketing some combination of grass and grain fed beef. See Schermerhorn *et al.* for a complete description of the market organization of the Hawaii beef cattle industry.

Freebairn and Rausser) because January 1 steer and heifer inventories are composed of animals on both feed and grass, and the proportion on feed depends on expected prices of products (grass and grain fed beef) and inputs (energy and feed).

No previous study was found that included both grain fed and grass fed beef prices in the grain fed beef production equation. The exclusion of the grass fed steer and heifer beef price from Martin's U.S. model is attributed to the lack of an adequate data series. Bain hypothesized that placements on feed were positively related to grain fed cattle prices and negatively related to grass fed cattle prices. He used the utility cow price to represent the grass fed beef price, but excluded it from the final equation because of a high standard error and an incorrect sign. In contrast, the Hawaii model includes both grain and grass fed steer and heifer beef prices in equation 15, with significant coefficients and anticipated signs.

The differences between one and two quarter lags in the Honolulu grain fed beef price (HGFBPRQ) and the crude oil wholesale price index (OILPQ) are included with negative and positive coefficients, respectively. The signs are explained through the relationship between inventory and slaughter age. Given the available inventory of steers and heifers, if more are shipped to the feedlot in the current quarter (shipped at younger ages) because of an expected price increase, less will be available for shipment in the next quarter, and hence, production would be lower two quarters down the line. The reverse would be true for increases in expected energy-related costs.

Other variables in equation 15 are a time trend (TQ) to capture increases in feedlot production efficiency and other trend influences, and various binary variables. The positive coefficient for DM1Q implies that animals were held to heavier weights during the 1973 price freeze. DM2Q and DM3Q are included to capture changes in shipping rules that required shipment of live animals in cattle trailers rather than on open barges after 1977. The positive coefficient for DM2Q suggests that ranchers shipped feeder animals at earlier ages to get them to the feedlot before trailers became mandatory. The negative coefficient for DM3Q reflects the higher cost of shipping feeder animals to the feedlot relative to leaving them on pasture. During droughts in Hawaii, ranchers ship a larger proportion of their feeder animals to feedlots, straining feedlot capacity. Cattle already in feedlots are slaughtered at lighter weights to accommodate the increase in placements. Hence, the negative coefficient for the weather variable (WQ) is as anticipated.

Equation 16 estimates grass fed steer and heifer beef production (NFBPQ) as a function of TSOHIQ and associated quarterly dummy variables and RSOHIQ with positively signed coefficients as in equation 15. A three quarter lag of grain fed beef production (GFBPQ(−3)) is included as a proxy for placements on feed four and five quarters lagged. Deflated HGFBPRQ, NFBPRQ, OILPQ and WQ lagged three quarters are included to capture the decision to send older animals to the feedlot as economic and environmental conditions change. Government regulations requiring feeders to be shipped in cattle trailers resulted in higher grass fed beef production as demonstrated by the positive coefficient for DM3Q.

Equation 16 was originally specified to include the current weather dummy variable (WQ). In Hawaii, cattle producers reduce placement rates on pasture during droughts by sending a larger proportion of their feeder cattle to feedlots, allowing pasture to be used to finish cattle already on grass. Consequently, droughts are unlikely to have a large effect on grass fed beef production in the current period. WQ was not significant in explaining grass fed steer and heifer beef production and was, therefore, excluded from the final version of equation 16.[8]

Quarterly cow and bull beef production are determined by equations 18 and 19. Bull beef production is estimated as a proportion of cow beef production in a partial adjustment framework with quarterly intercept shifting dummy variables. Quarterly cow beef production is estimated as a function of the January 1 cow inventory (CIQ) and associated slope shifting dummy variables, the change in the deflated Honolulu cow price (HCPRQ/CFPIQ − HCPRQ(−1)/CFPIQ(−1)), the change in the deflated Honolulu grain fed beef price (HGFBPRQ/CFPIQ − HGFBPRQ(−1)/CFPIQ(−1)), a time trend (TQ) and a drought dummy variable (WQ). The negative coefficient for CIQ is consistent with equations 11–12 which suggest a negative relationship between the number of heifers held for beef cow replacement and the Honolulu grain fed beef price and a positive relationship with the U.S. crude oil wholesale price index. The implication is that Hawaii producers react to higher grain fed beef prices and lower energy costs by decreasing both the culling rate and the replacement rate. This allows ranchers to take advantage of the higher expected profitability of heifer slaughter by holding less heifers for herd replacement and sending more to the feedlot.

The identities contained in Section IV of Table 2 simply convert quarterly prices to annual averages for use in Section II, or they convert annual inventories into a quarterly form for use in Section III.

TABLE 4. Forecasting Accuracy of the Hawaii Beef Econometric Model, 1972(I)–1980(IV).

Variable	Root-Mean-Square Simulation Error as a Proportion of Mean	Theil's U_2 Coefficient
TRANBQ	0.023	0.942
TRANFQ	0.034	0.956
HGFBPRQ	0.015	0.196
HNFBPRQ	0.034	0.571
HCPRQ	0.038	0.537
CFPQ	0.036	0.629
GFBPQ	0.078	0.587
NFBPQ	0.148	1.318
TSHBPQ	0.080	0.825
CBPQ	0.073	0.605
BBPQ	0.147	0.878
TBPQ	0.063	0.843
BCI	0.021	0.646
CI	0.018	0.613
HI	0.035	0.547
OHI	0.063	0.641
HHBCR	0.039	0.535
SI	0.058	0.646
CC	0.041	0.721

Model Validation and Simulation Results

The impact analysis of energy price escalations on Hawaii beef production and prices during the 1970s is performed through two simulations of the model. Simulation 1 serves as a base. It is a dynamic simulation from the first quarter of 1972 through the last quarter of 1980, with all exogenous variables set at their historical levels and previously determined endogenous variables assuming their predicted values. Theil U_2 coefficients (Leuthold) and root-mean-square simula-

[8] The original specification of equation 16 included TSOHIQ(-4)*D1Q, DM1Q, DM2Q and the quarterly dummy variables associated with RSOHIQ. The resulting equation showed symptoms of high multicollinearity. Estimated asymptotic standard errors were high and some key price variables had incorrect signs, reducing the equation's usefulness in later impact analysis. High collinearity existed between the quarterly dummy variables for TSOHIQ and RSOHIQ. For example, the correlation between RSOHIQ*D1Q and TSOHIQ(−4)*D1Q was .90. The exlcusion of possibly relevant variables may have introduced some bias into equation 16, but the tradeoff was considered worthwhile. There was also high correlation among some variables of equation 15, but multicollinearity did not appear to be a serious problem, given that most asymptotic standard errors were low relative to the size of their coefficients.

TABLE 5. Annual Average Beef Production and Cow Inventory Simulation Results, 1974–80.[a]

Variable	Simulation Number	1974	1975	1976	1977	1978	1979	1980
GFBPQ	1	19,589.9	17,668.3	20,653.3	19,694.7	18,304.1	17,634.3	14,395.3
	2	0.39	9.76	12.94	16.05	22.52	27.35	52.27
NFBPQ	1	3,815.9	4,875.0	5,111.6	5,068.6	4,931.5	6,754.8	6,984.1
	2	−0.65	−3.88	−11.45	−14.80	−15.11	−11.54	−12.44
TSHBPQ	1	23,405.9	22,543.3	25,764.9	24,763.3	23.235.5	24,389.1	21,379.5
	2	0.22	6.81	8.10	9.73	14.53	16.58	31.13
CBPQ	1	5,394.1	5,882.5	5,769.1	5,785.8	5,978.9	5,716.5	5,486.6
	2	−0.04	−1.33	−2.66	−3.88	−4.79	−6.46	−8.93
BBPQ	1	919.9	938.4	949.3	939.6	954.7	943.2	917.4
	2	−0.20	−0.58	−1.23	−1.92	−2.46	−3.19	−4.34
TBPQ	1	29,719.9	29,364.1	32,483.2	31,488.7	30,178.1	31,048.8	27,783.4
	2	0.17	4.94	5.92	6.88	10.16	11.74	22.05
BCI	1	92.0	89.0	86.0	82.0	80.0	80.0	82.0
	2	0.00	1.25	2.71	4.01	5.40	6.79	8.88

[a] Simulation 1 results are in 1,000's of pounds except for BCI which is in 1,000's of head. Simulation 2 results are expressed as percentage deviations from Simulation 1, with negative signs indicating decreases.

tion errors as proportions of endogenous variable means (RMSEM) are presented in Table 4. Grass fed steer and heifer beef production (NFBPQ) is the only endogenous variable with a Theil U_2 coefficient greater than one, suggesting that the equation is less accurate than the naive no-change extrapolation. It also has a RMSEM greater than 0.1, as does bull beef production (BBPQ). The relatively poor performance was expected for BBPQ but not for NFBPQ. The difficulty is that small simulation errors in steer and heifer inventories are greatly magnified in predicting NFBPQ.

Simulation 2 assumes that the U.S. crude oil wholesale price index (OILPQ) increases at its pre-oil embargo rate of 1.44 percent per quarter which is the average rate for the first quarter of 1968 through the last quarter of 1973. In Simulation 2, OILP averages 32, 38, 36, 37, 39, 49, and 63 percent below actual levels for the years 1974 through 1980, respectively.[9] All other exogenous variables are maintained at Simulation 1 levels so that other factors influencing Hawaii beef production and prices are unchanged.

Simulation results for selected beef production variables are presented in Table 5. The most important finding is that the composition of beef production in Hawaii would have been markedly different had energy prices not increased so rapidly after 1973. With energy prices increasing at pre-oil embargo rates, grain fed beef production (GFBPQ) would have been 52.27 percent higher and grass fed steer and heifer beef production (NFBPQ) 12.44 percent lower in 1980. As depicted in Figure 2, the pre-1974 trend toward less grass fed as a percentage of total steer and heifer beef production would not have been interrupted so dramatically had energy prices increased at pre-oil embargo rates.

[9] The analysis accounts for all energy price impacts on Hawaii beef production except the impacts through Mainland beef and feed prices. To simplify the analysis these impacts are not considered in this paper. However, if the indirect impacts are more important than the direct impacts, as Carter and Youde argue, then the results presented in this paper would be amplified rather than diminished.

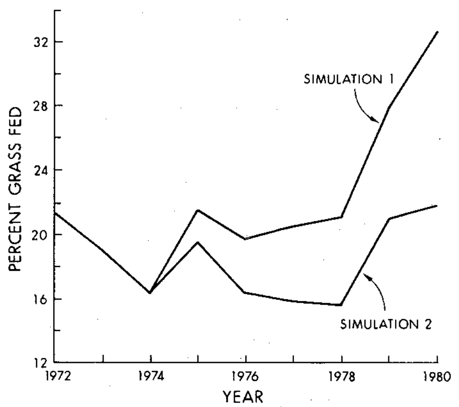

Figure 2. Estimated Grass Fed as a Percentage of Total Steer and Heifer Beef Production in Hawaii, 1972–80.

Cow (CBPQ) and bull (BBPQ) beef production decline by 8.93 and 4.34 percent in 1980 as ranchers reduce culling rates to build breeding herds in response to higher expected profits. These findings support the hypothesis that rapidly increasing energy prices substantially altered the composition of beef production in Hawaii.

Total Hawaii beef production (TBPQ) increases appreciably as larger percentages of steers and heifers are sent to feedlots, releasing pasture for breeding herd expansion. In 1980, total beef production is 22.05 percent higher than Simulation 1 levels. If this percentage increase were added to the actual 1980 level of 28.8 million pounds (see Table 1) then the 1980 beef production would be 35.2 million pounds, surpassing the 1971 high by 1.2 million pounds. Similar calculations for 1978 put total beef production at 36.9 million pounds, or 2.9 million pounds higher than the 1971 peak. The results give support to the hypothesis that the upward trend in beef production would have continued in the latest cattle cycle had energy prices not increased so rapidly after 1973. Of course, this assumes that other influences would have remained unchanged from historical 1972–80 levels.

Beef cow numbers would have declined in 1977–79 even with lower rates of increase in energy prices, but liquidation would not have been as rapid or sustained, allowing the cow herd to rebound in 1980. The cow herd in 1980 under Simulation 2 assumptions is 8.88 percent higher than in Simulation 1. This percentage increase added to the actual 1980 herd size of 83 thousand head would give a herd of 90 thousand head, which is comparable to the beef cow inventories of 1970–76 (Table 1). Thus, it appears that high energy prices were responsible in part for the decline in cow numbers after 1976.

In Table 6, the impacts of pre-oil embargo rates of increase in energy prices on freight rates and Hawaii beef and feed prices are presented. The impacts on beef and feed freight rates are quite similar, with TRANBQ and TRANFQ being 16.04 and 14.96 percent lower than Simulation 1 levels in 1980. Because freight rates decline, all beef and feed prices are reduced in Simulation 2. The impact is largest for the Hawaii cattle feed price (CFPQ) which declines by over twice as much as the Honolulu grain fed beef price (HGFBPRQ). The impacts are progressively larger for HGFBPRQ, HNFBPRQ, HCPRQ and CFPQ because freight costs constitute a progressively larger proportion of the Hawaii price. For example, in 1980 the feed freight rate was 19 percent of the Hawaii cattle feed price, while the beef freight rate accounted for only 4 percent of the Honolulu grain fed beef price (Matson Navigation Company; Hawaii Market News Service; Hawaii Agricultural Reporting Service).

Conclusions and Implications

The modeling exercise demonstrates the importance of energy prices in the decision framework of beef producers in Hawaii. State and national beef modeling implications can be drawn from this application. First, the use of local prices as determined by national prices and freight rates allows broadened policy analysis ca-

TABLE 6. Annual Average Simulation Results for Freight Rate and Price Variables, 1974–80.[a]

Variable	Simulation Number	1974	1975	1976	1977	1978	1979	1980
TRANBQ	1	3.59	3.78	3.91	4.06	4.23	4.51	5.03
	2	−4.33	−5.67	−5.42	−5.86	−6.47	−9.45	−16.04
TRANFQ	1	25.39	27.56	29.27	31.21	33.24	36.15	40.81
	2	−4.64	−5.89	−5.48	−5.76	−6.24	−8.92	−14.96
HGFBPRQ	1	80.64	87.69	77.37	80.00	97.47	120.62	128.18
	2	−0.88	−1.11	−1.25	−1.35	−1.28	−1.61	−2.86
HNFBPRQ	1	57.12	60.90	56.16	56.80	67.69	82.28	88.99
	2	−1.18	−1.53	−1.64	−1.82	−1.76	−2.25	−3.94
HCPRQ	1	59.60	49.43	56.94	55.61	69.77	93.56	96.21
	2	−1.34	−2.22	−1.91	−2.19	−2.01	−2.33	−4.29
CPFQ	1	8.60	9.33	9.01	8.63	8.73	9.47	10.60
	2	−1.41	−2.36	−2.63	−2.96	−3.32	−4.15	−7.57

[a] Simulation 1 results are in dollars per 100 pounds except TRANFQ which is in dollars per ton. Simulation 2 results are expressed as percentage deviations from Simulation 1, with negative signs indicating decreases.

pabilities not possessed by the model developed by Baum *et al.* For example, the impacts of deregulating freight rates on a particular state's beef industry could be studied. Also, the state impacts of national energy policies could be analyzed by linkage with a national model. Second, state and national beef modelers might find it useful to incorporate energy prices directly in the equations determining the allocation of feeder cattle to grain or grass finishing. The importance of energy prices would depend upon the location of slaughterhouses relative to feedlots.

Simulation results suggest that spiraling energy prices between 1974 and 1980 curtailed total beef production in Hawaii, depressed the size of the cow herd, and altered the composition of production toward more grass fed relative to grain fed beef. Although these results are specific to Hawaii, they suggest a need for additional research at the national level. It would be useful to determine the extent to which energy prices influenced the sharp decline in U.S. cow inventories, beef production, and per capita beef consumption after 1975. This knowledge would permit projections of the impacts of national energy policies on the U.S. beef industry.

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