A New General Conceptual Approach to Modeling the Livestock Sector: An Application to the Japanese Swine-Pork Sector [1]

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Abstract

Many livestock sector models have limited coverage of relevant variables, and are somewhat ad hoc in their choice of what should be specified as behavioral equations. This study develops a generic conceptual approach to modeling the livestock sector that provides consistent rules of specification and better coverage of variables. This approach is then applied to the swine-pork sector of Japan.

The new approach departs significantly from existing models. The structure clearly differentiates stock and flow variables; only flow variables have behavioral specifications and stock variables are accounting identities; flow variables are expressed in rates rather than levels; logistic functions are used in most flow variables to automatically impose biological-technological limits; and swine slaughter number and weight are disaggregated into sow and other swine (i.e., gilt-barrow).

The estimated Japanese swine-pork model has good fit, no serial correlation, significant coefficients, correct signs, and is better able to capture both the mean and variability of all endogenous variables.

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1.0 Introduction

This study develops a generic conceptual approach to modeling the livestock sector. The specific features of this approach are then applied to the Japanese swine-pork sector.

Many existing livestock sector models are limited in their variable coverage and ad hoc in the choice of what should be specified as behavioral equations and what is not specified. For example, the Organization for Economic Cooperation and Development (OECD) model of the Japanese swine-pork sector is a three-equation model that includes behavioral specification of a pork import demand, pork domestic demand, and pork production. There is no coverage of any live animal variables. Most of the U.S. Department of Agriculture's country models are similarly specified. The Food and Agricultural Policy Research Institute's (FAPRI) Japanese model, on the other hand, includes both meat and live animal inventory. It has six behavioral equations: sow inventory, swine inventory, swine slaughter, pork production, domestic demand, and import demand.

We develop a new and more general conceptual approach in modeling the livestock sector to richly capture the behavioral and biological processes unique in this sector. There are new contributions that depart from existing models in a significant way. First, stock and flow variables are clearly differentiated. This feature allows for proper accounting of live animals to ensure consistency in the underlying biologics of the model.

It also allows the model to easily accommodate adjustments in inventory and production that may result from exogenous shocks such as the swine FMD in Taiwan, and CSF in the EU. Second, only flow variables are specified with behavioral equations. These may include number of animals slaughtered, number of animals added to the breeding herd, slaughter weight, import, export, consumption, pork stock demand, pig crop, and mortality. On the other hand, stock variables such as sow inventory and other swine inventory are not directly specified as behavioral equations. Instead, their levels over time are simply derived, given their beginning levels, from the changes in the flow variables that impact them. Third, swine slaughter is disaggregated into sow and other swine slaughter to allow differential impacts of price changes in both direction and magnitude of these variables.

An econometric decomposition method is applied to derive a slaughter weight equation that can estimate a separate average slaughter weight for sows and other swine slaughtered. Pork production is a product of number slaughtered and slaughter weight for sows and other swine. Fourth, the flow variables are modeled as rates rather than as levels. For example, the rate of sow slaughter, which is defined as the ratio of the number of sows slaughtered and beginning sow inventory, is used rather than the number slaughtered. Based on historical data, the rates appear to have more stable behavior and are usually comparable over time and across countries. Fifth, biological-technological restrictions are imposed using a logistic function on some of the rates.

2.0 Model

The specification of the Japanese swine-pork sector includes eight flow variables: domestic demand, pig crop, swine death, sow slaughter, other swine slaughter (gilt-barrow), slaughter weight, sow addition, and pork import. The two stock variables are sow inventory and other swine inventory. There is also an equilibrium condition. A combination of linear, double log, and logistic functional forms are used. A linear function was specified for domestic demand and slaughter weight equation. A double log function was used for swine death, pork import, and pork stock. A logistic function was specified for pig crop, sow slaughter rate, other swine slaughter rate, and sow addition rate to automatically impose biological-technological limits on these rates. The logistic function is,

[1] $$y_t = \frac{K}{\left(1 - \exp^{-(x_t \beta)}\right)} + \varepsilon_t,$$

where y is the dependent variable, K is the upper limit of y, x is a vector of regressors, β is a vector of parameters to be estimated, and ε is an identically and independently distributed error process, and t is time index. The elasticity formula for a logistic function is,

[2] $$\eta = \beta \bar{x}\left(1 - \frac{\bar{y}}{K}\right).$$

The upper limit for the pig crop equation is 22 piglets per sow per year, 0.55 for sow slaughter rate, 0.70 for other swine slaughter rate, and 0.55 for sow addition rate.

Pork domestic demand is expressed as a function of own-price, price of substitute products including Wagyu beef, dairy beef, import beef, poultry price, fish price, and income. As technical flow variables, pig crop and swine death are expressed as functions of time trend. Slaughter weight, sow slaughter rate, other swine slaughter rate, and sow addition rate are expressed as functions primarily of the pork price and feed cost. Pork import is a function of domestic price, world price, and exchange rate. Pork stock is a function of pork price and CPI. Then trend, lag variables, and dummies are added when necessary.

The equations representing the other swine ending inventory and sow ending inventory are accounting identities;

[3] Other Swine Ending Inventory = Beginning Inventory + Pig Crop + Swine Import – Other Swine Death – Sow Addition – Swine Export – Other Swine Slaughter,

and

[4] Sow Ending Inventory = Beginning Inventory + Sow Addition – Sow Death – Sow Slaughter.

The model solves for a price that clears the market. That is, equilibrium price is determined by equating total supply (beginning pork stock plus production plus import) and total demand (ending pork stock plus consumption plus export).

3.0 Data Estimation and Results

Sources of Japanese data include USDA's PS&D database, the Agriculture and Livestock Industries Corporation, and the Food and Agricultural Policy Research Institute. Estimation and simulation were conducted in SAS 6.12.

Pork consumption ranks number one in Japan's meat consumption basket at 11.8 kg per person per year (see table 1). Poultry follows this at 11.0 kg, and beef is 7.8 kg. Japan is significant in the world pork market. Of the projected total world pork import of 2.25 mmt in 1998, Japan's pork imports account for 40.26 percent. Pork imports are

28.49 percent of consumption. The number of hog farms in Japan is reported to be about 14,400 with the average number of pigs per farm at 681. Sows and gilts for breeding were 9.8 million in 1997. For 1990 to 1997, average pig crop is 18.84 piglets per sow per year and the mortality rate is 10.17 percent. Sow slaughter rate is 47.05 percent and other swine slaughter rate is 62.3 percent. Average slaughter weight is 73 kilograms per head carcass weight. Other swine slaughter represents 97.39 percent of total slaughter, and the remaining 2.60 percent is accounted by sow slaughter. The sow addition rate is 46.95 percent.

The estimated model consists of 12 endogenous variables with 9 behavioral equations, 2 accounting identities, and an equilibrium condition. Table 2 shows that the fit in all equations is good. Of the 9 estimated behavioral equations, only 2 have R^2 in the upper 60s to mid 70s, and the R^2 of the other 7 equations are in the upper 80s to upper 90s. All the DW-statistics suggest the absence of serial correlation. Most of the coefficients are significant and all have the expected signs and magnitudes.

Table 3 shows the elasticity estimates. Demand elasticity is –0.394 and 0.695 for own-price and income. Imported beef and fish are the strongest substitute for pork. Also production elasticity is 0.126, derived as a weighted sum of the sow slaughter elasticity of –0.127 and other swine slaughter of 0.131, and the slaughter weight elasticity of 0.002.

Finally, all validation statistics suggest that the proposed structure is better able to capture both the mean and variability of all the endogenous variables in the model. For example, in the table of descriptive statistics (see table 4), the mean of actual wholesale price is 496 yen per kg while the mean of the solved market clearing price is 497. The mean of the simulation values of the other endogenous variables is also close to the mean of their actual values. The statistics of fit in table 5 shows that of the 12 endogenous variables, 9 have mean percentage error of less than 1 percent, with highest MPE in swine death at 2.3 percent, followed by pork stock at minus 1.8, and pork imports at 1.8. Table 6 shows the decomposition of the MSE. It suggests that the prediction error is mostly from random error. The share of bias for most variables is less than 3 percent, except for pork stock, which is 6.4 percent. Moreover, the Theil Inequality Coefficients all approach zero.

4.0 Summary and Conclusion

Many livestock sector models have limited coverage of relevant variables and are somewhat ad hoc in their structure in the choice of what should be specified as behavioral equations. This study developed a generic conceptual approach to modeling the livestock sector that provides consistent rules of specification and better coverage of variables.

The proposed approach has new and significant contributions. First, it clearly differentiates between stock and flow variables, where only flow variables are specified with a behavioral equation, while stock variables are derived from changes in the relevant flow variables using an accounting identity. Second, flow variables are modeled as rates rather than as levels. Third, logistic functional forms are used for some rates of flow variables to directly impose biological-technological limits. Fourth, slaughter number and slaughter weights are disaggregated into sow and other swine (i.e., gilt-barrow).

Estimates of the 12-equation Japanese swine-pork model of Japan have good fit, no serial correlation, and significant parameters with expected signs and magnitudes.

Finally, all validation statistics show that the proposed structure is better able to capture both the mean and the variability of all the endogenous variables in the model.

Table 1. Historical consumption and production data

Per Capita Consumption (kg/person)	
All Beef	7.80
Wagyu	1.40
Dairy	1.60
Import	4.80
Pork	11.80
Poultry	11.0
Production Parameters	
Pig Crop (pigs/sow/year)	18.84
Mortality (%)	10.17
Slaughter Rate (%)	
Sow Slaughter Rate	47.05
Other Swine Slaughter Rate	62.30
Average Slaughter Weight (kg/head)	
Sow Slaughter Weight	60.00
Other Swine Slaughter Weight	73.95
Proportion of Slaughter (%)	
Sow Slaughter	2.61
Other Swine Slaughter	97.39

Table 2. Diagnostics of parameter estimates

Equation	Functional Form	R^2	Adjusted R^2	DW
Demand	Double Log	0.990	0.987	1.880
Slaughter Weight	Linear	0.977	0.954	2.086
Pig Crop	Logistic	0.940	0.937	0.976
Mortality	Double Log	0.687	0.637	2.042
Sow Slaughter	Logistic	0.895	0.866	1.300
Other Slaughter	Logistic	0.757	0.738	0.882
Sow Addition	Logistic	0.949	0.940	1.079
Pork Import	Double Log	0.948	0.942	1.348
Pork Stock	Double Log	0.925	0.897	1.804

Table 3. Demand and supply elasticities

Elasticity	
Demand Elasticity	
Domestic Demand Elasticity	
Own-price	-0.3943
Wagyu Beef Price	0.0235
Dairy Beef Price	0.0300
Import Beef Price	0.1332
Poultry Price	0.0265
Fish Price	0.1131
Income	0.6954
Stock Demand Elasticity	
Import Demand Elasticity	
Supply Elasticity	
Sow Slaughter	-0.1269
Other Swine Slaughter	0.1308
Slaughter Weight	0.0016
Sow Addition	0.1609
Production	0.1257

Table 4. Descriptive statistics

	Actual		Simulation	
Endogenous Variable	Mean	S. Dev	Mean	S. Dev
Pork Price	496	38	497	36
Pork Consumption	2024	109	2027	83
Pig Crop	21188	2258	21096	1774
Other Swine Inventory	9862	626	9816	439
Sow Inventory	1088	112	1088	104
Swine Death	1462	591	1479	582
Slaughter Other Swine	19359	1590	19298	1920
Slaughter Weight	0.0745	0.0004	0.0745	0.0005
Slaughter Sow	454	38	452	36
Sow Addition	479	13	475	19
Pork Import	558	187	561	183
Pork Stock	110	31	106	26

Table 5. Statistics of fit

Endogenous Variable	MPE	MAPE	RMSE
Pork Price	0.442	3.772	4.130
Pork Consumption	0.225	1.377	1.746
Pig Crop	-0.193	2.061	2.573
Other Swine Inventory	0.028	8.250	9.026
Sow Inventory	0.138	2.344	2.798
Swine Death	2.323	9.711	11.514
Slaughter Other Swine	-0.430	2.074	2.719
Slaughter Weight	-0.048	0.505	0.576
Slaughter Sow	-0.213	4.778	5.886
Sow Addition	-0.709	4.713	5.584
Pork Import	1.802	6.440	8.587
Pork Stock	-1.831	13.407	17.382

Table 6. MSE decomposition and Theil forecast error statistics

Endogenous Variable	Bias	Dist	U1
Pork Price	0.006	0.951	0.041
Pork Consumption	0.008	0.563	0.016
Pig Crop	0.030	0.261	0.025
Other Swine Inventory	0.003	0.381	0.088
Sow Inventory	0.000	0.990	0.029
Swine Death	0.019	0.979	0.077
Slaughter Other Swine	0.015	0.487	0.026
Slaughter Weight	0.007	0.666	0.006
Slaughter Sow	0.005	0.917	0.055
Sow Addition	0.022	0.185	0.056
Pork Import	0.009	0.991	0.063
Pork Stock	0.064	0.936	0.149

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