A structural time series analysis of US broiler exports

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Abstract

A structural time series model is used to determine the dynamic characteristics, forecasting properties, and policy implications of factors affecting the US broiler export market. The emphasis is on international market responsiveness. The analysis indicates that in addition to the explanatory variables a trend component has been vital in the expansion of the broiler industry during the study period. The results indicate that export markets are more price responsive than the domestic markets, that interventions in the Canadian and Mexican markets reduce their imports, and exchange rate changes have significant impacts on US exports. ©1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

This study presents a multiple equation econometric model of United States broiler exports and analyzes some of its policy implications. The theoretical framework of the broiler exports model is structural time series models (STSMs) that can be recast in state space form and estimated by means of the Kalman filter method. The results permit the analysis of the impacts of selected exogenous factors on US broiler exports.

An objective of this research is to provide information that can be used to help understand and, thus, enhance exports of poultry products. The emphasis is on the international broiler market responsiveness to the US export prices, the impact of currency realignments on imports from the US (exchange rate impacts), per capita incomes of the importing countries, the prices

of substitutes, and government interventions in poultry markets.

2. Background

Studies dealing with the broiler industry date from an analysis of the apparent seasonal production and consumption patterns of the broiler industry by Boutwell and Seale, (1969). Malone and Reece (1976), Chavas and Johnson (1981, 1982), Wescott and Hull (1985) and Bhati (1987) estimated the impact of economic variables on production, consumption, and prices in the US poultry sector. Goodwin et al. (1996), estimated the supply and demand responses in the US broiler industry using the non-linear, two lag, autoregressive error, multiple regression program (NLREG) developed by Martin (1994). Malone and Reece (1976, p. 414) reported that "The production and consumption of broiler meat varies seasonally and is accompanied by seasonal fluctuating prices". Other studies analyzed the importance of the rational

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expectations hypothesis in poultry supply response (Huntzinger, 1979; Goodwin and Sheffrin, 1982; Aradhyula and Holt, 1989). Goodwin and Sheffrin (1982, p. 660) indicated that "the decision to supply broilers is, of course, made under uncertainty, and, in principle, other moments of the probability distribution of prices besides the mean could affect behavior".

In response to the increasing importance of poultry exports, some studies estimated poultry export models. Dixit and Roningen (1986), used the Static World Policy Simulation modeling framework. Haley (1990), evaluated the export enhancement program for poultry using a trade flow model that emphasized the Armington variant of the constant elasticity net trade model. This model differentiates poultry products by countries of export and of import. A cross-country approach to trade flow analysis was used by Alston and Scobie (1987), and Harling and Thompson (1985). Models by Martinez et al. (1986), Leong and Elterich (1985), and Yasin (1992) concentrated primarily on modeling poultry export and import demands. Bishop et al. (1990), evaluated markets for poultry in a variety of countries and showed how trade liberalization could lead to an expansion in these markets and, probably, to decreased prices.

Other authors (Rausser and Cargill, 1970; Chavas, 1983) built poultry models that allow coefficients to vary with time, so as to solve parametric variation problems. Rausser and Cargill used the spectral analysis approach and concluded that the inherent cyclical tendencies of the broiler industry appear to have been altered by such factors as improved technology, market growth, and vertical integration. Chavas (1983) analyzed structural changes in the demand for meat using a random coefficient model, based on the Kalman filter estimation technique and estimated the variance of the random coefficients using the one-step-ahead prediction error approach. The results suggest that the price and income elasticities of beef have been decreasing in the last few years, while the income elasticity for poultry has been increasing (0.012 in 1975 and 0.275 in 1979).

2.1. The Structural time series approach

The structural time series approach has been proposed by Harvey and others in a number of papers

and monographs (Harvey, 1989, 1994; Harvey et al., 1986; Gonzalez and Moral, 1995). These models are formulated directly in terms of components of interest (i.e. trend, seasonal, cyclical and the residual–irregular–components). In a structural time series model, the explanatory variables enter into the model side by side with the unobserved components. In the absence of these components, the model reverts to a standard regression (Harvey, 1989, p. 12).

2.2. Stochastic components formulation

A structural time series model for quarterly or monthly observations might consist of trend, cycle, seasonal and irregular components. Thus,

$$y_t = \mu_t + \psi_t + \gamma_t + \epsilon_t, \quad t = 1, \ldots, T \quad (1)$$

where μ_t is the trend, y_t is the cycle, γ_t is the seasonal and ϵ_t is the irregular component. All the four components are stochastic and the disturbances driving them are mutually uncorrelated. The trend, seasonals and cycles are all derived from deterministic functions of time and reduce to these functions as limiting cases. The irregular ϵ_t is white noise.

2.3. Explanatory and intervention variables

The structural model may be extended by adding exogenous explanatory variables to the right hand side of Eq. (1) giving:

$$y_t = \mu_t + \psi_t + \gamma_t + \sum_{J=1}^{K} \delta_j x_{jt} + \lambda_t + \epsilon_t, \quad (2)$$

here x_{jt} is the value of the jth explanatory variable at time t, δ_j is its coefficient and w_t is the intervention variable.. There is no necessity for the x_{jt} to have any stationary properties, either before or after differencing. If $\delta^2_\eta = \delta^2_\zeta = \delta^2_\kappa = \delta^2_\omega = 0$, the model collapses to a standard regression model with a linear time trend, deterministic cyclical component and seasonal dummies in addition to the explanatory variables.

The structural modeling framework can be used to estimate the effect of an intervention, such as the imposition of tariff rate and import quotas on poultry imports from the US, at a particular point of time $t = \tau$. Following Harvey and Durbin (p. 190), it is

assumed that the effect of the intervention occurs instantaneously at time t and leads to an immediate change in the level of the series which remains constant at an amount of, say, λ. In the simplest case, where the response is instantaneous and constant, w_t is a standard dummy variable.

2.4. Statistical treatment

The broiler export structural time series model can be efficiently fitted by powerful, but straightforward, general techniques. The key to these techniques is that the broiler export model can be put into state space form and then handled routinely by the Kalman filter. In its general univariate form, the state space model consists of the following two equations:

$$y_t = Z_t \alpha_t + \epsilon_t, \quad t = 1, \ldots, T \tag{3}$$

called the measurement or observation equation, and

$$\alpha_t = T_t \alpha_{t-1} + \eta_t, \quad t = 1, \ldots, T \tag{4}$$

called the transition or state equation. Here, y_t is the observation of interest, Z_t is a non-stochastic vector, α_t is an $m \times 1$ state vector, T_t is a non-stochastic $m \times m$ matrix, and ϵ_t, and η_t are (normally, independently distributed) NID(0, $\sigma^2 h_t$) and (0, $\sigma^2 Q_t$) disturbances, where h_t and Q_t are a scalar and an $m \times m$ matrix, respectively, and σ^2 is a positive scalar. Maximum likelihood estimation can be performed either in the time domain, using the Kalman filter, or in the frequency domain; see Harvey and Peters (1990) for details and Nerlove et al. (1986) (pp. 132–139) for a general discussion of estimation in the frequency domain. If the disturbances in the model are assumed to be normally distributed, the hyperparameters ($\sigma^2 \eta$, $\sigma^2 \zeta$, $\sigma^2 \omega$, $\sigma^2 k$, ρ, λ_c, $\sigma^2 \epsilon$) may be estimated by maximum likelihood. The time domain estimation procedure is used in this study. Once these have been estimated, the state space form may be used to make predictions and construct estimators of the unobserved components.

3. The broiler export model specification and estimation

Data used for model estimation cover a more recent period, 1970 through 1995, than previous studies.

Data from January 1994 to December 1995 are used to check the forecasting performance of the model. Quarterly data are used for US broiler production, demand, inventories, exports and meat prices; annual values for broiler import demand equations for Japan, Hong-Kong, Canada and Mexico. The broiler export model's functional relationship is assumed to be linear in parameters to simplify the estimation and subsequent dynamic analysis. All monetary values are deflated by the gross national product deflator for the US and those of the importing countries, where appropriate. All prices are deflated by the consumer price indexes of the US and importing countries. All quantity variables in the broiler exports model equations are expressed in per capita units. These transformations are made to preserve the linearity of the system and to allow the straightforward induction of the linear (in parameters) structural form from the structural estimates for the broiler export model specification (see Chambers and Just, 1981, p. 33).

3.1. Stochastic components specification

To determine the most appropriate specification to be followed for the broiler exports STS model, some insights are gained by examining the statistical characteristics or generating processes of the individual variable series. These processes typically have been identified with trend, seasonal or cyclical, and irregular components; the stochastic character of these components is a concern.

3.1.1. Trend component

The stationary property of the series is examined using the Augmented Dickey–Fuller (ADF) and the Phillips and Perron (1988) (PP) tests. Table 1 reports the results of the tests for the variable series. Most of the variable series remained nonstationary, no matter whether the original ADF equation, or its modifications with a constant or with a constant and trend, are used. The variable series were then first-differenced and this resulted in stationarity for all the series. The results of the PP test indicated that the series are stationary for first differences only, no matter whether or not a trend and/or a constant is included. The outcome of these tests is that the presence of stationarity in the broiler model variable series is mixed and indicates

Table 1
Unit roots test results, 1970.1–993.4[q] or 1970–993[y]

Variable series	$k=0$	ADF test[a]			PP test[b]		
		−	c	$c+\beta t$	−	c	$c+\beta t$
Broiler supply (q)	QBP[L]	3.19[**]	−1.04	−1.28	2.9	1.05	−1.31
	ΔQBP	−1.67[*]	−2.35[*]	−12.56	−11.7[*]	−12.35[*]	−11.57[*]
Broiler demand (q)	QBD	−0.28	−2.108	−6.86[*]	−0.30	−2.11	3.2
	ΔQBD	−19.72[*]	−19.78[*]	−19.72[*]	−19.73[*]	−19.79[*]	−19.72[*]
Broiler Inventory (q)	QBID	−0.95	−3.0	−4.29[*]	−0.94	−3.1	−3.3
	ΔQBID	−11.79[*]	−11.75[*]	−11.72[*]	−11.79[*]	−11.75[*]	−11.71[*]
Broiler Exports (q)	QBX	−2.36	−3.2	−3.9[**]	−2.37	−3.22	−3.42
	ΔQBX	−14.87[*]	−14.82[*]	−14.79[*]	−14.87[*]	−14.82[*]	−14.79[*]
Broiler price (q)	WPBR	−0.025	−2.05	−5.44[*]	−0.024	−2.04	−3.42
	ΔWPBR	−13.77[*]	−13.76[*]	−13.71[*]	−13.69[*]	−13.74[*]	−13.70[*]
Beef price (q)	CRBP	1.83	−0.25	−2.07	1.81	−0.23	−2.05
	ΔCRBP	−10.80[*]	−11.06[*]	−11.03[*]	−10.76[*]	−11.04[*]	−11.01[*]
Pork price (q)	RPP	0.984	−1.09	−3.5	0.98	1.07	−3.3
	ΔRPP	−10.80[*]	−10.88[*]	−10.84[*]	−10.67[*]	−10.72[*]	−10.56[*]
Turkey price (q)	RPT	0.85	−0.86	−2.60	0.76	−0.82	−2.45
	ΔRPT	−10.64[*]	−10.70[*]	−10.64[*]	−10.43[*]	−10.46[*]	−10.44[*]
Feed price (q)	PBF	0.42	−1.29	−1.97	0.38	−1.18	−1.76
	ΔPBF	−10.51[*]	−10.54[*]	−10.52[*]	−10.34[*]	−10.36[*]	−10.35[*]
Japanese-US broiler imports (y)	JAUSBID	0.37	−0.52	−2.26	0.36	−0.51	−2.18
	ΔJAUSBID	−5.13[*]	−5.56[*]	−5.44[*]	−5.08[*]	−5.21[*]	−5.32[*]
Hong-K.-US broiler imports (y)	HOUSBID	1.88	0.81	−2.26	1.76	0.75	−2.15
	ΔHOUSBID	−4.29[*]	−5.17[*]	−5.60[*]	−4.28[*]	−5.10[*]	−5.54[*]
Canada-US broiler imports (y)	CAUSBID	−0.28	−0.80	−2.36	−0.26	−0.76	−2.25
	ΔCAUSBID	−5.05[*]	−5.45[*]	−5.43[*]	−5.01[*]	−5.32[*]	−5.36[*]
Mexico-US broiler imports (y)	MEUSBID	−0.47	−0.84	−2.82	−0.45	−0.82	−2.76
	ΔMEUSBID	−4.32[*]	−4.44[*]	−4.34[**]	−4.31[*]	4.43[*]	−4.34[**]

[a] Augmented Dickey–Fuller Test (Dickey and Fuller, 1979).

[b] Phillips-Perron Test; L–Variable in levels; (q)–Quarterly observations; (y)–yearly observations.

* Significant at 1% level; **Significant at 5% level; D–First difference of the variable. Critical values: 2.58–4.025 and 2.66–4.37 for (q) and (y), respectively (at 1% level of significance); 1.94 to 3.44 and 1.95 to 3.61 for (q) and (y), respectively (at 5% level of significance).

that the underlying trends might be stochastic rather than deterministic (see Harvey, 1989, p. 30).

3.1.2. Seasonal components

A two-step procedure is used to identify possible seasonal components. As a first step, each variable series is plotted. These plots suggest the presence of a seasonal pattern in each series. The second step consists of the estimation of the selected model. The features of the output directly relevant to seasonal effects are: (1) The seasonal hyperparameter is non-zero, indicating that there are changes in the seasonal pattern. (2) The state has s-1 (4−1 = 3) elements to capture seasonality. (3) As the broiler exports model data are in logs, the seasonal effects are given as factors of proportionality with which the other components

are multiplied to get the systematic part of the series. For US broiler demand (RF), the seasonal factors are $-0.031S_1$ and $+0.02S_2$, indicating that in the second season, spring, the level of the trend needs to be multiplied by 0.02. (4) Finally, the importance of the seasonal factor is assessed by means of the seasonal test of the statistical significance of the seasonal pattern at the end of the period. It is asymptotically χ^2. For instance, the estimation of the broiler exports (RF) model gives the following: (1) broiler demand: $\chi^2(3) = 40.42$ (critical value = 11.34 at 1% level of significance); (2) broiler inventory: $\chi^2(3) = 9.006$ (7.82 at 5% level of significance); (3) broiler wholesale price: $\chi^2(3) = 33.97$ (11.34 at 1% level of significance); (4) pork price: $\chi^2(3) = 30$ (11.34 at 1% level of significance); (5) turkey price: $\chi^2(3) = 30.64$ (11.34 at 1% level of significance); and (6) feed price:

$\chi^2(3) = 6.94$ (6.25 at 10% level of significance). But, this test may be misleading if the seasonal pattern is stochastic and has changed substantially over the sample period. Thus, if the seasonal component has become smaller, it may be insignificant at the end, but not at the beginning.

3.1.3. Cyclical components

A two-step procedure is also used to identify possible cyclical components. Only the beef price has a cyclical component included in its model specification, based on both the literature review and economic theory related to beef production. As the first step correlograms were computed for the beef price series using 20 lags. These suggest that the sample autocorrelations of beef price series are close to zero. The sample autocorrelations also displayed evidence of a cycle buried within the noise. The second step was to use the STAMP 5.0 estimation procedure to test for the presence of a possible stochastic cycle (see Harvey and Souza, 1987) based on the Lagrangian multiplier (LM) test. From a theoretical and practical point of view, this test is important since in the case where $\rho = 0$ (ρ = damping factor of the cycle) the model ceases to be identifiable. The damping factor of the cycle (ρ) became zero in the beef price reduced form model (RF), ceased to be identifiable, and was dropped from the beef price reduced form equation.

3.2. The structural model

The econometric broiler export model consists of 14 equations, one of which is an identity (Table 3). The three major components of the model are supply side equations (supply, demand, inventories, and export demand functions), price linkages (prices of broilers, beef, pork, turkey, and feed functions), and import side equations (import demand functions for Japan, Hong Kong, Canada and Mexico). Table 2 identifies variables and Table 3 presents the specified broiler model equations for each exogenous variable included in the model.

Following Labys and Pollack (1984, p. 53), Martinez et al. (1986), and Aradhyula and Holt (1989) the broiler supply function is specified as a function of the changes in the lagged one quarter wholesale broiler price, real price of broiler feed, the hatch of broilers

in commercial hatcheries, and a one-quarter lag in the dependent variable. Because the biological production lag for broilers is approximately 2 months, it follows that the current quarter production depends on the expectations formed by producers in the previous quarter. The only input price included is for feed, determined as a weighted average of the prices of corn and soybean meal, which accounts for 64–73% of the total broiler production costs (Rogers, 1979). Feed cost and wholesale broiler price lags assume a one-quarter delay in response to changing profitability.

The per capita broiler demand equation is specified as a function of the retail prices of beef, pork, turkey, wholesale price of broilers, per capita income, and its one quarter lag.[1] The broiler demand formulation does not represent a consumer demand curve per se because price is determined at the wholesale, rather than the retail, level (see Chavas, 1983; Aradhyula and Holt, 1989). Pork, beef and turkey are included as substitutes in consumption of broilers.

The broiler inventory demand equation is specified as a function of the wholesale price of broilers, the quantities of broilers produced and demanded, and its one quarter lag. The estimated inventory demand equation is based on the hypothesis that inventories are inversely related to own-price and are consistent with the partial adjustment inventory model suggested by Labys (1973, pp. 70–71). Logically, as the own-price rises, the opportunity cost of carrying broilers out for a given period rises and the incentives for profit taking increase. The inverse is expected as the price falls.

The broiler export supply equation is specified as a function of the wholesale price, real exchange rate, and, its one quarter lag variable. The exchange rate between the dollar and the Japanese yen is used as a proxy for the exchange rate with other countries. It is hypothesized that an increase in the value of the dollar makes US exports more expensive, reducing broiler demand abroad.

The supply side equations form a system representing a US meat demand model by introducing price linkage equations which connect broiler prices

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[1] It was hypothesized that fish may have become a substitute for broilers especially for some health conscious consumers. But a preliminary estimation of the broiler demand equation found that the fish retail price was not statistically significant, thus, the fish price was dropped from the broiler demand equation specification.

Table 2
Variable definitions

Endogenous Variables		
QBP	Quantity of broiler production	(mil. lbs)
QBD	Quantity of broilers consumed, ready to cook	(mil. lbs)
QBID	Quantity of broilers inventories demand	(>000 lbs)
QBX	Quantity of broiler exports	(>000 lbs)
WPB	Wholesale price of broilers	($/100 lb)
BID_i	Per capita imports of US broilers by country i	(lbs)
CRBP	Retail price of beef	($/100 lb)
RPP	Retail price of pork	($/100 lb)
RPT	Retail price of turkey	($/100 lb)
PBF	Real price of broiler feed	(4/lb)
Exogenous Variables		
One quarter lagged dependent variables		
HATCH	Hatch of broiler in commercial hatcheries	(>000 head)
PCI	Per capita disposable personal income	(Current $/person)
$RFOPBr_i$	Real FOB price of broilers imported by country i	($/metric ton)
$RFOBIP_i$	Real FOB price of beef imported by country i	
$RFOPOIP_i$	Real FOB price of pork imported by country i	
YE_i	Real per capita gross domestic product (GDP) of the importingcountry in the currency of the importer (base year 1985)	
$PCQBP_i$	Per capita production of broilers in the ith importing country	Kg per capita)
RSD_i	Real exchange rate between currency of the importing country and one U.S. dollar (base year 1987)	($ U.S.)
m_t	Stochastic trend component	
g_t	Stochastic seasonal component	
y_t	Stochastic cyclical component	
e_t	Disturbance term	

with beef, pork, turkey, and feed prices. These equations specify the price linkage functions for broilers, retail choice beef, pork, turkey and broiler feed, respectively.

Import demand equations are included for four major markets: Japan, Hong Kong, Canada, and Mexico.[2] The import demand for US broilers in the ith country ($i = 1, 2, 3, 4$) is specified as a function of the one quarter lagged dependent variable, the real FOB prices of broilers, beef and pork imported by country i, the real per capita gross domestic product of the importing country, per capita production of broilers in the ith importing country, and the real exchange rate between the currency of the ith importing country and the US dollar. Binary variables are included in the Mexican and Canadian import demand equations to account for trade distorting policies in those countries.

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[2] While China and Russia have become important importers of US broilers in recent years, the length of time they have been importing significant quantities is not sufficient to include them in this model.

4. Estimation results

The estimated model equations are presented in Table 4.[3] The coefficients of these maximum likelihood reduced form estimates are impact multipliers and present a more accurate picture of total effects of predetermined variables than simple elasticities computed from the structural form of the model. In particular, the reduced form provides equations for the jointly dependent prices while recognizing the effect that broiler production has on per capita consumption and exports of broilers and prices of beef, pork, turkey, broilers and grower feed. The reduced form is also used to generate the dynamic multipliers associated with the exogenous variables.

4.1. Broiler exports

Impacts of changes in broiler production level and prices of broilers and turkeys on broiler exports

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[3] The equations in Table 4 are the results of a final model which contains only the statistically significant variables.

Table 3
Structural form equations

Broiler supply function	$QBP_t = \mu_t + \gamma_t + a_1 WPB_{t-1} + a_2 PBF_{t-1} + a_3 HATCH_{t-1} + a_4 QBP_{t-1} + \epsilon_{1t}$
Broiler demand function	$QBD_t = \mu_t + \gamma_t + a_5 WPB_t + a_6 CRBP_t + a_7 RPP_t + a_8 RPT_t + a_9 PCI_t + a_{10} QBD_{t-1} + \epsilon_{2t}$
Broiler inventories function	$QBID_t = \mu_t + \gamma_t + a_{11} WPB_t + a_{12} QBP_t + a_{13} QBD_t + a_{14} QBID_{t-1} + \epsilon_{3t}$
Broiler export demand function	$QBX_t = \mu_t + \gamma_t + a_{15} WPB_t + a_{16} SDR_t + a_{17} QBX_{t-1} + \epsilon_{4t}$
Wholesale price of broilers function	$WPB_t = \mu_t + \gamma_t + a_{18} WPB_{t-1} + a_{19} QBD_t + a_{20} CRBP_t + a_{21} RPP_t + a_{22} RPT_t + a_{23} PCI_t + \epsilon_{5t}$
Retail price of beef function	$CRBP_t = \mu_t + \psi_t + a_{24} CRBP_{t-1} + a_{25} QBD_t + a_{26} WPB_t + a_{27} RPP_t + a_{28} RPT_t + a_{29} PCI_t + \epsilon_{6t}$
Retail price of pork function:	$RPP_t = \mu_t + \gamma_t + a_{30} RPP_{t-1} + a_{31} QBD_t + a_{32} WPB_t + a_{33} CRBP_t + a_{34} RPT_t + a_{35} PCI_t + \epsilon_{7t}$
Retail price of turkey function	$RPT_t = \mu_t + g_t + a_{36} RPT_{t-1} + a_{37} QBD_t + a_{38} WPB_t + a_{39} CRBP_t + a_{40} RPP_t + a_{41} PCI_t + \epsilon_{8t}$
Price of broiler feed function	$PBF_t = \mu_t + \gamma_t + a_{42} PBF_{t-1} + a_{43} HATCH_{t-1} + a_{44} QBP_{t-1} + a_{45} WPB_t + \epsilon_{9t}$
Broiler imports demand function	$BID_{it} = m_{it} + b_1 BID_{it-1} + b_2 FOBP_{it} + b_3 FOBIP_{it} + b_4 FOPOIP_{it} + b_5 RYE_{it} + b_6 PCBP_{it} + b_7 RSD_{it} + \epsilon_{it}$ $(i=1, 2, 3, 4)$.
Identity function (where $M=0$ for US)	$QBX_t = QBP_t + QBID_{t-1} - QBD_t - QBID_t$

appear important (Table 4). The elasticity of exports with respect to broiler and pork prices and broiler production were –0.1, 0.75 and 1.2%, respectively. Broiler exports appear to be very elastic in their response to broiler production level changes. They are related to the level of broiler production, an interesting result because it suggests that the broiler export market is positively related to increases in the level of production while responding negatively to increases in broiler prices. Finally, broiler exports are responsive to the turkey price, with an elasticity of 0.75.

4.2. Broiler imports

The results of estimating US broiler import demand equations indicate that Japanese demand for US broiler imports is negatively influenced by the exchange rate (SDRJP) and per capita Japanese broiler production. The exchange rate plays an important role in the export of US broilers to Japan. Import demand decreases by 0.96% with a 1.0% increase in the yen–dollar exchange rate. Japanese production of broilers is a significant determinant of import demand. A 1% increase in Japanese production of broilers would decrease broiler imports by 1.2%. This result is consistent with the presence of a strong association between production and import demand for US broilers over the time used in this study. Other variables were not significant.

Hong Kong's demand for US broiler imports is negatively influenced by the exchange rate and broiler import price. One percent increases in the Hong Kong–US$ exchange rate and broiler import price decrease imports by 0.56 and 0.51%, respectively.

Canadian demand for US broiler imports is positively influenced by beef import price and negatively influenced by the trade policy measures taken by the Canadian Chicken Marketing Agency to decrease imports. A 1% increase in beef import price would increase Canadian imports of US broilers by 0.61%. An intervention variable for the 1973 imposition of a Canadian import quota for US broiler imports was negative (–0.37) and statistically significant.

Mexican demand for US broiler imports is negatively influenced by the exchange rate, broiler import price, and the trade policy measures taken after 1982. Mexican tariff rate quotas and broiler import prices play a significant role in the import of US broilers by Mexico. A 1% increase in broiler import price decreases imports by 0.72%. Also, a 1% increase in the peso-dollar exchange rate would decrease imports by 0.58%. The imposition of the tariff rate quotas in 1983 has decreased Mexican imports of US broilers; although liberalizing its trade policy in 1982, Mexico kept high trade tariff rate quotas on poultry imports from the US.

4.3. Other significant findings

Among the more important findings of the estimations are the significance of the trend and seasonal components in many of the model's equations. The trend component was statistically significant in all but three of the equations (pork price, turkey price, and feed price). This result implies that factors not included or directly measurable, such as changes in technology and tastes and preferences, are affecting (shifting) the supply and demand for broilers and other meat

Table 4
Reduced form: maximum likelihood estimates of final broiler export mode[a,b]

(1) $QBP_t = 1.54\mu^{***} + .0.69WPBr_{t-4}^{***} + .73HATCH_t^{***} - 0.05PBF_{t-4} + E$
         (0.26)   (0.02)   (0.063)   (0.03)
      Std. Error $= 0.019$ $N = 0.78$ $Q(9) = 5.41$ $H(29) = 0.71$ $R^2_D = 0.85$ $R^2_S = 0.51$ DW $= 1.95$

(2) $LPCQBD_t = 1.7\mu^{***} - 0.03Sea_1^{***} + 0.2Sea_2^{**} + 0.4RPP_{t-1}^{***} - 0.02PBR_{t-1} + 0.8HATCH_{t-1}^{***} - 0.035QBX_{t-1}^{***} + E_t$
             (0.10)   (0.21)   (0.21)   (0.02)   (0.16)   (0.04)   (0.01)
      Std. Error $= 0.016$ $N = 0.17$ $Q(9) = 9.62$ $H(30) = 0.8$ $R^2_D = 0.89$ $R^2_S = 0.60$ DW $= 2.18$

(3) $QBID_t = 4.85\mu^{**} - 0.07Sea_2^* - 0.05Sea_3^* - 0.55WPBr_{t-1}^{***} + 0.42QBID_{t-1}^{***} - 0.85CRBP_{t-1}^* + 0.66RPT_{t-1}^* + E_t$
         (0.17)   (0.24)   (0.24)   (0.17)   (0.09)   (0.45)   (0.33)
      Std. Error $= 0.141$ $N = 1.1$ $Q(9) = 5.3$ $H(30) = 1.67$ $R^2_D = 0.26$ $R^2_S = 0.18$ DW $= 1.92$

(4) $QBX_t = 4.25\mu^* - 0.1WPBr_{t-1}^* + 0.75RPT_{t-1}^{**} + 1.2QBP_{t-1}^* + E_t$
         (0.16)   (0.21)   (0.35)   (0.71)
      Std. Error $= 0.16$ $N = 1.66$ $Q(10) = 8.57$ $H(30) = 0.61$ $R^2_D = 0.23$ $R^2_S = 0.15$ DW $= 1.91$

(5) $WPBr_t = 1.26\mu^{***} - 0.4Sea_1^{***} + 0.026Sea_3^* + .7WPBr_{t-1}^{**} + 0.24RPP_{t-1}^{***} + 0.37RPT_{t-1}^* - 0.15DRJ_t^{***} + E_t$
         (0.09)   (0.03)   (0.03)   (0.08)   (0.08)   (0.14)   (0.07)
      Std. Error $= 0.071$ $N = 1.47$ $Q(9) = 5.02$ $H(30) = 0.78$ $R^2_D = 0.45$ $R^2_S = 0.22$ DW $= 1.93$

(6) $RBP_t = 3.97\mu^* + 0.95PCI_t^* - 0.11PBF_{t-1}^* + E_t$
         (0.13)   (0.31)   (0.065)
      Std. Error $= 0.031$ $N = 2.53$ $Q(9) = 5.0$ $H(31) = 0.32$ $R^2_D = 0.25$ $R^2_S = 0.192$ DW $= 1.9$

(7) $RPP_t = 0.011Sea_1^* - 0.3Sea_2^{***} - 0.01Sea_3^* + 62RPP_{t-1}^{***} + 0.20RPT_{t-1} + 0.14WPBr_{t-1}^{**} - 0.17PBF_{t-1} + E_t$
         (0.02)   (0.02)   (0.02)   (0.08)   (0.11)   (0.07)   (0.10)
      Std. Error $= 0.043$ $N = 2.03$ $Q(10) = 8.5$ $H(30) = 0.22$ $R^2_D = 0.30$ $R^2_S = 0.20$ DW $= 1.9$

(8) $RPT_t = -0.02Sea_1^{**} - 0.03Sea_2^{**} - 0.01Sea_3^{***} + 0.24WPBr_{t-1}^{***} + 0.3RPT_{t-1}^{***} - 0.4HATCH_{t-1}^{***} + E_t$
         (0.18)   (0.18)   (0.18)   (0.04)   (0.09)   (0.13)
      Std. Error $= 0.03$ $N = 1.07$ $Q(9) = 6.45$ $H(30) = 0.59$ $R^2_D = 0.40$ $R^2_S = 0.35$ DW $= 1.9$

(9) $PBF_t = -0.02Sea_2^* - 0.01Sea_3^* + 0.13WPBr_{t-1}^* - 0.27HATCH_{t-1}^* + 0.29LRPBF_{t-1}^{***} + 0.9LRPCI_t^* + E_t$
         (.01)   (0.003)   (0.061)   (0.17)   (00.1)   (0.48)
      Std. Error $= 0.045$ $N = 0.19$ $Q(9) = 9.8$ $H(30) = 1.93$ $R^2_D = 0.15$ $R^2_S = 0.13$ DW $= 1.93$

(10) $JAUSBID_t = 14.9\mu^{***} - 0.96DRJP_t^{***} - 1.2JAQBPt^* + 0.32JAUSBID_{t-1}^{***} + E_t$
            (0.36)   (0.29)   (0.67)   (0.07)
      Std. Error $= 0.11$ $N = 0.23$ $Q(9) = 3.54$ $H(7) = 1.06$ $R^2_D = 0.74$ DW $= 1.51$

(11) $HOUSBID_t = 13.36\mu^{***} - 0.56HORSD_t^* - 0.51HOFOBP_t^{**} + 0.53LPHOUSBID_{t-1}^{***} + E_t$
            (0.72)   (0.3)   (0.21)   (0.05)
      Std. Error $= 0.088$ $N = 0.21$ $Q(8) = 8.37$ $H(7) = 0.33$ $R^2_D = 0.86$ DW $= 1.5$

(12) $CAUSBID_t = 6.06\mu^{***} + 0.64CAFOBIPt^{***} + 0.48CAUSBID_{t-1}^{***} - 0.38W_{t75}^* + E$
            (0.56)   (0.22)   (0.06)   (0.2)
      Std. Error $= 0.151$ $N = 1.06$ $Q(9) = 10.54$ $H(7) = 0.42$ $R^2_D = 0.735$ DW $= 1.68$

(13) $MEUSBID_t = 11.92\mu^{***} - 0.58MERSD_t^{***} - 0.72MEFOBP_t^{***} - 1.22W_{t83}^{***} + E$
            (1.50)   (0.14)   (0.17)   (0.17)
      Std. Error $= 0.152$ $N = 0.293$ $Q(8) = 8.11$ $H(7) = 0.34$ $R^2_D = 0.85$ DW $= 2.13$

[a] Values in square brackets are standard deviations for the state and explanatory variable coefficients at the end of period.

[b] ***Significant at 1% level, **significant at 5% level, and *significant at 10% level. N: the Jarque and Bera statistic for testing normality, which follows asymptotically a x^2 distribution with two degrees of freedom under the null hypothesis. $Q(P)$: the Box–Ljung statistic, based on the first P residual autocorrelations. $H(m)$: a test for heteroscedasticity (unequal variances). R^2: not very useful as a measure of goodness of fit when analyzing time series that exhibit strong upwards or downwards trends and/or seasonal cycles. Harvey (1991) proposes new coefficients of determination: R^2_D: substituting the observations by their first differences, if the series presents seasonal behaviour; R^2_S: substituting the observations by the first differences of the series around the seasonal means.

products, although care must be used in making specific attributions.

Seasonal components were significant in six of the equations (broiler demand, broiler inventories, broiler price, pork price, turkey price, and feed price). While significant, the results also indicate that the magnitudes of the seasonal changes have decreased compared to those of earlier time periods. Another useful

finding is a confirmation of the tendency for the own price elasticity to become more inelastic. Findings by Martinez et al. (1986, p. 2071), indicate that demand has been becoming more inelastic and the elasticity estimate from the current model is −0.02. A surprising result, however, is that the demand for broilers does not appear to be responsive to changes in income, a relationship that was fairly strong in the previous studies of broiler demand.

The demand for broiler exports is somewhat less price inelastic, with a price elasticity of −0.1. However, within the individual importing countries except in Japan where the price variable was not statistically significant, demands were considerably less inelastic with the price elasticities being −0.56 in Hong Kong, −0.64 in Canada, and −0.72 in Mexico.

The inclusion of the inventory equation in the model seems to have been justified. Broiler inventories demand is negatively influenced by the prices of broilers and beef and positively related to the price of turkey. Short run elasticities of broiler inventories demand with respect to prices of broilers, beef and turkey are −0.55, −0.85 and 0.66%, respectively. Other variables, i.e., consumption, exports, income, real exchange rate, etc, have only minor influences on the demand for broiler inventories.

4.4. Maximum likelihood estimates of the hyperparameters

These are the fundamental parameters in the reduced form model. They govern the movements in the components and give information on goodness of fit of the estimated reduced form model equations (Table 5). The maximum likelihood estimates of the variances estimates of the white noise disturbances for the trend (level and slope), seasonal, cyclical and irregular components (σ^2_η, σ^2_ζ, σ^2_ω, and σ^2_ϵ) show that most of the variances estimates are zero or close to zero. A zero parameter value means that the corresponding component is fixed. Thus, in the present case, the trend (level and slope), seasonal and irregular components are almost fixed. The higher values vary from 0.0010 to 0.0079. Lower values of the variances estimates show that the diagnostics are satisfactory for the broiler exports reduced form model.

Most of the prediction error variances estimates (σ^2_p) are low, varying from 0.0003 to 0.0051 in the broiler quarterly model equations and from 0.0013 to 0.0078 in the yearly model equations (Table 5). Based on the magnitude of the prediction error variances estimates, the goodness of fit is satisfactory for the broiler exports model (reduced form model). The log-likelihood function (LogL) is the actual value at its maximum. Its value varies from 155.3 to 347.2 for the broiler quarterly model equations and from 25.9 to 42.2 for the yearly model equations.

5. Dynamic characteristics

Expressing the model as a first order, linear difference equation system permits studying the dynamic behavior of the model with standard procedures of linear system analysis. Table 6 reports the dynamic (impact, interim and total) multipliers associated with those changes for the current period and lag periods of one to four quarters, for quarterly models (US broiler domestic market) and 1–2 years, for the annual models. Given the ability of broiler producers to adjust production (it takes 7–8 weeks to produce a 3.5–4.5 pound broiler) in response to changing profit conditions, these multipliers (calculated after 4 quarters or 2 years) represent a fairly long and smooth adjustment process once the initial shocks are over, and is consistent with the study by Goodwin et al. (1996, p. 37).

The results suggest that in the long-run: (1) The wholesale price of broiler impacts on the other jointly dependent variables such as broiler supply, demand, inventory, exports, and prices of pork, turkey and broiler feed; (2) broiler feed prices impact on broiler supply and prices of beef and pork; (3) hatch of broilers impacts on broiler supply, demand and prices of turkey and broiler feed; (4) turkey prices impact on broiler inventory, exports and prices of broilers and pork; (5) broiler exports impact on the quantity of broilers demanded (disappearance); (6) pork price does impact on demand and wholesale price of broilers; (7) real exchange rates impact on broiler wholesale price; (8) broiler supply does impact on broiler exports, and (9) real per capita disposable income impacts on beef prices and broiler feed prices.

Table 5
Reduced form: maximum likelihood estimates of parameters, for: (a) stochastic trend plus seasonal (1970.I–1993.IV, (b) trend (1970–1993)[a]

Series	Model	σ^2_η	σ^2_ζ	σ^2_ω	σ^2_ϵ	σ^2_p	LogL
					10^{-4}		
Supply (a)		0.00	0.00	0.00	1.8	3.62	325.3
Demand (a)		000	0.00	0.00	2.1	2.70	338.9
Inventories (a)		57	0.00	0.57	79	20	161.1
Exports (a)		000	16	2.2	13	26	155.3
Broiler wholesale price (a)		1.0	0.00	0.00	47	51	215.8
Choice beef price (a)		8.0	0.00	0.00	0.00	8.4	301.8
Pork retail price (a)		3.2	0.00	0.00	21	28	247.9
Turkey retail price (a)		10	0.00	0.00	0.00	10	293.3
Real feed price (a)		10	0.00	0.00	7.2	20	260.1
Japanese imports (b)		0.00	16	–	0.00	13	40.5
Hong Kong imports (b)		73	6.8	–	0.00	78	42.2
Canada imports (b)		0.00	17	–	0.00	23	12.9
Mexico imports (b)		0.00	3.0	–	19	23	25.9

[a] The diagnostics indicate that the models are appropriate for the data. σ^2_p: the estimated one-step-ahead-prediction error variance.

Table 6
Dynamic multipliers for selected endogenous and exogenous

Endogenous variables	Exogenous variables								
	Impact[a]	Interim[b]	Total[c]	Impact	Interim	Total	Impact	Interim	Total
	Wholesale price of broilers			Hatch of broilers			Broiler feed price		
US broiler supply	0.057	0.048	0.130	0.77	0.73	1.50	−0.051	−0.027	−1.02
US broiler demand	−0.031	−0.017	−0.050	0.66	0.65	1.50			
	Wholesale price of broilers			Turkey price			Pork price		
US broiler exports	−0.163	−0.135	−0.214	0.520	0.270	0.890	0.920	0.0520	1.760
	Real exchange rate			Japanese broiler production			Hong-Kong broiler price		
Japanese broiler imports	−1.10	−0.450	−1.42	−1.36	−1.10	−1.70	–	–	–
Hong-Kong broiler imports	0.740	−0.420	−1.50	–	–	–	−0.670	−0.500	−1.200
	Canadian beef import price			Canadian			Import quotas		
Canadian broiler imports	+0.390	+0.360	+0.760	−0.420	−0.220	−0.550	–	–	–
	Mexican tariff rate quotas			Real exchange rate			Mexican broiler import price		
Mexican. Broiler Imports	−1.320	−1.20	−1.880	−0.740	0.260	−0.840	−0.640	−0.250	−0.970

[a] The impact multipliers refer to the current-period (zero-period lag) effect of a change in the exogenous variable on the endogenous variables.

[b] The interim multipliers refer to a 1 year-period lag effects of changes in the exogenous variable on the endogenous variable.

[c] The total multipliers refer to the situation where the increase in the exogenous variables is sustained for a 2 year-period lag.

5.1. Multipliers for broiler exports

A sustained 1% increase in the broiler wholesale price would cause broiler exports to decrease by 0.214% in the long-run (total effects), compared to a decrease of 0.163 and 0.135% in the current period and after one quarter, respectively. Also, a 1% increase in turkey price would cause broiler exports to increase by 0.89% in the long-run, compared to an increases of 0.52 and 0.27% in the current period and after one quarter, respectively. Finally, a sustained 1%

increase in the broiler supply would increase broiler exports by 1.76% in the long-run, compared to an increase of 0.92 and 0.52% in the current period and after one quarter, respectively.

5.2. Multipliers for import demands

A sustained 1% increase in the yen–dollar real exchange rate would cause Japanese–US broiler imports demand to decrease by 1.42% in the long-run (total effects), compared to −1.1 and 0.45% in the current

and after 1 year, respectively. Also, a sustained 1% increase in the Japanese broiler production would cause Japanese–US broiler imports demand to decrease by −1.7% in the long-run, compared to −1.36 and −1.1% in the current period and after 1 year, respectively.

A sustained 1% increase in the real exchange rate would cause Hong-Kong–US broiler imports demand to decrease by −1.5% in the long-run (total effects), compared to a decrease of 0.74 and −0.42% in the current period and after 1 year, respectively. Also, a sustained 1% increase in the broiler import price would cause Hong-Kong–US broiler imports demand to decrease by −1.2% in the long-run (total effects), compared to a decrease of −0.67 and −0.50% in the current period and after 1 year, respectively.

A sustained 1% increase in beef import price would cause Canada-US broiler imports demand to increase by 0.76% in the long-run (total effects), compared to an increase of 0.39 and 0.36% in the current period and after 1 year, respectively.

A sustained 1% increase in the peso–dollar real exchange rate would cause Mexico–US imports demand to decrease by −0.84% in the long-run (total effects), compared to −0.74 and −0.26% in the current period and after 1 year, respectively. Also, a sustained 1% increase in the broiler import price would cause Mexico's imports of US broilers to decrease by 0.97% in the long-run (total effects), compared to a decrease of 0.64 and 0.25% in the current period and after 1 year, respectively.

6. Forecasting accuracy

Forecasting performance of the broiler exports model is evaluated using ex-post predictions. The extrapolation of the models beyond the end of the sample in 1993 represents the forecasting of broiler supply, demand, prices, etc. The calculations were carried out using the Kalman filter technique. The forecasts and actual exports are shown in Fig. 1.[4] The forecasts values for 1994.I to 1995.IV are close to the average for each series, and they show that
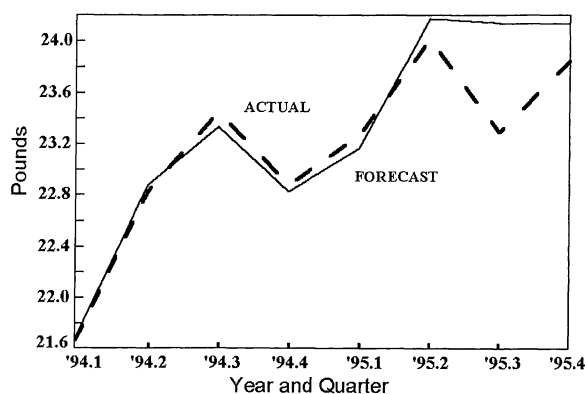

Fig. 1. Forecast and Actual Broiler Supplies, 1994(I)–1995(IV).

the models were predicting the real situation for each quarter. Another way of interpreting the broiler model forecasting results is to look at the prediction of a directional change for each variable. Analysis of Fig. 1 shows that the directional changes were correctly forecast in most of the cases for the broiler model variables.

7. Conclusions and policy implications

Knowledge of the variables that influence US broiler exports can assist policy-makers in planning growth strategies for the broiler industry. This is particularly important for broiler producers, processors and others connected with the industry and trade. The results reported in this study lead to the following conclusions and policy implications.

The volume of broiler purchases by importers is responsive to prices and somewhat irregular in nature, making it difficult for individual processors to plan to ship from normal production. A consistent supply available for export can be essential in planning for growth of the broiler industry through expanding US exports to actual and potential importers. One response to increase broiler exports more efficiently and meet an increasing but variable international demand, would be to invest in building cold storage facilities to increase broiler meat inventories, reduce shipment difficulties and respond more effectively to export market volatility.

A reduction in or elimination of tariff rate and import quotas, under NAFTA negotiations with Mexico

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[4] The fitting of the quarterly STS models indicate a savings of 20–75% in root mean square errors (RMSE) for the one quarter ahead forecasts. These are not reported here due to space limitations. This information is available from the authors.

and Canada, should benefit the US broiler industry, by diminishing import restrictions and inducing more stable and reliable product flows. It is expected that trade liberalization will play an increasingly important role in the continued expansion of the US broiler industry.

The long-run own-price elasticity of exports for US broilers is less than one and very low (−0.1), implying that lower prices is not an effective way to increase the value of US broiler exports. Strengthening the import demand for US broilers through such means as the USDA's Market Promotion Program and efforts by broiler processing companies could be a better marketing strategy for maintaining or increasing the current level of US broiler exports. Finally, US government policy of providing an export promotion subsidy in line with recent GATT negotiations is a potential strategy to promote broiler sales in international markets, since poultry promotion subsidies could be increased because current levels of subsidies are less than the 1986–1990 base.

Since much of the cost of producing poultry can be attributed to feeds (these account for approximately two-thirds of cash expenses for poultry producers in the US), price policies can produce important effects on the poultry market. Adjustments to feed price policies resulting from the 1996 FAIR act (Federal Agricultural Improvement and Reform Act) are likely to cause simultaneous shifts in the broiler supply function and the demand function for feeds, thus influencing quantities produced and feed inputs as well as prices. If, as expected, prices of feed rise due to the removal of production subsidies, poultry production costs will increase and supplies and exports will tend to decrease.

The econometric analysis of US broiler exports indicates that the broiler export market is very sensitive to changes in the real exchange rate and trade distortion policies. These results suggest that the US can increase its broiler exports by extending efforts on international macroeconomic policy coordination (rather than depending strictly on domestic sectoral policies) and working toward elimination of trade distortion practices through NAFTA, GATT and other trade negotiations.

The STSM, formulated directly in terms of unobserved components such as trends, seasonals and cycles, make it an attractive methodology in the con-

text of modeling broiler exports. The introduction of a stochastic trend component in the econometric models turned out to be a powerful tool to proxy the influence of unobserved variables such as changes in tastes, preferences, productivity, technology, etc. Also, the use of quarterly data for the models provides results that produce more accurate short term forecasts of the future values of supply, demand, inventories, exports and meat prices.

More work is required to extend this study's framework to analyze the competitive position of the US broiler industry, formulate a fully integrated international model of world poultry trade by including other poultry producers and importers and include, where possible, social, political, environmental and waste impacts in the model's specification, estimation, forecasting and policy analysis

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