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Measuring Contestability of Korean and Japanese Imported Beef Markets

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Keywords

Beef, Collusion, International market, Japan, Market power, South Korea

Abstract

This study analyzes the competitiveness and market power dynamics in the Korean and Japanese imported beef markets using an extended menu approach and the rivalry index method. By re-evaluating these markets with a Bayesian estimation procedure, the research addresses limitations of previous studies. Findings reveal that the quantity cartel model best fits the South Korean market, while the price cartel model suits the Japanese market. Despite structural model indications of potential cartel behavior, the rivalry index shows no significant collusion between US and Australian beef exporters. This absence of collusive behavior is attributed to the market's nature, characterized by multiple exporters in both countries. The presence of numerous exporters makes unified strategies for competition or collusion challenging, even with support from organizations like US Meat Export Federation (USMEF) and Australian Meat and Livestock Corporation (MLA).

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한국과 일본의 수입 소고기 시장의 경쟁성 측정

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Keywords

수입 소고기, 담합, 국제무역, 일본, 시장독과점, 한국

Abstract

본 연구는 확장된 메뉴 접근법과 경쟁 지수 방법을 활용하여 한국과 일본의 수입 쇠고기 시장에서의 경쟁력 및 시장 지배력 동태를 분석하였다. 베이지안 추정 절차를 통해 이러한 시장을 재평가함으로써 이전 연구의 한계를 보완하였다. 연구 결과, 한국 시장에는 수량 카르텔 모델이, 일본 시장에는 가격 카르텔 모델이 가장 적합한 것으로 나타났다. 구조적 모델이 잠재적 카르텔 행동을 시사하는 반면, 경쟁 지수는 미국과 호주 쇠고기 수출업자 간의 유의미한 담합이 없음을 보여준다. 이러한 담합의 부재는 양국 모두 다수의 수출업자가 존재하는 시장의 특성에 기인한다. 다수의 수출업자로 구성된 환경은 통일된 경쟁 또는 담합 전략을 채택하기 어렵게 만들며, 미국육류수출협회 및 호주축산공사와 같은 조직의 관리와 지원이 있더라도 각 수출업체의 전략을 완전히 통제하지는 않는다.

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1. Introduction

South Korea and Japan are major international beef markets, ranked among the top six beef-importing countries worldwide. Australia and the United States dominate these markets, accounting for the majority of beef imports. In 2018, US beef exports constituted 52% of South Korea's imports and 44% of Japan's imports, while Australia accounted for 44% and 49% of the imports to South Korea and Japan, respectively. According to the CEPII database (Gaulier and Zignago, 2010), the value of beef imports for South Korea and Japan was 2.61 million USD and 3.33 billion US dollars, respectively.

These markets appear to function under a duopolistic competitive structure, which has prompted studies on their market dynamics. Carter and MacLaren (1997) are notable for utilizing the menu approach to analyze Japanese beef imports from the United States and Australia, building on the foundational work of Gasmi et al. (1992). Their method employs structural equations to represent alternative market structures within the frameworks of perfect competition, including the Bertrand, Cournot, and Stackelberg models. They concluded that Australia acted as a Stackelberg price-setting leader.

In the Korean imported beef market, Lee et al. (2023) applied Carter and MacLaren's (1997) method, identifying the United States and Australia as the two main competitors. Their findings indicated that for fresh or chilled beef cuts with bone-in, the Stackelberg model with U.S. quantity leadership best fit the data. Conversely, for boneless fresh or chilled beef, bone-in frozen beef, and boneless frozen beef, the Stackelberg model with Australian quantity leadership was more suitable.

Previous studies successfully determine the structure of imperfectly competitive markets in international beef imports but fall short of measuring the degree of market power. For instance, a study may identify a quantity Stackelberg market structure, yet the degree of market power—or the extent of collusion or imperfect competitiveness—may be weak. This makes it challenging to confirm the market's imperfect competitiveness if the market power is insignificant.

An alternative approach to studying market competitiveness is the pricing-to-market method (Krugman, 1987; Knetter, 1989) and the conjectural variation (CV) approach developed by Karp and Perloff (1989, 1993). While these methods allow for measuring the degree of market power, they assume that all exporters are identical, which limits their ability to determine the nature of imperfect market structures.

To address this limitation, Choi and Lambert (2021) proposed a method to measure market power called the rivalry index, extending Carter and MacLaren's (1997) models to capture both imperfectly competitive market structures and the degree of market power. Similar to conjectural elasticities under conventional new empirical industrial organization (NEIO) assumptions, the rivalry index ranges from 0 to 1, where 1 indicates a perfectly competitive market and 0 indicates a cartel or monopolistic structure. Intermediate values correspond to oligopolistic behavior. This index is advantageous due to its relative ease of calculation and its ability to measure the degree of collusion between rivals using structural models to estimate market structure and conjectural parameters.

The objective of this study is to re-evaluate the Korean and Japanese imported beef markets using the menu approach while simultaneously measuring the degree of market power. By comparing the findings with previous literature, such as Carter and MacLaren (1997) and Lee et al. (2023), this study aims to provide a deeper understanding of the international imported beef market, specifically for South Korea. Additionally, this study employs a Bayesian estimation procedure, addressing issues like the incorrect signs of parameter estimations reported in Carter and MacLaren (1997) and Lee et al. (2023), including cross-price and quantity elasticity and covariates affecting the price and quantity settings of exporters.

The collusive behavior between the United States and Australia, as concluded in previous studies, may be unreliable due to the presence of multiple exporters in both countries. It is unrealistic to assume that multiple exporters in one country would adopt the same strategy to compete or collude with exporters from a rival country. Previous studies justify country-level collusive behavior of exporters by citing high market shares and the existence of national trade associations that support and control their exports.

Carter and MacLaren (1997) noted that the United States and Australia supply 95% of beef exports to Japan, with a few large and several smaller packers from the United States and licensed companies from Australia. The US Meat Export Federation (USMEF) and the Australian Meat and Livestock Corporation (AMLC) support the market through non-price services and quality control, which could control market entry through their licensing system. Government institutes like the USDA Foreign Agricultural Service (USDA-FAS) and Meat & Livestock Australia (MLA) are also aware of each other's production and exports.

In the Korean market, Lee et al. (2023) observed that the United States and Australia account for the majority of market share (91.5% in 2021), suggesting potential collusive behavior and market power exertion. However, it remains unclear if these countries indeed engage in collusive behavior and exert significant market power, also considering oligopsony power in Korean and Japanese markets. In South Korea, the number of major members listed in Korea Meat Import Association is 21, while in Japan, the number of major members listed in Japan Meat Traders Association (JMTA) is 31. By determining the market competitiveness structure and the degree of market power simultaneously, this study aims to evaluate the nature of competitiveness in the Korean imported beef market, addressing the limitations of previous studies.

2. Conceptual Framework

The rivalry index (Choi and Lambert, 2021) is derived from the first-order conditions of profit-maximizing firms or exporters under Bertrand, Cournot, cartel, or Stackelberg (BCCS) assumptions. This approach can be extended to price or quantity competition with multiple differentiated traded goods, firms, or exporters. The index is first developed under price competition assumptions, followed by quantity competition assumptions. Like Carter and MacLaren (1997)'s structural models of contested markets, both the price and quantity models encompass Cournot, Bertrand, Stackelberg, or cartel cases under the null assumption of perfect competition.

This study assumes that imported beef products from the United States and Australia are treated as differentiated products, leading to two distinct demand functions for US and Australian beef products, respectively, in the model. As noted by Carter and MacLaren (1997) and Lee et al. (2023), US beef is typically grain-fed, whereas Australian beef is primarily grass-fed. US beef products in Korean and Japanese markets are generally priced higher than their Australian counterparts. This price gap may be attributed to the fact that US beef products are primarily grain-fed, resulting in a higher fat content that aligns with the preferences of South Korean and Japanese consumers (Chung et al. 2009; Lee and Kennedy 2009; Obara et al. 2010). This conclusion is supported by the OECD's agreement that the Pacific beef market should be regarded as segmented into high-quality (grain-fed) and low-quality (grass-fed) products.

In the case of homogeneous goods, the Bertrand price model exhibits the Bertrand paradox, which states that a Bertrand-contested market tends to converge towards perfect competition when goods are perfect substitutes. However, this paradox fails when firms or exporters offer differentiated products (Tirole, 1988). This empirical example considers the differentiation of an exporter's tradable goods (beef) based on consumer preferences in the importing country. The model encompasses two variables: the price (p_{it}) and quantity (q_{it}) of beef exported by the ith exporter. For simplicity, the time subscript (t) has been omitted in the subsequent model section. Let $(i, j) \in \{1,2\}$index two exporters for the simplicity of deriving essential relationships.

2.1. Price Competition

Following the Bertrand, Cournot, cartel, or Stackelberg models denoted by Tirole (1988), Carter and MacLaren (1997), and Choi and Lambert (2021), the linear system of equations of the Nash equilibrium of the United States. and Australia's reaction functions is:

$$\begin{bmatrix} 1 & -\frac{\partial p_i}{\partial p_j} \\ -\frac{\partial p_j}{\partial p_i} & 1 \end{bmatrix} \begin{bmatrix} p_i \\ p_j \end{bmatrix} = \begin{bmatrix} \mathrm{I}_i \\ \mathrm{I}_j \end{bmatrix} \forall\, i \neq j \tag{1}$$

\where $\frac{\partial_{pi}}{\partial_{pj}}$ is the slope of the i th best response function and I_i includes exogenous behavioral parameters (intercept term) whose form depends on the market structure assumption. For example,

$$\frac{\partial p_j}{\partial p_i} = \begin{cases} \frac{-\beta_{ij}}{2 \cdot \beta_{jj}} \text{ (Bertrand)} \\ \frac{-2 \cdot \beta_{ii} \cdot \beta_{ij}}{4 \cdot \beta_{ii} \cdot \beta_{jj} - \beta_{ij} \cdot \beta_{ji}} \text{ (Stackelberg Price Leader)} \\ \frac{-\beta_{ij}}{2 \cdot \beta_{jj}} \text{ (Stackelberg Price Follower)} \\ -\frac{\beta_{ij} + \beta_{ji}}{2\beta_{jj}} \text{ (Price Setting Cartel)} \end{cases} \forall\, i \neq j, \frac{\partial p_i}{\partial p_i} = 1 \tag{2}$$

$$\mathrm{I}_i = \begin{cases} \dfrac{\beta_{ii} \cdot c_i - \alpha_i}{2 \cdot \beta_{ii}} \text{ (Bertrand)} \\ \dfrac{\left(\dfrac{4 \cdot \beta_{ii} \cdot \beta_{jj} - \beta_{ij} \cdot \beta_{ji}}{2 \cdot \beta_{jj}}\right) \cdot c_i - \alpha_i}{\left(\dfrac{4 \cdot \beta_{ii} \cdot \beta_{jj} - \beta_{ij} \cdot \beta_{ji}}{2 \cdot \beta_{jj}}\right)} \text{ (Stackelberg Price Leader)} \\ \dfrac{\beta_{ii} \cdot c_i - \alpha_i}{2 \cdot \beta_{ii}} \text{ (Stackelberg Price Follower)} \\ \dfrac{\beta_{ii} \cdot c_i - \alpha_i}{2 \cdot \beta_{ii}} \text{ (Price Setting Cartel)} \end{cases} \tag{3}$$

The Jacobian matrix, which includes $\partial p_i/\partial p_i$ (=1) and $-\partial p_i/\partial p_j$, embodies all the information required to measure rivalry intensity. Denote the Jacobian matrix by **R**.

The vector of equilibrium prices for the exporters solves as follows:

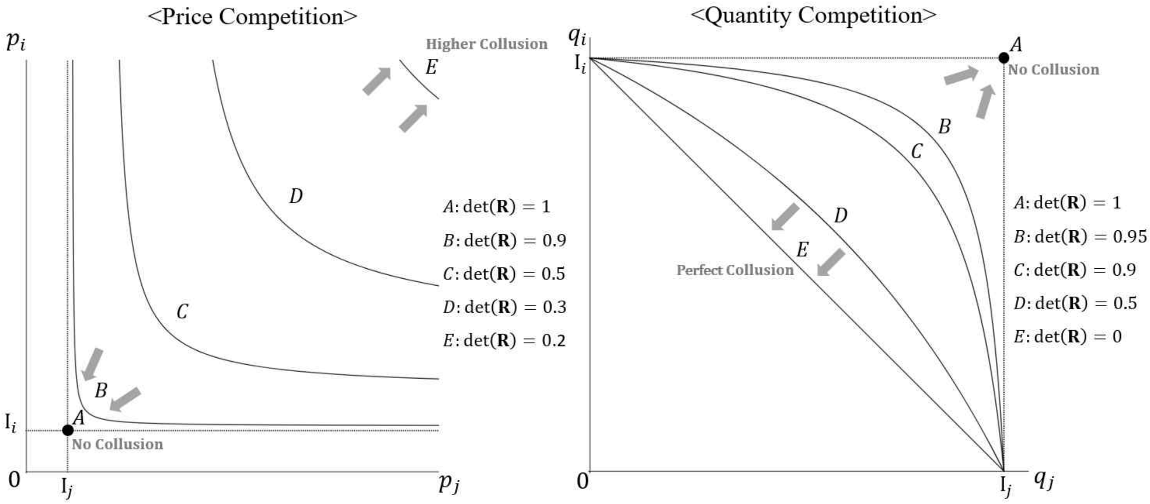
$$\begin{bmatrix} p_i^* \\ p_j^* \end{bmatrix} = \frac{\text{adj}(\mathbf{R})}{\det(\mathbf{R})} \begin{bmatrix} \mathrm{I}_i \\ \mathrm{I}_j \end{bmatrix} \tag{4}$$

where p_i^* and p_j^* are exporters' equilibrium prices, 'adj' and 'det' are adjoint and determinant operators, respectively, and $\frac{adj(R)}{\det(R)}$ is the matrix inverse of **R**.

Determinant det(**R**) measures the intensity of rivalry competition between i and j. The determinant is bounded between zero and one. Negative equilibrium prices or unobtainable Nash equilibrium result when the determinant falls outside this condition. Matrix **R** is non-invertible when det(**R**) is zero. When this happens, exporter responsiveness to its rivals is equivalent for all exporters. Geometrically, this means all exporter reaction functions are parallel or overlapping. In this case, exporters are in a cartel relationship because all exporters identically change their prices. Conversely, when det(**R**) approaches one, all exporter responses to rivals diminish. This indicates a lack of collusion among exporters when setting prices. As det(**R**) approaches zero, exporters increase their prices towards the level observed in a cartel. Conversely, as det(R) approaches one, exporters lower their prices, approximating those found in a perfectly competitive market.

Figure 1 illustrates iso-determinant curves that maps the trajectory of Nash equilibriums while holding det(**R**) constant, for varying determinant values. Higher determinant values signify a lower degree of collusion between exporters, as both exporters increase their prices collectively. Conversely, lower determinant values suggest a higher degree of collusion among exporters.

Figure 1. Combinations of Nash Equilibriums under Price and Quantity Competitions with Two Competitors



Note: {*A, B, C, D, E*} is the iso-determinant curve under different determinant (det(**R**)); I_i is the intercept of ***i*** th best response function; The closer to *A* indicates lower collusion between exporters, whereas the further from *A* indicates higher collusion.

2.2. Quantity Competition

The rivalry index for the quantity competition models follows the same logic as the price competition case. The comparative statics for the equilibrium of the United States and Australia's reaction functions can be written as a linear system of equations that solves the Nash equilibrium under quantity competition:

$$\begin{bmatrix} 1 & -\frac{\partial q_i}{\partial q_j} \\ -\frac{\partial q_j}{\partial q_i} & 1 \end{bmatrix} \begin{bmatrix} q_i \\ q_j \end{bmatrix} = \begin{bmatrix} I_i \\ I_j \end{bmatrix} \forall\, i \neq j \tag{5}$$

where $\frac{\partial q_j}{\partial q_i}$ is the slope of the th best response function and I_i is a function of parameters and costs:

$$\frac{\partial q_j}{\partial q_i} = \begin{cases} \dfrac{-\beta_{ij}}{2 \cdot \beta_{jj}} \text{ (Cournot)} \\ \dfrac{-2 \cdot \beta_{ij} \cdot \beta_{ii}}{4 \cdot \beta_{jj} \cdot \beta_{ii} - \beta_{ij} \cdot \beta_{ji}} \text{ (Stackelberg Quantity Leader)} \\ \dfrac{-\beta_{ij}}{2 \cdot \beta_{jj}} \text{ (Stackelberg Quantity Follower)} \\ -\dfrac{\beta_{ij} + \beta_{ji}}{2\beta_{jj}} \text{ (Quantity Setting Cartel)} \end{cases} , \forall\, i \neq j, \frac{\partial q_i}{\partial q_i} = 1 \quad (6)$$

$$\mathrm{I}_i = \begin{cases} \dfrac{c_i - \alpha_i}{2 \cdot \beta_{ii}} \text{ (Cournot)} \\ \dfrac{c_i - \alpha_i}{4 \cdot \beta_{jj} \cdot \beta_{ii} - \beta_{ij} \cdot \beta_{ji}} \text{ (Stackelberg Quantity Leader)} \\ \dfrac{c_i - \alpha_i}{2 \cdot \beta_{ii}} \text{ (Stackelberg Quantity Follower)} \\ \dfrac{c_i - \alpha_i}{2 \cdot \beta_{ii}} \text{ (Quantity Setting Cartel)} \end{cases} \quad (7)$$

The matrix determinant of the Jacobian measures exporter responsiveness includes $\frac{\partial q_i}{\partial q_i}$(= 1) and $-\frac{\partial q_j}{\partial q_i}$. The vector of export quantities at the Nash equilibrium is:

$$\begin{bmatrix} q_i^* \\ q_j^* \end{bmatrix} = \frac{\mathrm{adj}(\boldsymbol{R})}{\det(\boldsymbol{R})} \begin{bmatrix} \mathrm{I}_i \\ \mathrm{I}_j \end{bmatrix} \quad (8)$$

Like the price competition rivalry index, the determinant det(**R**) is interpreted as the degree of competitiveness. Under quantity competition, det(**R**) is also bounded between zero and one. When det(**R**) equals one, the off-diagonal elements of the quantity responsiveness matrix are zero, which means that the exporters do not collude in setting quantities. Quantity levels approach a cartel equilibrium as det(**R**) approaches zero. One the contrary, when det(**R**) approaches one, exporters set their quantities closer to levels consistent with a perfectly competitive market. Figure 1 (quantity competition) shows iso-determinant curves evaluated at different determinant values. Higher determinant values indicate lower levels of collusion between exporters because both exporters reduce their export quantities. Conversely, lower determinant values indicate higher levels of collusion. Determinants outside the (0, 1)-interval result in unstable equilibrium scenarios.

3. Estimation Procedure

The price and quantity competition models are used to estimate the parameters required to calculate the rivalry indexes. Carter and MacLaren (1997) estimated the system equations using full-information maximum-likelihood under Bertrand, Cournot, and Stackelberg assumptions. Lee et al. (2023) followed the same estimation method to generate results. However, both studies reported incorrect signs for parameter estimates in the cross-price or quantity elasticity parameters and covariates. Considering that the parameter estimates for the cross elasticities are crucial for forming oligopolistic structural models (BCCS assumption), obtaining the correct signs for these parameters is essential to determine the best fitting model. To address this issue, this study utilizes the Bayesian estimation method due to its ability to impose theoretical restrictions on behavioral parameters more easily. Bayesian estimation allows for incorporating prior information and constraints, which helps in obtaining more reliable parameter estimates that align with theoretical expectations.

The system of equations is:

$$\mathbf{Y} \sim MVN\left(\boldsymbol{\mu}, \text{diag}(\boldsymbol{\sigma})\boldsymbol{\Omega}\text{diag}(\boldsymbol{\sigma})\right) \tag{9}$$

with,

$$\mathbf{Y}_{Price} = \begin{bmatrix} q_i \\ q_j \\ p_i^{BEST} \\ p_j^{BEST} \end{bmatrix} \text{ or, } \mathbf{Y}_{Quantity} = \begin{bmatrix} p_i \\ p_j \\ q_i^{BEST} \\ q_j^{BEST} \end{bmatrix} \tag{10}$$

where $\mathbf{Y}$ is a vector of demands and the best response functions ('BEST'), and $\boldsymbol{\mu}$ is a mean vector that includes exporter demand and best response functions.

For the price competition models ($\mathbf{Y}_{Price}$), $\boldsymbol{\mu}$ is the right-hand side of exporter's demand functions and reaction functions. Similarly, for the quantity competition models ($\mathbf{Y}_{Quantity}$), $\boldsymbol{\mu}$ is the right-hand side of exporter's demand functions and reaction functions. The vector $\boldsymbol{\sigma}$ is a conformable matrix of scalar terms (model error standard deviations), and $\boldsymbol{\Omega}$ is a correlation matrix that follows the Lewandowski-Kurowicka-Joe (LKJ) prior distribution (Lewandowski et al., 2009). Pre- and post-multiplying the vector of scalars with the correlation matrix yields a positive-semidefinite covariance matrix.

For estimation, the demand intercept term, α_i includes *i* th exporting country's demand-shifting variables:

$$\alpha_i = \lambda_i + \gamma_i \cdot GDP + \delta_i \cdot TARIFF_i + \kappa_i \cdot BSE \tag{11}$$

where *GDP* is the importing country's *GDP* per capita, *TARIFF* is the tariff rate for imported beef from *i* th exporting country, *BSE* is a dummy variable identifying when the outbreak of bovine spongiform encephalopathy (BSE) that affected South Korea and Japan[1], and λ_i, γ_i, δ_i, and κ_i are parameters. The exporter's marginal cost[2] to provide imported beef products, including production cost, c_i, is:

$$c_i = \eta_i \cdot DISTANCE_i + \tau_i \cdot MAIZEP_i + \upsilon_i \cdot IRATE_i \tag{12}$$

where *DISTANCE* is the exporter's distance[3] to an importing country, *MAIZEP* is the exporter's domestic maize price, *IRATE* is the exporter's real interest rates, and η_i, τ_i, and υ_i are parameters. The priors for the model parameters based on BCCS assumptions are:

$$(\lambda_i, \delta_i, \kappa_i) \sim N(0,10),\ \ \beta_{ii} \sim N_{-\infty}^{0}(0,10),\ \ (\gamma, \eta_i, \tau_i, \upsilon_i) \sim N_0^{\infty}(0,10),$$
$$\beta_{ij} \sim \begin{cases} N_0^{\infty}(0,10) \text{ (for the price competition case)}, \\ N_{-\infty}^{0}(0,10) \text{ (for the quantity competition case)} \end{cases} \tag{13}$$
$$\boldsymbol{\sigma} \sim \text{Exponential}(1),\ \ \boldsymbol{\Omega} \sim \text{LKJcorr}(2)$$

All parameter priors are normally distributed with zero mean and 10 standard deviations except the priors for $\boldsymbol{\sigma}$ and $\boldsymbol{\Omega}$. McElreath (2020) suggests using an exponential distribution as a prior for the scale parameters. The exponential prior carries no more information than an average standard deviation from a mean when the rate parameter is set to one (McElreath, 2020). The priors for β_{ii} and β_{ij} are truncated positive or negative, depending on the BCCS assumption. GDP per capita (*GDP*) is assumed to be positively correlated with import quantities or prices. Distance between exporters and importers ($DISTANCE_i$), maize prices ($MAIZEP_i$), and the real interest ($IRATE_i$) are hypothesized to increase

1) This dummy variable captures the separate US beef import bans implemented by South Korea and Japan, respectively.

2) Carter and MacLaren (1997) also incorporated the price of corn and the interest rate in their specification of marginal cost.

3) The distance variable functions as a constant term as it is time invariant.

exporter marginal costs. Thus, the priors for γ_i, η_i, τ_i, and ν_i are positive and truncated above zero.

R-Stan's Hamiltonian Monte Carlo No U-turn Sampler (HMC-NUTS) (Stan Development Team 2022) is used to generate posterior distributions for the model parameter estimates. The HMC-NUTS performance is superior to Gibbs or Metropolis-Hastings samplers regarding the number of iterations required for convergence (Gelman et al. 2013). Four chains were used, each with 20,000 iterations and 10,000 warm-up samples for the adaptation phase. Thinning, maximum tree depth, and target acceptance (adaptation) rate were set to 10, 15, and 0.95, respectively, to achieve convergence. Therefore, 4 × 1,000 posterior samples are used to calculate the means and standard deviations of the posterior distributions.

3.1. Model Comparison

Two criteria are used to compare the performance of each BCCS model. The first criterion is the widely applicable information criterion (WAIC), which is calculated with a model's log-posterior density (McElreath, 2020). A probability weight is calculated for each model using the ensemble of computed WAIC. Each probability weight represents the likelihood that a model is preferred among competing models. Larger weights indicate a better-fitting model.

The second model comparison method uses Bayes factors (BF). The BF are used to make pairwise comparisons between two models and are based on each model's marginal likelihood (Gelman et al., 2013). When a BF exceeds 1, there is evidence in favor of a competing model (H_1) over a reference model (H_0). Following Lee and Wagenmaker (2014)'s research, which is based on Jeffreys (1961)'s rubric for interpreting BF, a BF 〉 10 is considered strong evidence for favoring the competing model, while a BF 〈 1/10 strongly favors the reference model.

4. Data

Annual data on beef exports to Japan and South Korea from the US and Australia were collected from 1995 to 2018 (Table 1). To comprehensively assess market trends and competition, frozen and chilled beef products are combined into a single category. International trade data for bovine meat, specifically chilled beef (HS 0201) and frozen beef (HS 0202), were obtained from the BACI (Base pour l'Analyse du Commerce International) database, curated by the French research center CEPII (Centre d'Etudes Prospectives et d'Informations Internationales) (Gaulier and Zignago, 2010). The BACI database includes export quantities of US and Australian beef and the value paid by importing countries. The value of US beef consistently surpasses that of Australian beef in the frozen and chilled beef segments, except during the period affected by the US BSE outbreak.

The international beef trade data for South Korea and Japan were analyzed separately for each beef import market. Therefore, one demand function per exporter exists for each of the two importing markets, South Korea and Japan. Beef prices were determined by considering the weighted values of categories within the HS 6-digit units, which include HS 020110, 020120, 020130, 020210, 020220, and 020230. This calculation took into account the importing and exporting countries involved.

Gross Domestic Product (GDP) normalized by population, tariff rates to the exporting country, and a dummy variable for the outbreak of BSE in the US are used as demand-shifting variables. South Korea and Japan's GDP per capita and tariff rates are from the World Bank's Data Bank (World Bank, 2021) and MLA reports for overseas markets (MLA 2022), respectively. The BSE dummy variable, indicating the period from 2004 to 2009 (BSE=1), was set based on the year after the ban on imported beef from the US by South Korea (2003) and the year after reopening to importing US beef (2008). This standard is based on the fact that during the period from 2004 to 2008, the value of imported US beef to Korea and Japan was reduced by over 50% compared to the yearly average value during the total sample period.

Cost-shifting variables affecting the marginal costs of exporting beef include each exporting country's corn price and interest rate. Interest rates are also from the World Bank's Data Bank (World Bank, 2021). Real domestic maize prices are from the Food and Agriculture Organization's Food Price Monitoring and Analysis data (FAO, 2021). The distance (in kilometers) between exporters and importers is sourced from Distance From To (Distance From To, 2022).

Table 1. Descriptive Statistics

Variable	Unit	Mean	Standard Deviation	Minimum	Maximum
US GDP Deflator	2015=100	86.204	11.434	105.417	68.688
US Real Interest Rate ($IRATE_1$)	%	3.608	2.039	7.148	1.137
US Domestic Maize Price ($MAIZEP_1$)	US Dollars /metric tons	223.143	90.504	464.57	123.43
Australia Real Interest Rate ($IRATE_2$)	%	4.328	1.867	8.057	0.97
Australia Domestic Maize Price ($MAIZEP_2$)	US Dollars /metric tons	247.268	85.683	361.19	83.58
The Korean Beef Importing Market					
US Unit Price (p_1)	Thousands current USD /metric tons	4.621	1.497	2.501	7.294
US Quantity (q_1)	Metric tons	105993	68619	76	267473
Tariff Rate to US ($TARIFF_1$)	%	37.708	6.22	21.3	43.6
Distance to US ($DISTANCE_1$)	Kilometer	10743	-	-	-
Australia Unit Price (p_2)	Thousands current USD /metric tons	3.482	1.353	1.637	5.512
Australia Quantity (q_2)	Metric tons	123771	47079	38948	196376
Tariff Rate to Australia ($TARIFF_2$)	%	39.154	4.241	26.6	43.6
Distance to Australia ($DISTANCE_2$)	Kilometer	6832	-	-	-
GDP per capita (GDP)	US dollars per capita	20181	7364	8282	33423
The Japanese Beef Importing Market					
US Unit Price (p_1)	Thousands current USD /metric tons	4.873	1.039	2.951	6.425
US Quantity (q_1)	Metric tons	207958	133088	816	483050
Tariff Rate to US ($TARIFF_1$)	%	40.202	3.804	38.5	50
Distance to US ($DISTANCE_1$)	Kilometer	10173			
Australia Unit Price (p_2)	Thousands current USD /metric tons	3.968	0.968	2.534	5.866
Australia Quantity (q_2)	Metric tons	334689	50703	246054	439067
Tariff Rate to Australia ($TARIFF_2$)	%	38.745	5.5	28.55	50
Distance to Australia ($DISTANCE_2$)	Kilometer	6852	-	-	-
GDP per capita (GDP)	US dollars per capita	38400	4292	31916	48633

Note: The number of observations is 24. The dummy variable indicating BSE (*BSE*) is '1' for 2004–2009. Stand deviation, minimum, and maximum of distance variables are omitted because distance is fixed.

5. Results

The rivalry indices in equations (4) and (8) were estimated separately under each BCCS quantity and price assumption for the South Korean and Japanese markets. Three of the eight models converged. The Cournot and Stackelberg models did not converge, as evidenced by the potential scale reduction factor ($\hat{R}$), which were all greater than 1.01 (Appendixes Ⅰ and Ⅲ). The effective sample sizes were also relatively small for the non-converged models (Appendixes Ⅱ and Ⅳ). In Bayesian inference, a model that fails to converge is unsuitable for accurately fitting the data (Gelman et al., 2013)[4]. Therefore, the lack of convergence suggests a weak fit between the model and the observed data, highlighting the need for improvement and refinement.

The discussion focuses on the converged models. The Bertrand and cartel models converged, with the largest $\hat{R}$ less than 1.01 and the smallest effective sample size of 3,379. For all models, all own-quantity and own-price parameters (β_{ii}) are negative, which is consistent with the behavioral assumptions (Tables 2 and 3). The cross-price parameters (β_{ji}) are less than zero for the quantity competition models and positive for the price competition models and is consistent with theoretical expectations.

All parameters of the marginal cost function (η_i, τ_i, υ_i) and GDP per capita (γ_i) are positive and consistent with their hypothesized relationships (Tables 2 and 3). All parameters on tariff rates (δ_i) are negative, suggesting that tariff rates decrease exporting prices and demand. Lastly, all parameters of the BSE dummy variable (κ_i) are negative for the US and positive for Australia. The estimated sign of the BSE dummy parameter implies that the BSE outbreak in US negatively affected US beef export price and quantity. In contrast, Australia benefitted from the BSE outbreak in terms of higher export prices and demand.

[4] Convergence is a crucial indicator that a model has reached a stable state, where the posterior distribution remains relatively unchanged. Failure to achieve convergence suggests that the posterior distribution is still undergoing significant changes, indicating that the model struggles to accurately represent the underlying data.

Table 2. Posterior Means and Standard Deviations (South Korea)

Parameter (1 = US, 2 = Au.)	Bertrand		Price Cartel		Quantity Cartel	
	Mean	S.D.[a]	Mean	S.D.	Mean	S.D.
λ_1	0.172	9.921	0.312	9.994	4.805	1.776
β_{11}	-139.544	6.026	-139.343	6.079	-5.24E-05	1.08E-06
β_{21}	7.625	5.828	9.211	6.610	-1.46E-07	1.21E-07
γ_1	4.405	0.047	4.407	0.047	1.10E-04	3.24E-05
δ_1	-18.627	8.874	-19.617	8.842	-0.050	0.030
κ_1	-1.888	9.919	-1.887	9.800	-0.443	0.313
η_1	0.001	0.001	0.001	0.001	9.78E-05	9.58E-05
τ_1	0.599	0.230	0.602	0.237	0.003	0.003
υ_1	1.74E-04	1.74E-04	1.62E-04	1.64E-04	6.57E-07	6.57E-07
λ_2	-1.418	10.017	-1.050	10.109	0.001	1.251
β_{22}	-151.972	5.996	-151.967	6.082	-2.50E-05	2.53E-07
β_{12}	6.311	5.094	5.648	4.687	-7.85E-07	6.92E-07
γ_2	5.706	0.025	5.704	0.025	1.83E-04	1.73E-05
δ_2	-63.220	9.515	-62.120	9.407	-0.007	0.023
κ_2	0.861	9.971	0.889	10.060	0.150	0.174
η_2	0.004	0.003	0.004	0.003	0.001	1.25E-04
τ_2	0.198	0.156	0.194	0.153	0.036	0.006
υ_2	0.002	0.001	0.002	0.001	5.42E-05	7.65E-06
det(R)	0.999	0.001	0.997	0.004	0.999	4.64E-04
r_{11}	1	0[b]	1	0	1	0
r_{12}	-0.021	0.017	-0.049	0.027	0.019	0.014
r_{21}	-0.027	0.021	-0.053	0.029	0.009	0.007
r_{22}	1	0	1	0	1	0
WAIC	9560		9595		9285	

Note: See Appendix Ⅰ and Ⅱ for convergence statistics. The number of observations is 24. r_{ii} is the diagonal element of the Jacobian matrix (R) and th own responsiveness of price or quantity, which is fixed to one.
[a] Standard deviations.
[b] Standard deviations of r_{ii} is zero because r_{ii} is fixed to one.

Table 3. Posterior Means and Standard Deviations (Japan)

Parameter (1 = US, 2 = Au.)	Bertrand		Price Cartel		Quantity Cartel	
	Mean	S.D.[a]	Mean	S.D.	Mean	S.D.
λ_1	0.191	9.973	0.351	9.988	0.711	1.732
β_{11}	-162.445	5.915	-162.429	5.808	-1.38E-05	3.44E-07
β_{21}	8.404	6.237	9.675	6.754	-3.16E-08	3.11E-08
γ_1	4.588	0.034	4.587	0.034	7.28E-05	1.85E-05
δ_1	18.020	8.077	18.011	7.924	0.049	0.036
κ_1	-1.883	10.043	-1.778	9.909	-0.834	0.577
η_1	0.007	0.004	0.007	0.004	0.006	2.43E-04
τ_1	0.597	0.204	0.604	0.203	2.22E-04	2.17E-04
υ_1	4.32E-04	3.21E-04	4.24E-04	3.19E-04	2.83E-07	2.78E-07
λ_2	0.661	10.095	0.979	9.983	4.578	0.583
β_{22}	-190.904	6.037	-191.036	6.009	-1.11E-05	1.20E-07
β_{12}	7.422	5.680	7.510	5.802	-4.05E-06	2.75E-07
γ_2	7.295	0.022	7.295	0.022	2.47E-05	8.44E-06
δ_2	17.603	8.616	17.454	8.915	-0.027	0.014
κ_2	2.122	10.125	1.795	10.042	-0.123	0.255
η_2	0.002	0.002	0.002	0.002	0.003	1.21E-04
τ_2	0.134	0.123	0.140	0.127	0.025	0.005
υ_2	4.88E-04	4.41E-04	4.84E-04	4.39E-04	2.67E-07	2.67E-07
det(R)	0.999	0.001	0.997	0.003	0.973	0.004
r_{11}	1	0[b]	1	0	1	0
r_{12}	-0.019	0.015	-0.045	0.023	0.183	0.013
r_{21}	-0.026	0.019	-0.053	0.028	0.148	0.013
r_{22}	1	0	1	0	1	0
WAIC	14857		14801		16048	

Note: See Appendix Ⅲ and Ⅳ for convergence statistics. The number of observations is 24. r_{ii} is the diagonal element of the Jacobian matrix (R) and th own responsiveness of price or quantity, which is fixed to one.

[a] Standard deviations.

[b] Standard deviations of r_{ii} is zero because r_{ii} is fixed to one.

5.1. Model Comparison

Based on the WAIC criterion, the quantity cartel model demonstrates a superior fit compared to the other models in characterizing the structure of South Korean imports of US and Australian beef products (Table 4). The probability weights assigned to the competing models are effectively zero, indicating that their fit is comparatively worse than that of the quantity cartel model. Similarly, when analyzing the Japanese beef import market in Table 4, the price cartel model emerges as the most favorable option, supported by the probability weights of other models, which are all zero.

Table 4. Widely Applicable Information Criterion (WAIC) and Model Probability Weights

Model	WAIC	seWAIC	△WAIC	se△WAIC	weight
South Korea					
Quantity Cartel	9285	2065.5	0	-	1
Bertrand	9560	1803.7	276	849	0
Price Cartel	9595	1816.7	310	844	0
Japan					
Price Cartel	14801	2108	0	-	1
Bertrand	14857	2118	56	35	0
Quantity Cartel	16048	3191	1246	2576	0

Note: se(WAIC) is the standard error of WAIC; subscription i denotes model; △WAIC is [$WAIC_i$ − min(WAIC)]; and se(△WAIC) is the standard error of △WAIC. A higher weight indicates a better fitting model.

Table 5 compares each model with the Bayes factors (BF). The BF comparison suggests that the quantity cartel is preferred for the South Korean beef import market. The BF for the Japanese market suggests that Bertrand and the price cartel are preferred compared to the quantity cartel model. Comparing the Bertrand (H_1) with the price cartel model (H_0), the corresponding BF is 4.67, which is inconclusive. Thus, the BF comparisons are generally consistent with the WAIC findings. Results suggest that the South Korean and Japanese import market structure for beef from the US or Australia is most similar to the quantity cartel and the price cartel[5] models, respectively.

[5] This potential cartel-like behavior may be due to the rocket and feather effect, which explains that prices rise quickly when costs increase but fall slowly when costs decrease. This means that both the United States and Australia may unintentionally set their prices following the rocket and feather pattern. When costs, such as oil or other energy prices, rise, both exporters increase their prices quickly but reduce them slowly when the costs fall.

Table 5. Model Comparison: Bayes Factor (BF)[a]

H_0 \ H_1	Bertrand	Price Cartel	Quantity Cartel
		---South Korea---	
Bertrand	1	1.616	〉999
Price Cartel	0.619	1	〉999
Quantity Cartel	〈0.001	〈0.001	1
		---Japan---	
Bertrand	1	0.214	〈0.001
Price Cartel	4.665	1	〈0.001
Quantity Cartel	〉999	〉999	1

[a] The column entries are numerators and row entries is the denominator for calculating a Bayes factors, $BF = p(y|H_1)/p(y|H_0)$. A BF 〉 1 indicates H_1 is preferred to H_0.

The model comparison results are similar to previous studies, indicating that the strategic factors for collusion (or competition) are quantity and price in the Korean and Japanese markets, respectively.[6] Comparing with Carter and MacLaren (1997), who used Japanese beef import data from 1973 to 1990, they concluded that the best-fitting model is a Stackelberg model with Australia as the price leader, which aligns with this study's finding that price is the strategic factor for collusion in the Japanese imported beef market. On the other hand, comparing to Lee et al. (2023), who used Korean beef import data from 2000 to 2020, they concluded that price is the strategic factor for collusion among the United States and Australia. This study's findings for the South Korean market, however, suggest that quantity is the more significant strategic factor.

Nevertheless, these results are unexpected because different beef qualities, tariff rates, regulations, and trade agreements by the exporting countries make collusion difficult for major exporters in the international beef market. There is also limited information on the interaction between the US and Australian beef exporters. National trade associations support beef exports, such as the US Meat Export Federation (USMEF) and Meat & Livestock Australia (MLA). However, it is unlikely that the USMEF and MLA intentionally collude because these associations are comprised of atomistic beef exporters. The rivalry index resolves this dilemma.

6) The discrepancies between the results of this study and previous studies can be attributed to differences in the dataset periods, covariates, and estimation methods. Notably, this study employs a Bayesian estimation method, which incorporates prior information and yields parameter estimates with signs consistent with economic theory.

5.2. Rivalry Index

The rivalry index gauges the intensity of collusion (or competition) between price- or quantity-competing firms or exporters. The rivalry matrix for each model was derived from the posteriors of the model parameters (Tables 2 and 3, calculated with equations (4) and (8)). The posterior means of the matrix determinant test under Bertrand, price cartel, and quantity cartel models are 0.999, 0.997, and 0.999 for the Korean market, and 0.999, 0.997, and 0.973 for the Japanese market. Contrary to the results of the structural model, which suggested cartel-like behavior, the rivalry index indicates that there is effectively no quantity or price collusion between Australian and US beef exporters. This index serves as an ex-post ‘litmus test’, either supporting or contradicting the results implied by statistical comparisons of structural equation models.[7)]

As mentioned in the introduction, the distinct collusive behavior between the United States and Australia is unlikely due to the unrealistic assumption that multiple exporters in one country would adopt the same strategy to compete or collude with exporters from a rival country. National trade associations, such as the US Meat Export Federation (USMEF) and Meat & Livestock Australia (MLA), can support their beef exporters through marketing and advertising in Korean and Japanese imported beef markets to differentiate their products from their rivals, thereby avoiding direct competition. However, it is limited to suggest that these two countries collude by manipulating quantity and price settings.

As noted by Lee et al. (2023), the government’s policy of reducing or abolishing the quota tariff on imported beef aims to stabilize prices and improve trade agreements, which is expected to decrease the import price of beef and increase import volume. The increased demand for imported beef products in Korea may intensify interactions between US and Australian beef exporters, whether these interactions are competitive or collusive.

Import regulations implemented by Korean authorities can significantly impact market competitiveness. According to USDA-FAS (2021), Australia is expected to be more price-competitive in South Korea’s beef market because it must meet South Korea’s safeguard levels, which impose restrictions on quantity setting for export, making Australia more likely to focus on price setting. The Agricultural Safeguard clause in the Korea-Australia

7) Similar to the relationship between mean values and p-values in frequentist statistics, even if parameter estimates have some values, they are statistically insignificant and effectively interpreted as zero (no effect).

Free Trade Agreement subjects beef imported from Australia to a 30 percent tariff rate (revised from a previous rate of 16 percent) once imports exceed 181,120 metric tons. This example demonstrates how import regulations can affect any potential market power exercised by the US or Australia, as these regulations restrict exporters' decisions regarding price and quantity settings.

However, this study expects that considering the gradual reduction of regulations by regional trade agreements in the Korean imported beef market, exporters' oligopolistic behavior will remain limited because multiple exporters in one country are not a single entity. This makes it difficult to align price or quantity adjustments with other exporters in the same country. The rivalry index indicates that there is effectively no quantity or price collusion between the United States and Australia in the Korean and Japanese beef importing markets.

6. Conclusion

This study offers a comprehensive analysis of the competitiveness and market power dynamics in the Korean and Japanese imported beef markets. By utilizing an extended menu approach from Carter and MacLaren (1997) and integrating the rivalry index method (Choi and Lambert, 2021), this research provides detailed insights into these markets. Employing a Bayesian estimation procedure alongside the rivalry index addresses the limitations of previous studies and delivers robust insights into the nature of competition among key exporters.

The findings indicate that the quantity cartel model is the most fitting for the South Korean beef import market, while the price cartel model better suits the Japanese market. These results align with previous literature, suggesting that strategic factors for collusion differ between these two markets. Despite the structural model results suggesting potential cartel behavior, the rivalry index reveals no significant collusion in terms of price or quantity between Australian and US beef exporters. This discrepancy underscores the value of the rivalry index as a validation tool for structural model outcomes.

The absence of collusive behavior between US and Australian beef exporters is attributed to the nature of the beef export market, characterized by multiple exporters in both countries. The presence of numerous exporters makes it challenging for all to adopt a unified strategy to compete or collude, even under the guidance of organizations like USMEF and MLA, which support marketing strategies but do not control export behaviors entirely.

As free trade agreements, such as the Korea-United States and Korea-Australia agreements, will reduce more trade regulations and barriers in the Korean imported beef markets, major exporters will have more flexibility to adjust strategic factors like quantity and price settings. However, the ability to manipulate and engage in collusion will remain limited due to the inherent nature of multiple exporters within the international beef market.

In conclusion, this study advances the understanding of market power and competitiveness in the Korean and Japanese imported beef trade. By employing a Bayesian estimation procedure and the rivalry index, it addresses the limitations of previous studies and provides robust insights into the nature of competition among key exporters. There are caveats to this research, such as beef quality or specific cuts in one country were not considered. Future research can explore the interactions between multiple exporters within the same country and the role of national trade associations in shaping market dynamics, as well as the quality and specific cuts of beef products. Additionally, ongoing evaluation of trade policies and their impacts on market structures will be crucial for maintaining fair and competitive international trade practices.

References

Carter, C. A., & MacLaren, D. (1997). Price or quantity competition? Oligopolistic structures in *international commodity markets. Review of International Economics*, 5(3), 373–385. https://doi.org/10.1111/1467-9396.00063

Chung, C., Boyer, T., & Han, S. (2009). Valuing quality attributes and country of origin in the Korean beef market. *Journal of Agricultural Economics*, 60(3), 682–698. https://doi.org/10.1111/j.1477-9552.2009.00218.x

Choi, Y., & Lambert, D. M. (2021). Bayesian matrix determinant test for Bertrand competitors: An application examining the international beef market. In *2021 Annual Meeting, August 1-3, Austin, Texas* (No. 312807). Agricultural and Applied Economics Association.

DistanceFromTo. (2022). https://www.distancefromto.net/countries.php

Food and Agriculture Organization of the United Nations (FAO). (2021). Food price monitoring and analysis. https://fpma.apps.fao.org/giews/food-prices/tool/public/#/dataset/international

Gasmi, F., Laffont, J. J., & Vuong, Q. (1992). Econometric analysis of collusive behavior in a soft-drink market. *Journal of Economics & Management Strategy*, 1(2), 277–311. https://doi.org/10.1111/j.1430-9134.1992.00277.x

Gaulier, G., & Zignago, S. (2010). BACI: International trade database at the product-level. The 1994-2007 version. *CEPII Working Paper*, 2010-23.

Gelman, A., Carlin, J. B., Stern, H. S., Dunson, D. B., Vehtari, A., & Rubin, D. B. (2013). *Bayesian data analysis* (3rd ed.). Boca Raton: Chapman and Hall/CRC.

Jeffreys, H. (1961). *The theory of probability*. Oxford University Press.

Karp, L. S., & Perloff, J. M. (1993). A dynamic model of oligopoly in the coffee export market. *American Journal of Agricultural Economics*, 75(2), 448–457. https://doi.org/10.2307/1242929

Karp, L. S., & Perloff, J. M. (1989). Dynamic oligopoly in the rice export market. *The Review of Economics and Statistics*, 71(3), 462–470. https://doi.org/10.2307/1926903

Knetter, M. M. (1989). Price discrimination by U.S. and German exporters. American Economic Review, 79(1), 198–210.

Krugman, P. R. (1987). Is free trade passé? *Journal of Economic Perspectives*, 1(2), 131–144. https://doi.org/10.1257/jep.1.2.131

Lee, M. D., & Wagenmakers, E.-J. (2014). *Bayesian cognitive modeling: A practical course*. Cambridge University Press.

Lee, S., Kim, S.-W., & Yoon, B.-S. (2023). Oligopolistic market structure in the Korean beef import market. *Korean Journal of Agricultural Management and Policy*, 50(2), 253–274.

Lee, Y., & Kennedy, P. L. (2009). Effects of price and quality differences in source differentiated beef on market demand. *Journal of Agricultural and Applied Economics*, 41(1), 241–252. https://doi.org/10.1017/S1074070800002662

Lewandowski, D., Kurowicka, D., & Joe, H. (2009). Generating random correlation matrices based on vines and extended onion method. *Journal of Multivariate Analysis*, 100(9), 1989–2001. https://doi.org/10.1016/j.jmva.2009.04.008

McElreath, R. (2020). *Statistical rethinking: A Bayesian course with examples in R and Stan* (2nd ed.). Boca Raton: Taylor and Francis, CRC Press.

MLA. (2022). Overseas market data and insights | Meat & Livestock Australia. *MLA Corporate*. https://www.mla.com.au/prices-markets/overseas-markets/

Obara, K., Mcconnell, M. J., & Dyck, J. (2010). Japan's beef market. *U.S. Department of Agriculture*. http://www.ers.usda.gov/publications/pub-details/?pubid=37411

Reimer, J. J., & Stiegert, K. (2006). Imperfect competition and strategic trade theory: Evidence for international food and agricultural markets. *Journal of Agricultural & Food Industrial Organization*, 4(1). https://doi.org/10.2202/1542-0485.1134

Stan Development Team. (2022). *RStan: The R interface to Stan. R package version 2.21.5*. https://mc-stan.org/

Tirole, J. (1988). *The theory of industrial organization*. Cambridge, MA: MIT Press.

U.S. Department of Agriculture-Foreign Agricultural Service (USDA-FAS). (2019). *Australia: Livestock and products annual*. https://www.fas.usda.gov/data/australia-livestock-and-products-annual-3

U.S. Department of Agriculture-Foreign Agricultural Service (USDA-FAS). (2021). *South Korea: Livestock and products semi-annual*. https://www.fas.usda.gov/data/south-korea-livestock-and-products-semi-annual-5

U.S. Meat Export Federation, Korea Office. https://www.usmef.co.kr

Vuong, Q. H. (1989). Likelihood ratio tests for model selection and non-nested hypotheses. *Econometrica*, 57(2), 307–333. https://doi.org/10.2307/1912557

World Bank. (2021). *Data Bank*. https://data.worldbank.org/indicator/FR.INR.RINR

Appendix Ⅰ. Convergence criteria, $\hat{R}$ (South Korea)

Para-meter (1 = US, 2 = Au.)	Price Competition				Quantity Competition			
	Bertrand	Price Cartel	Australia Price Leader	US Price Leader	Cournot	Quantity Cartel	Australia Quantity Leader	US Quantity Leader
α_1	1.000	1.000	0.999	0.999	205.111	1.000	1.179	4.316
β_{11}	1.001	1.000	2.838	17.053	63.707	1.000	10.209	4.020
β_{21}	1.000	1.001	11.008	10.939	98.508	1.000	2.018	59.659
γ_1	1.000	1.000	1.562	1.272	39.891	1.000	2.078	19.980
δ_1	1.000	1.001	1.804	2.233	1.003	1.000	1.170	3.403
ε_1	0.999	1.000	1.000	1.000	94.731	1.000	1.223	1.535
η_1	1.000	1.000	1.196	2.653	74.489	1.001	2.015	147.816
τ_1	1.000	1.000	1.032	1.144	33.480	1.000	11.213	42.168
υ_1	1.000	0.999	1.041	7.495	98.091	1.000	4.591	135.305
α_2	1.000	1.000	1.000	1.000	188.121	1.000	1.025	2.087
β_{22}	1.000	1.000	19.321	3.019	79.428	1.000	1.034	185.649
β_{12}	1.000	1.000	11.805	11.557	147.817	1.000	1.015	6.819
γ_2	1.000	0.999	1.335	1.135	124.472	1.000	1.062	10.942
δ_2	1.000	0.999	1.073	1.235	1.022	1.000	1.038	2.008
ε_2	1.000	0.999	1.000	1.000	65.341	1.000	1.029	3.284
η_2	1.000	1.000	4.354	1.111	4.682	1.000	2.455	18.076
τ_2	1.000	0.999	1.373	1.146	112.075	1.000	1.259	40.552
υ_2	1.000	1.001	6.366	1.573	19.070	0.999	2.361	30.490
det(R)	1.000	1.000	64.706	60.967	42.958	1.001	1.000	94.497
r_{11}	-[a]	-	-	-	-	-	-	-
r_{12}	1.000	1.001	12.023	10.840	214.681	1.000	1.000	1.958
r_{21}	1.000	1.001	10.355	12.362	28.774	1.000	1.058	1.369
r_{22}	-	-	-	-	-	-	-	-

Note: $\hat{R}$ is indicator of convergence.
[a] r_{ii} has no value (-) because r_{ii} is fixed to one.

Appendix Ⅱ. Posterior Effective Sample Size (South Korea)

Parameter (1 = US, 2 = Au.)	Price Competition				Quantity Competition			
	Bertrand	Price Cartel	Australia Price Leader	US Price Leader	Cournot	Quantity Cartel	Australia Quantity Leader	US Quantity Leader
α_1	4386	3982	3932	3873	2	3898	8	2
β_{11}	3670	4036	2	2	2	3911	2	2
β_{21}	4031	4240	2	2	2	3618	3	2
γ_1	4002	3882	3	5	2	3832	3	2
δ_1	4292	4068	3	2	3942	3921	9	2
ε_1	3682	4119	4034	4161	2	4014	25	6
η_1	4084	3930	7	2	2	3689	3	2
τ_1	3671	3899	79	9	2	4006	2	2
υ_1	4079	3936	54	2	2	3855	2	2
α_2	4061	4058	4139	3640	2	3670	502	6
β_{22}	3858	3967	2	2	2	3912	102	2
β_{12}	3886	3418	2	2	2	4176	1859	2
γ_2	3938	4049	4	9	2	3676	30	2
δ_2	3980	4059	18	6	344	3764	100	7
ε_2	3909	4015	4039	4043	2	3952	193	2
η_2	3896	3682	2	12	2	3625	2	2
τ_2	4018	4035	4	9	2	3878	5	2
υ_2	3999	3960	2	3	2	4158	2	2
det(R)	3736	4073	2	2	2	4091	4010	2
r_{11}	-[a]	-	-	-	-	-	-	-
r_{12}	3881	4178	2	2	2	4149	4016	4
r_{21}	4028	4133	2	2	2	4155	24	7
r_{22}	-	-	-	-	-	-	-	-

Note: Larger effective sample sizes are evidence in favor of model convergence.
[a] r_{ii} has no value (-) because r_{ii} is fixed to one.

Appendix Ⅲ. Convergence criteria, $\hat{R}$ (Japan)

Para-meter (1 = US, 2 = Au.)	Price Competition				Quantity Competition			
	Bertrand	Price Cartel	Australia Price Leader	US Price Leader	Cournot	Quantity Cartel	Australia Quantity Leader	US Quantity Leader
α_1	1.000	1.001	1.000	1.000	467.351	1.000	3.707	3.194
β_{11}	1.000	1.001	2.293	20.720	144.282	1.000	1.593	4.267
β_{21}	1.000	1.000	12.017	12.135	44.526	1.000	6.897	54.508
γ_1	1.000	1.000	1.236	1.001	31.245	1.000	1.112	5.117
δ_1	1.000	1.000	1.060	1.034	1.044	1.001	1.100	4.192
ε_1	1.000	1.002	1.000	1.000	211.308	1.000	1.722	6.293
η_1	1.000	0.999	1.068	1.312	63.456	1.000	1.014	85.841
τ_1	1.000	0.999	1.052	4.134	53.930	1.000	1.012	231.907
υ_1	1.000	0.999	1.004	11.190	82.353	1.000	1.073	393.196
α_2	1.000	1.000	1.000	1.000	586.997	0.999	1.996	4.534
β_{22}	1.000	1.000	24.210	2.786	44.320	0.999	1.000	80.174
β_{12}	1.000	0.999	12.451	12.618	269.321	1.000	6.417	36.147
γ_2	1.000	1.000	1.084	1.241	47.248	1.000	1.081	24.540
δ_2	1.000	1.000	1.014	1.016	1.176	0.999	2.387	6.679
ε_2	1.000	1.000	1.000	1.000	290.836	1.000	1.680	14.295
η_2	1.000	1.000	1.277	1.192	150.514	0.999	69.200	144.888
τ_2	1.000	0.999	1.434	1.201	54.309	1.000	1.024	10.193
υ_2	1.000	1.000	12.115	1.004	32.373	1.000	1.306	221.454
det(R)	1.000	0.999	71.483	78.923	155.195	1.000	1.000	18291.0
r_{11}	-[a]	-	-	-	-	-	-	-
r_{12}	1.000	0.999	13.563	12.406	371.879	1.000	1.003	8.324
r_{21}	1.000	0.999	11.212	14.953	182.433	1.000	7.165	7.989
r_{22}	-	-	-	-	-	-	-	-

Note: $\hat{R}$ < 1.01 is indicator of convergence.
[a] r_{ii} has no value (-) because r_{ii} is fixed to one.

Appendix Ⅳ. Posterior Effective Sample Size (Japan)

Para-meter (1 = US, 2 = Au.)	Price Competition				Quantity Competition			
	Bertrand	Price Cartel	Australia Price Leader	US Price Leader	Cournot	Quantity Cartel	Australia Quantity Leader	US Quantity Leader
α_1	4051	3717	3764	3966	2	3686	2	3
β_{11}	3857	4116	2	2	2	3767	3	2
β_{21}	3963	3887	2	2	2	3884	2	2
γ_1	3781	4084	6	3817	2	3881	11	2
δ_1	3511	3767	24	60	91	3745	13	2
ε_1	3932	3379	3897	3734	2	3891	3	2
η_1	3653	3677	21	5	2	3840	1793	2
τ_1	3978	3836	32	2	2	3983	2552	2
υ_1	3871	3669	3096	2	2	3707	19	2
α_2	3788	3595	3546	3977	2	3912	3	2
β_{22}	3951	3941	2	2	2	3996	3954	2
β_{12}	3929	4065	2	2	2	3795	2	2
γ_2	3947	3721	15	6	2	3840	16	2
δ_2	3716	4115	517	425	14	4010	2	2
ε_2	3966	3667	4028	3651	2	4120	3	2
η_2	3955	3903	5	7	2	4023	2	2
τ_2	3926	4073	4	7	2	3906	142	2
υ_2	4194	3968	2	3873	2	3905	5	2
det(R)	3746	4144	2	2	2	3828	4011	2
r_{11}	-[a]	-	-	-	-	-	-	-
r_{12}	3935	4081	2	2	2	3819	3124	2
r_{21}	3972	4094	2	2	2	3831	2	2
r_{22}	-	-	-		-	-	-	-

Note: Larger effective sample sizes are evidence in favor of model convergence.
[a] r_{ii} has no value (-) because r_{ii} is fixed to one.