Bayesian Matrix Determinant Test for Bertrand Competitors: An Application Examining the International Beef Market

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Introduction

The question of whether the international agricultural market is price or quantity competitive is an important issue because, depending on the type of competition, the market can be characterized as an imperfectly competitive market that reduces social welfare and changes the status of food provision. The characteristic of competition between exporters is closely associated with the variable to compete. By the category of products and the environment of the international agricultural market, the key variable of competition may vary. Major export countries control a decision variable to compete with other major exporters. The international agricultural market can be characterized by differentiated products from various export countries and unique demands from import countries' importing policies and consumers. Bertrand, Cournot, and Stackelberg models are well-known to describe the different characteristics of imperfect competition. Once the key variable for the competition is revealed, market managers such as the authority of the export and import country can make better policies to control demand and supply to reduce the loss of social welfare.

Since Gasmi et al. (1992) provided a methodology to determine whether the market is price or quantity competitive, some studies have followed the method and provided pieces of evidence to capture the character of competition. However, these studies did not provide information for how much the market is competitive. That is, researchers are available to specify the type of game played, they would not be able to know the level of competitiveness on the market. If one study concludes that the structure of the market to analysis is Bertrand type competitive, the degree of competition may be very small, which can weaken the conclusion of the study significantly. The degree of competition in the international agricultural market has been widely considered in the field of agricultural economics. New empirical industrial organization (NEIO) is a well-known tool to measure the degree of market power and the extent to which how much market is competitive, using the concept of conjectural elasticity. As Carter and Maclaren (1997) mentioned, NEIO approach has drawbacks in that it does not reveal the nature of the game being played and it ignores differentiated products of each game player. The conjectural elasticity of NEIO does little to inform the intensity of interaction between firms (producers, retailers, or exporters) wielding market power. This is because many NEIO studies simply assume commodity homogeneity and a number of identical firms competing with each other in terms of quantity. These assumptions are typically made because of data limitations.

In this paper, we provide a new method to capture the nature of competition between major exporters as well as to measure the extent to which how much the major exporters aware of each other in the international beef market. As an illustration, we propose a novel index that characterizes the intensity of firm interaction and competition under Bertrand, Cournot, Cartel, and Stackelberg (BCCS) assumptions. This rivalry index compensates for the drawback of the NEIO framework by quantifying the intensity of interaction between market participants, including firms or exporters. Major export countries control their decision variable to compete with other major exporters under different assumptions. The rivalry index is derived from best response functions, with a focus on the relative intensity of interaction between market participants and conditioned on an assumed BCCS structure. Similar to the conjectural elasticity of NEIO, the proposed rivalry index is bounded between 0 and 1, with 0 indicating the absence of BCCS behavior and 1 indicating strong BCCS collusion or reaction and a rival's response to changes in price and quantity.

The international beef market is expected to be concentrated, which may yield imperfect competition throughout the world. In the international bovine meat market (HS codes: 20110, 20120, 20130, 20210, 20220, 20230), major beef exporting countries account for over 50% of the total traded value. Specifically, the shares of the top five exporters: India, Brazil, the United States, Argentina, and Australia are 18.9%, 13.0%, 9.6%, 9.2%, and 9.1% in 2018 respectively (CEPII database). The empirical example of this paper focuses on two major beef exporters; the United States, and Australia (including New Zealand); and two importers, South Korea and Japan. The share of the United States accounts for 52% and 44% of the 2018 exported beef markets in South Korea and Japan respectively. Likewise, Australia accounts for 44% and 49% of beef imports in South Korea and Japan. Both northeast Asian countries are major international beef markets as they ranked in the top six beef import countries all around the world. The values of importing of South Korea and Japan account for respectively 513,324 and 744,038 thousand US dollars in the international beef market. Moreover, they have similar preferences for imported beef products in that they share similar cultures in food and taste. These indicate that the two major import countries are ideal markets to verify the method we suggest and measure the rivalry indices by the various competition types respectively.

Bayesian estimation methods

As estimation methods, Bayesian estimation procedures are used to recover the best response parameters. The rivalry index is derived from the own price or quantity elasticity of one exporter's demand function and the corresponding elasticity of its rival exporters. To measure accurate rivalry indices, statistically significant parameters and appropriate signs of them are important. The previous studies that determined the nature of competition used the frequentist (maximum likelihood) estimation approach. One problem of the previous studies is that some parameters return incorrect signs against the economic theory. For example, the signs of own price elasticities in demand function sometimes are positive. When it comes to imposing sign restrictions on the parameters to estimate, the estimation results return a corner solution that gives zero-valued parameters. Bayesian estimation procedures are more flexible and help overcome this issue by using informative priors for parameters, constraints, and their distributions (Poirier 1995; O'Donnell et al. 2007). The priors used in this paper include information pertaining to the expected sign of parameters. Additional information from the prior distributions should improve the estimation of the model of this study.

Review of Literature

The issues for imperfect competition in the international market have been widely studied. To test the existence of imperfect competition and market power, largely there are three types of categories (Reimer and Stiegert 2006). Pricing-to-market method is one of the testing methods, which analyzes price discrimination in international trade (Krugman 1987; Knetter 1989). The price discrimination occurs when exporters make pricing decisions considering bilateral exchange rate change, which indicates the presence of market power in the international market. Although this method demands fewer data to estimate, it does not reveal the degree of market power and type of game played by exporters.

NEIO approach has also been used to detect market power in international agricultural markets. Early NEIO studies include Karp and Perloff (1989, 1993) and Buschena and Perloff (1991). Their researches measured conjectural variations to measure market competitiveness in international markets assuming the one homogeneous trade good and quantity competitive markets. Goldberg and Knetter (1999) developed a model that measures market power from the elasticity of residual demand function. If there exists significant market power in the market, the elasticity is a non-zero value, indicating the steeper the residual demand curve with more severe market power. They applied the model to the international market of German beer and US liner board paper, and detected market powers that are consistent with other market competition indicators such as market share and the number of firms competing with each other. Reed and Saghaian (2004) used the residual elasticity model of Goldberg and Knetter (1999) and measured market power in the Japanese imported beef market. They estimated residual demands of four major beef exporters: US, Canada, Australia, and New Zealand, and found the highest degree of market power for US, moderate market power for Australia and New Zealand due to the advantage of the location to export, and limited market power for Canada. One of the major limitations of NEIO studies is that the conjectural variation only provides information about the degree of market power under imperfectly competitive quantity setting behavior of market participants but little else in the way of information for identifying the type of competition in which market participants engage.

To address the limitation of NEIO, Carter and MacLaren (1997) followed the menu approach of Gasmi et al. (1992) to identify the ‘best fitting’ market structure for the Japanese exported beef market. Assuming that beef products from US and Australia are differentiated as US and Australian beef products represent grain-fed (high quality) and grass-fed (low quality) respectively, two different demand functions were applied for the differentiated beef products. They tested a series of non-nested hypotheses based on a likelihood ratio (LR) test developed by Vuong (1989). Among the different non-cooperative market structures (Bertrand, Cournot, and price and quantity Stackelberg), they concluded that the Stackelberg model guided by Australia’s price-setting was the best fitting model and most aptly described the trade market. Asgari and Saghaian (2013) applied Carter and MacLaren (1997)’s menu approach and found that the Japanese Pistachio import market was Stackelberg led by the United States’ quantity setting. As mentioned above, some studies identified the best fitting market structure but, few studies measured conjectural variations under the various market structures. This research uses a menu approach to characterize various international market structures under Bertrand, Cournot, Cartel, and Stackelberg (BCCS) assumptions.

The Model

The matrix determinant test is a novel method for measuring the degree of rivalry under Bertrand, Cournot, Cartel, and Stackelberg (BCCS) market assumptions. The approach is easily extended to price or quantity competition with multiple traded goods, firms, or exporters. This research focuses on traded goods, specifically beef, and exporters. Assuming each game player competing for each other for the same category of product, the traded goods of the game players are differentiated and substitutions each other. Let $i, j \in \{1, 2\}$ index two firms for the simplicity of deriving equations.

Price Competition

Under the price competition assumption, export demand for i th export country is:

$$\ll \text{Insert equation here} \gg \quad (1)$$

where q_i is exporter i's demanded quantity, p_i is price; j indexes i's potential rivals; $\beta_{ii} \leq 0$; and $\beta_{ij} \geq 0$ as the rival j's good is a substitute of exporter i's good, $income_i$ is the import country's GDP per capita with its parameter, $\gamma_i \geq 0$, and d_{k-1} is the dummy variable indicating $k-1$ th import country. The exporters' profit function is:

$$\ll \text{Insert equation here} \gg \quad (2)$$

where c_i is the i th exporter's marginal cost function that includes the distance ($distance_i$) between the exporter and its importers, corn price ($cornp_i$), and real interest rate

($interest_i$) that adjusts for inflation as measured by the GDP deflator, and their corresponding parameters are bounded as $\eta_i, \tau_i, \upsilon_i \geq 0$;. Under Bertrand (BE) and Pricing Stackelberg (PL: Price Leader; PF: Price Follower), the first order conditions (FOC) for profit maximizing exporters are, respectively:

Bertrand: ≪ Insert equation here ≫ (3)

Stackelberg Price Leader: ≪ Insert equation here ≫

Stackelberg Price Follower: ≪ Insert equation here ≫

where $p_j(p_i)$ is Stackelberg price leader i's reaction to its follower j's pricing strategy. On the other hand, the Bertrand game players and Stackelberg price follower's FOC does not include their rival's reaction, which means that they do not consider their rivals' pricing behavior $\left(\frac{\partial p_j}{\partial p_i} = 0\right)$ when they determine their price levels.

Exporter i's corresponding best response function derived from the FOCs above are, respectively:

Bertrand: ≪ Insert equation here ≫ (4)

Stackelberg Price Leader: ≪ Insert equation here ≫

Stackelberg Price Follower: ≪ Insert equation here ≫

where the price leader knows its followers' reaction as $\frac{\partial p_j}{\partial p_i} = -\frac{\beta_{ij}}{2\beta_{jj}}$.

When exporters collude with each other under a price setting Cartel assumption, the Cartel profit function is:

≪ Insert equation here ≫

Under Price Cartel (PT) price-setting assumption, the first order conditions (FOC) for profit maximizing exporters are:

Price Cartel: ≪ Insert equation here ≫

The FOC condition of the Cartel is more complicated compared with the previous conditions because it includes all Cartel members' profits. A Cartel member's best response function includes the other members' price and marginal cost terms:

Price Cartel: ≪ Insert equation here ≫

Finally, differentiating each of the best response functions (BR_i) above with respect to price, the degree of bilateral price responses under BCCS assumptions are:

≪ Insert equation here ≫

Exporters in price competitive markets adjust prices downward when prices exceed the Nash equilibrium price (p_i^*). Simultaneously considering all price responses of exporters, a small change can trigger knock-on effects throughout the entire market. Figure 1 shows how the system of price competition works. The slope of the j th best response function (BR_j) indicates the price response of j th exporter $\left(\frac{\partial p_j}{\partial p_i}\right)$. A price reduction by one exporter affects all other exporter prices, including its own price. All exporters eventually adjust their prices to equal the Nash equilibria (NE). If there are vague price responses of exporters $\left(\frac{\partial p_j}{\partial p_i} \approx 0\right)$, then the market is not Bertrand price competitive market because the j th exporter does not make any price adjustments, given a price change of its rival. Multilateral price response is therefore a proxy for the degree of price competitive market power. Considering two exporters, the derivatives of the exporters' best responses (r_{ij}) with respect to prices enter the matrix:

$$\ll \text{Insert equation here} \gg \quad (5)$$

The response matrix of the Bertrand (BE) assumption is for example:

$$\ll \text{Insert equation here} \gg$$

The off-diagonal elements under the Bertrand assumption are $r_{ij} \geq 0$ because $\beta_{ij} \geq 0$ and $\beta_{ii} \leq 0$. Note that $-\infty < \det(\mathbf{R}) \leq 1$ because $0 \leq r_{ij}$ and $r_{ii} = 1$ when $r_{ij} = 0$ (no Bertrand price competition), then $\det(\mathbf{R})$ = 1. The rivalry index (θ) is calculated as:

$$\ll \text{Insert equation here} \gg \quad (6)$$

which bounds the degree of price competition on $0 < \theta \leq 1$. Bertrand price competition dissipates as $\theta \to 0$. On the other hand, Bertrand price competition intensifies as $\theta \to 1$. The Cartel case follows the same procedure to derive the rivalry index.

However, the degree of rivalry for the price Stackelberg case is derived from the absolute value of the exporter leader' best responses (r_{ij}) because r_{ij} is unbounded $\left(-\infty \leq r_{ij} \leq \infty\right)$. The denominator ($4\beta_{jj}\beta_{ii} - \beta_{ij}\beta_{ji}$) of the leader's r_{ij} is the key to determine the sign of the leader's reaction. The determinant $|\det(\mathbf{R})|$ in the price Stackelberg case is calculated as:

$$\ll \text{Insert equation here} \gg$$

where r_{ij} and r_{ji} is the price leader's and follower's reaction respectively. The rival index (θ) in the price Stackelberg competition is calculated in the same way as the other cases, and it bounds $0 < \theta \leq 1$ like the other cases. But, the interpretation of the Stackelberg rival index is different.

In the theory of Stackelberg competition, the leader sets its price level, then the followers comply with the price level set by the leader, indicating that the level of the price responses is very restrictive. In contrast with Bertrand and price Cartel, price Stackelberg competition dissipates as $\theta \to 1$ and intensifies as $\theta \to 0$.

Quantity Competition

Using the same logic and under the quantity competition market assumption, export demand for the i th exporter's beef is:

≪ Insert equation here ≫ (7)

where; $\beta_{ii} \leq 0$; and $\beta_{ij} \geq 0$ as q_i and q_j are substitutional relation[1]. The exporters' profit function is:

≪ Insert equation here ≫ (8)

When exporters collude under the quantity setting Cartel assumption, the Cartel's profit function is:

≪ Insert equation here ≫

Under Cournot (CN), Quantity Stackelberg (QL: Quantity Leader; QF: Quantity Follower), and Quantity setting Cartel (QT) price-setting behavior, the first order conditions (FOC) maximizing the exporter profit are, respectively:

Cournot: ≪ Insert equation here ≫ (9)

[1] We assume that although q_i and q_j are differentiated goods, they belong to total demanded imported beef: $Q = q_i + q_j$, meaning q_i and q_j are substitutes. As the game player i and j compete each other, increase of q_j increases Q and consequently p_i decreases.

Stackelberg Quantity Leader: ≪ Insert equation here ≫

Stackelberg Quantity Follower: ≪ Insert equation here ≫

Quantity Cartel: ≪ Insert equation here ≫

The corresponding best response function derived from the FOCs above are, respectively:

Cournot: ≪ Insert equation here ≫ (10)

Stackelberg Quantity Leader: ≪ Insert equation here ≫

Stackelberg Quantity Follower: ≪ Insert equation here ≫

Quantity Cartel: ≪ Insert equation here ≫

The degree of bilateral quantity responses under the different assumptions are:

≪ Insert equation here ≫

The structure of the best response functions for quantity setting exporters differs from those under price, but the structure of bilateral responses is the same. By the same logic under price competition, the quantity reaction matrix is:

≪ Insert equation here ≫ (11)

where $\frac{\partial q_i}{\partial q_i} = 1$ and the characteristic of $\det(\mathbf{R})$ and the rivalry index of market competitiveness θ is similarly calculated for Cournot competition and quantity Cartel. Unlike with the price competition cases, the quantity response (r_{ij}) of exporters in Cournot and quantity Cartel are negative values ($r_{ij} \leq 0$) because $\beta_{ij} \leq 0$ and $\beta_{ii} \leq 0$. Exporters in quantity competitive market adjust their supply quantities to the Nash equilibrium quantities (q_i^*) similar to the price competitive cases (Figure 2). In the quantity competitive market, the slopes of the best response functions are negative values as the exporters compete with each other to take the total demanded quantity in the market. Expanding one exporter's share leads to shrinking other exporters' shares in the market. The rivalry index for the quantity Stackelberg is similarly calculated with the case of the price Stackelberg above, but the response of the quantity leader should be a negative value to offset the negative sign of the quantity follower's response. By adding a negative sign to the absolute value of the leader's response, the determinant for quantity Stackelberg is calculated as:

≪ Insert equation here ≫

where r_{ij} and r_{ji} is the quantity leader's and follower's reaction respectively. The rival index (θ) in quantity is similarly calculated and interpreted with the price Stackelberg competition.

The Hypothesis Test for the Rivalry Index

The degree of rivalry derived from the rivalry matrix is testable using a parametric test method. The tests for the rivalry index (θ) of Bertrand, Cournot, Cartels, and Stackelberg (BCCS) use the exponential distribution. θ is the exact same value of the cumulative exponential distribution function regarding with $1 - \det(\mathbf{R})$ and the parameter of distribution, $\lambda = 1$ where $1 - \det(\mathbf{R}) \geq 0$.

≪ Insert equation here ≫

Figure 3 shows the graphs for PDF and CDF of the exponential distribution for $1 - \det(\mathbf{R})$. Specifically, the hypothesis test statistically tests either $\theta = 0$ or $\theta > 0$.

≪ Insert equation here ≫

The null hypothesis (H_0) is that there is no interaction between exporters in the market, meaning there is no evidence for imperfectly competitive market pertaining to Bertrand, Cournot, Stackelberg, or Cartel structure. The alternative hypothesis (H_1) is that there is evidence for imperfect competition in the market. The critical value to reject the null hypothesis relies on the value of θ. Greater θ ensures rejecting the null hypothesis with lower possibility for occurring the type I error. This paper sets the critical value to 0.63 because this is the case when $\det(\mathbf{R}) = 0$, indicating the interactions of exporters are vigorous in that the multiplication of off-diagonal elements of the rivalry matrix is one ($r_{ij} \cdot r_{ji} = 1$). Figure 3 illustrates the PDF and CDF for the hypothesis test for the rivalry index.

Model Comparison

To select the best fitting model among BCCS assumptions, two predictive criteria are applied to conduct model comparison procedure. Widely applicable information criterion (WAIC) is one of information criteria approach to evaluate the predictive accuracy of multiple models by estimating the out-of-sample deviance (McElreath 2020). WAIC is calculated by log-posterior-predictive density (lppd) with the subtraction of a penalty proportional to the variance in the posterior predictions (prediction penalty term, p_{WAIC})

$$\ll \text{Insert equation here} \gg$$

where y_i is i th observed data, and θ_s is s th set of sampled parameter values in the posterior distribution. The weight of WAIC is the ratio of the difference of WAIC values between model i and the best value of WAIC in the set of models. The weight of the model is a proxy of the extent to which how much is the fitness of each model, and the sum of weight is 1 ($\sum_i w_i = 1$). Higher weight indicates better model fitness comparing with other models.

≪ Insert equation here ≫

The other for model comparison is Bayes factor (BF) that compares the ratio of the marginal likelihood of data given in models by:

≪ Insert equation here ≫

where H is hypothesis that pertains certain model structure such as Bertrand or Cournot, θ is the parameters in hypothesis H, and $p(y|\mathrm{H})$ is the marginal likelihood that is the probability of the observed data under the hypothesis. When BF is over than 1, then the interpretation is that there is evidence to prefer hypothesis 1 (H_1) over H_0. If BF is less than 0, then H_0 is preferred than H_1. Using the weight of WAIC and Bayes factor, this paper compares models under BCCS assumptions.

Data

This paper uses international trade data for bovine animal meat and is from the Centre d'Etudes Prospectives et d Informations Internationales (CEPII) database. Yearly data were used from 1995 to 2018. The export quantity and prices of the major beef exporters (the U.S., Australia, and New Zealand) by the import country are from the CEPII database. This paper considers two import countries: South Korea and Japan, but the data of the two countries are aggregated into one demand function per exporter: the United States and Australia. For simplicity of the model, the export quantity of New Zealand is included in Australia and the price of Australia is derived from the weighted average with Zealand in terms of export value. The cost-shifting variables related to the marginal cost of exporting are from various sources. The exporters' real interest rates are from the World Bank. The distances between an exporter and an importer are from www.distancefromto.net. Exporters' real domestic maize prices are from the Food and Agriculture Organization of the United Nations (FAO). Table 1 reports the descriptive statistics about the data used for this study.

Empirical Procedures

This paper uses R-Stan's Hamiltonian Monte Carlo No U-turn Sampler (HMC-NUTS) to generate posterior distributions of model parameters. The HMC-NUTS performance is superior to Gibbs or Metropolis-Hastings samplers in terms of the number of iterations required for convergence. A Bayesian instrument variable (IV) approach is used to recover the parameters to consider the endogenous variables such as prices and quantities of inputs and output. The system of equations is:

$$\ll \text{Insert equation here} \gg$$

where **Y** is a vector of the left-hand side variables the determinant test (Equation 12); $\boldsymbol{\mu}$ is a mean response vector (Equations 1 and 4 for price competition, and Equations 7 and 10 for quantity competition).; $\boldsymbol{\tau}$ is a vector of standard deviations, and $\boldsymbol{\Omega}$ is a correlation matrix that follows Lewandowski-Kurowicka-Joe (LKJ) distribution (Lewandowski, Kurowicka, and Joe, 2009).

$$\ll \text{Insert equation here} \gg \quad (12)$$

The mean vector $\boldsymbol{\mu}$ of the determinant test model includes the exporters' demand and the corresponding best response functions under BCCS assumptions. Pre- and post-multiplication of these parameters yield a positive-definite covariance matrix. Based on the economic theory at the model part above, the model parameter's priors are:

$\ll \text{Insert equation here} \gg$In practice, R-Stan 2.21.1 version was used to recover the parameter posteriors under IV structure, and practical Markov chain Monte Carlo (MCMC) algorithms include four chains with 20,000 iterations and 10,000 warm-up samples for the adaptation phase.

Results

Table 2 reports the descriptive statistics for the posterior of parameters for each model. The signs of all parameters were estimated as expected. All own quantity (β_{ii}) or price elasticities show negative signs, and cross elasticities (β_{ji}) shows negative signs for quantity competition and positive signs for price competition. All signs for the parameters related to cost function are positive under the economic theory illustrated at the model section. For the Markov chain Monte Carlo diagnostics, we used trace plots, potential scale reduction ($\hat{R}$), and the number of effective (N_{eff}). Without Stackelberg models, all models including Bertrand, Cournot, and Cartel provided strong evidence of convergence for all parameters. All parameters for Bertrand, Cournot, and Cartel models reported $\hat{R} < 1.01$ and enough number of N_{eff} ($N_{\text{eff}} > 10{,}000$). In the case of Stackelberg models, parameter posteriors show unreliable results as their standard deviations are high, $\hat{R} > 1.01$, and $N_{\text{eff}} < 10{,}000$, implying that the Stackelberg models failed to converge.

For model comparison, Table 3 reports the value of WAIC and the WAIC weight of models. WAIC suggests that price Cartel model is better than other models to fit the international beef market in South Korea and Japan. The other models have no weight, meaning they are not appropriate to explain the market structure. Table 4 shows the result of Bayes factors for each model comparison. The Bayes factors indicate that Bertrand and price Cartel models are the best preferred model compared with the other models. To sum up, both predictive criteria suggest that Bertrand or price Cartel are the best fitting models.

The estimation results for the rivalry matrix (**R**) and the rivalry index are reported at Table 5. The rivalry matrix for each model was recovered from the posteriors of parameters reported in Table 2 following Equation 5 and 11. By the same procedure, the rivalry index (θ) was also recovered from the posterior distribution for the determinant of the rivalry matrix. P-value in Table 5 is the criterion to reject the null hypothesis that there is no interaction between exporters in the market. The diagonal elements (r_{ii}) of the rivalry matrix are fixed to one with zero standard deviation as own elasticity of own price or quantity are always one ($r_{ii} = 1$).

The mean values of the rivalry indexes' posterior distribution (θ) under Cournot, quantity Cartel, US and Australia quantity Stackelberg leaders, Bertrand, price Cartel, and US and Australia price Stackelberg leaders are, respectively 0.475, 0.000, 0.209, 0.201, 0.000, 0.003, 0.159, and 0.159, indicating that the exporters considered are sluggish price competitors under Bertrand and price Cartel assumptions, but vigorous rivals in terms of quantity under Cournot. The P-values for all models are not enough to reject the null hypothesis that there is no interaction between exporters. This concludes that under the Bertrand, Cournot, Cartel, and Stackelberg assumptions, there is no significant competition and rivalry in the international beef market at South Korea and Japan. Considering the results of the model comparison, the rivalry test in this study indicates that the market is characterized by price competitive market, however, the degree of competition and rivalry is very limited.

Conclusion

This paper is to answer the question of whether the international agricultural market is price or quantity competitive and how much the degree of rivalry between major exporters is. We developed a new method to capture the nature of competition between exporters and to measure the degree of the rivalry of the exporters under Bertrand, Cournot, Cartel, and

Stackelberg assumptions. The empirical example of this paper focuses on two major beef exporters; the United States and Australia (including New Zealand); and two importers, South Korea and Japan. Bayesian estimation procedures are used to recover best response parameters.

The model comparison suggests that the market condition fits price competitive cases including price Cartel or Bertrand. However, the degree of rivalry index is too vague to confirm that there are significant competitive interactions between US and Australia; the value of the rivalry index (θ) is not enough to reject the null hypothesis that assumes no interaction between exporters. This result concludes that the international beef markets in South Korea and Japan are price competitive but not significant. The expected reason for this is that trade barriers such as high rate tariff and safeguard hinder fostering the competitive market condition. This study used 24 yearly data (1995 – 2018) for analysis. At that timeline, the impacts of free trade agreements and other economic partnerships such as comprehensive and progressive agreement for trans-pacific partnership (CPTPP) are restrictive. In 2018, there were still high rates of tariff for imported beef products (chilled and frozen) from the United States and Australia; 21.3% and 26.6% for US and Australia to South Korea respectively; 38.5% and 27.5% for US and Australia to Japan. Exporters decide pricing or quantity adjustment under very restrictive conditions. Import countries relax the regulations or trade barriers for imported beef products when they want to adjust price levels. For example, South Korea expanded the quantity of imported beef temporarily when the foot-and-mouth diseases occurred in Korea. Nevertheless, free trade agreements and other economic partnerships will make the international beef market more competitive eventually. Exporters can make decisions for adjusting their price and quantity under the relaxed trade barriers. As time passed, the high rate tariff will disappear with other regulations for imported beef products; In South Korea, no tariff for US and Australia beef products in 2027. When the free trade agreement works fully (no tariff for imported beef), there will be significant price competitive behaviors of exporters at the international beef market South Korea and Japan).

Further research will evaluate the rivalry index for updated data containing free trade market conditions. Lower rates of tariff and relaxed trade regulations will show high values of the rivalry index (θ) under the BCCS assumptions. The rivalry index can be widely applied to other international markets with various agricultural products, exporters, and importers.

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Table 1. Descriptive Statistics

Variable	Unit	Mean	Standard Deviation	Minimum	Maximum	Number of Observations
U.S. GDP Deflator	2015=100	86.204	11.434	105.417	68.688	48
GDP	U.S. dollars per capita	29290	10923	48633	8282	48
US Real Price	Thousands current USD /metric tons	4.747	1.295	7.294	2.501	48
US Quantity	Metric tons	156,976	117,515	483,050	76	48
US Real Interest Rate	%	3.608	2.039	7.148	1.137	48
US Distance to import countries	Km	10458	285	10743	10173	48
US Real Domestic Maize Price	U.S. Dollars /ton	223.143	90.504	464.570	123.430	48
Australia[a] Real Price	Thousands current USD /metric tons	3.725	1.201	5.866	1.637	48
Australia Quantity	Metric tons	229,230	116,255	439,067	38,948	48
Australia Real Interest Rate	%	4.328	1.867	8.057	0.970	48
Australia Distance to import countries	Km	6842	10	6852	6832	48
Australia Real Domestic Maize Price	U.S. Dollars /ton	247.268	85.683	361.190	83.580	48

[a] The export quantity of New Zealand is included in Australia and the price of Australia is derived from the weighted average with Zealand in terms of export value.

Table 2. Posterior Mean and (Standard Deviation) for the Model Parameters

Parameter (1 = US; 2 = Au.)	Quantity Competition				Price Competition			
	Cournot	Quantity Cartel	US Quantity Leader	Australia Quantity Leader	Bertrand	Price Cartel	US Price Leader	Australia Price Leader
α_1	6.751	3.098	6.749	17.480	0.034	-0.046	0.012	0.051
	(1.704)	(1.519)	(2.961)	(20.563)	(10.027)	(9.901)	(9.915)	(10.031)
β_{11}	-3.05E-05	-3.02E-05	-2.79E-05	-3.05E-05	-166.445	-166.100	-124.922	-155.340
	(7.00E-07)	(6.64E-07)	(1.11E-05)	(8.00E-07)	(5.968)	(5.952)	(72.120)	(20.007)
β_{21}	-2.97E-05	-7.40E-09	-3.49E-05	-7.31E-05	8.975	14.944	49.324	50.324
	(4.50E-06)	(7.40E-09)	(2.62E-05)	(9.08E-05)	(6.438)	(8.451)	(71.274)	(73.244)
γ_1	3.25E-04	1.87E-04	3.55E-04	2.81E-04	4.562	4.562	0.276	0.138
	(3.99E-05)	(3.20E-05)	(1.31E-04)	(5.59E-05)	(0.033)	(0.033)	(10.005)	(10.004)
δ_1	-1.768	1.141	-2.189	-0.433	0.306	0.319	4.551	4.544
	(1.199)	(1.045)	(2.804)	(1.701)	(9.901)	(10.041)	(0.039)	(0.046)
α_2	5.671	4.179	5.982	4.877	-1.286	-1.265	-1.275	-1.186
	(1.271)	(0.870)	(3.118)	(3.555)	(9.967)	(10.101)	(9.978)	(9.983)
β_{22}	-1.27E-05	-1.26E-05	-1.27E-05	-1.58E-05	-201.217	-201.248	-188.457	-151.058
	(2.00E-07)	(1.58E-07)	(2.00E-07)	(1.00E-05)	(6.166)	(6.114)	(22.866)	(87.146)
β_{12}	-3.45E-05	-2.41E-08	-1.39E-05	-8.70E-05	4.181	3.695	45.307	46.379
	(7.20E-06)	(2.42E-08)	(1.82E-05)	(1.45E-04)	(3.709)	(3.338)	(72.152)	(74.215)
γ_2	2.23E-04	1.23E-04	1.25E-04	4.62E-04	6.951	6.951	-3.821	-3.793
	(3.28E-05)	(1.83E-05)	(2.77E-05)	(5.70E-04)	(0.021)	(0.021)	(9.922)	(10.003)
δ_2	-1.754	-2.369	-1.763	0.613	-3.986	-4.042	6.939	6.940
	(0.855)	(0.601)	(1.078)	(5.898)	(9.954)	(9.989)	(0.029)	(0.028)
η_1	6.00E-07	5.90E-07	4.44E-04	6.00E-07	3.09E-04	2.83E-04	0.015	2.94E-04
	(6.00E-07)	(5.94E-07)	(7.70E-04)	(6.00E-07)	(1.77E-04)	(1.75E-04)	(0.025)	(2.04E-04)
τ_1	0.004	0.004	0.003	0.004	0.002	0.002	0.499	0.004
	(3.90E-04)	(3.71E-04)	(0.002)	(4.69E-04)	(0.002)	(0.002)	(0.884)	(0.007)
υ_1	5.67E-04	5.84E-04	0.300	5.56E-04	0.400	0.432	2.840	0.492
	(5.64E-04)	(5.86E-04)	(0.522)	(5.63E-04)	(0.101)	(0.107)	(5.277)	(0.416)
η_2	7.60E-06	6.89E-06	5.50E-06	0.010	3.37E-04	3.18E-04	3.63E-04	0.042
	(6.00E-06)	(5.62E-06)	(5.20E-06)	(0.018)	(3.31E-04)	(3.12E-04)	(3.66E-04)	(0.074)
τ_2	0.004	0.004	0.004	0.004	0.001	0.001	0.004	0.247
	(1.46E-04)	(1.43E-04)	(1.44E-04)	(0.001)	(0.001)	(0.001)	(0.007)	(0.474)
υ_2	0.046	0.044	0.041	0.042	0.076	0.075	0.230	3.440
	(0.007)	(0.007)	(0.009)	(0.018)	(0.067)	(0.065)	(0.444)	(6.962)

Note: All parameters for Cournot, Bertrand, Quantity and Price Cartels verify $\hat{R} < 1.01$ and show appropriate trace plots, meaning the models are converged well. However, all Stackelberg models fail to be converged properly. Cross elasticity parameters β_{ji} in Stackelberg models show $\hat{R} > 1.01$.

Table 3. Model Comparison: WAIC

Model	WAIC	se[a](WAIC)	ΔWAIC_i	$\text{se}(\Delta\text{WAIC}_i)$	p_{WAIC}	w_i
Price Cartel	17102.8	2141.66	0	-	673	0.999
Bertrand	17119.5	2145.16	16.6	11.38	677.5	2.49E-04
US Price Leader	18073	2190.15	970.2	126.08	1140.9	2.11E-211
Australia Price Leader	18244.9	2199.89	1142	208.32	1226.1	1.04E-248
Cournot	20061.2	2626.14	2958.3	1711.94	1135.7	0
Quantity Cartel	20125.8	2630.54	3023	1716.56	1129.7	0
US Quantity Leader	98090.8	28563.3	80987.9	27948.46	41262.4	0
Australia Quantity Leader	173641.9	30054.37	156539.1	30855.06	79105.7	0

[a] Standard error of WAIC

Table 4. Model Comparison: Bayes Factor (BF_{10}^{a})

H_0 \ H_1	Cournot	Quantity Cartel	US Quantity Leader	Australia Quantity Leader	Bertrand	Price Cartel	US Price Leader	Australia Price Leader
Cournot	1	0.000	0.0000	-[b]	> 999	> 999	> 999	> 999
Quantity Cartel	> 999	1	> 999	-	> 999	> 999	> 999	> 999
US Quantity Leader	> 999	0.000	1	-	> 999	> 999	> 999	> 999
Australia Quantity Leader	-	-	-	-	-	-	-	-
Bertrand	0.000	0.000	0.000	-	1	0.543	0.000	0.000
Price Cartel	0.000	0.000	0.000	-	1.840	1	0.000	0.000
US Price Leader	0.000	0.000	0.000	-	> 999	> 999	1	> 999
Australia Price Leader	0.000	0.000	0.000	-	> 999	> 999	0.000	1

[a] The column the numerator and the row is the denominator at the Bayes factors $\left(BF_{10} = \frac{p(y|H_1)}{p(y|H_0)}\right)$, and BF > 1 indicates that H1 is preferred over H0.

[b] The Bayes factors for the case of Australia price leader are omitted because the model was not converged well, thus calculating marginal likelihood of the model was unavailable.

Table 5. Posterior Mean and (Standard Deviation) for the Matrix Determinant Test

Parameter (1=US; 2=Au.)	Cournot	Quantity Cartel	US Quantity Leader	Australia Quantity Leader	Bertrand	Price Cartel	US Price Leader	Australia Price Leader
θ	0.475	1.10E-06	0.209	0.201	2.81E-04	0.003	0.159	0.159
	(0.039)	(2.00E-06)	(0.291)	(0.260)	(3.70E-04)	(0.003)	(0.275)	(0.275)
P-value[a]	0.525	0.999	0.791	0.799	0.999	0.997	0.841	0.841
$\|\mathbf{R}\|$	0.354	0.999	0.650	0.699	0.999	0.997	0.748	0.748
	(0.074)	(2.00E-06)	(0.553)	(0.428)	(3.70E-04)	(0.003)	(0.436)	(0.436)
r_{11}	1	1	1	1	1	1	1	1
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
r_{12}	-1.364	-0.001	-0.538	-0.201	0.010	0.046	0.149	0.355
	(0.283)	(-0.001)	(0.696)	(0.142)	(0.009)	(0.023)	(0.242)	(0.600)
r_{21}	-0.487	-5.23E-04	-0.444	-1.178	0.027	0.056	0.464	0.200
	(0.077)	(4.20E-04)	(0.259)	(1.448)	(0.019)	(0.028)	(0.761)	(0.304)
r_{22}	1	1	1	1	1	1	1	1
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)

[a] The critical P-value to reject the null hypothesis that there is no interaction between game players is 0.37.

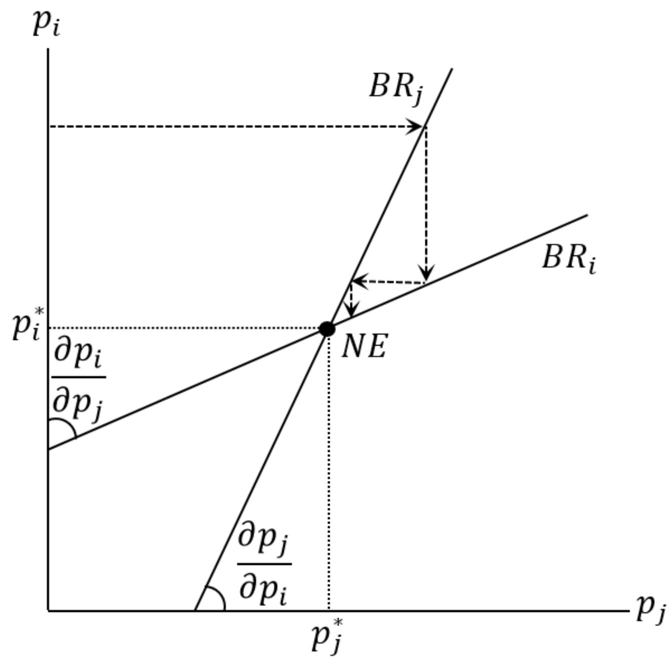

Figure 1. Price Competition for Two Game Players

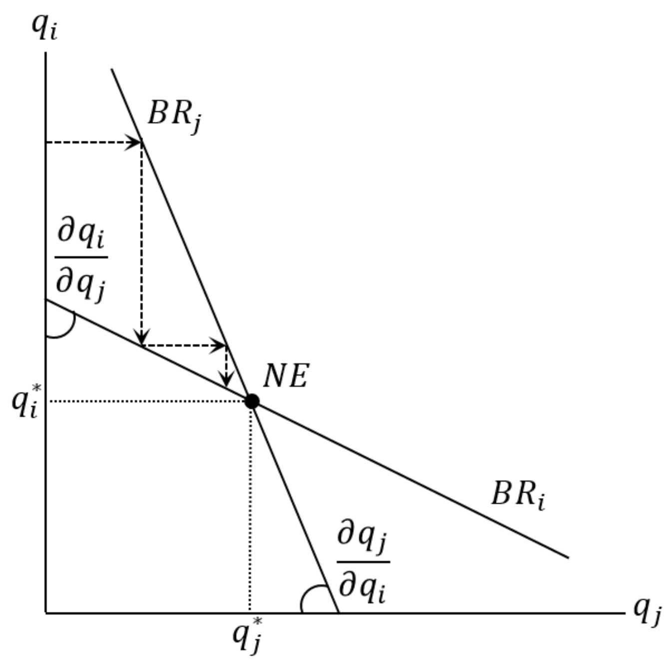

Figure 2. Quantity Competition for Two Game Players

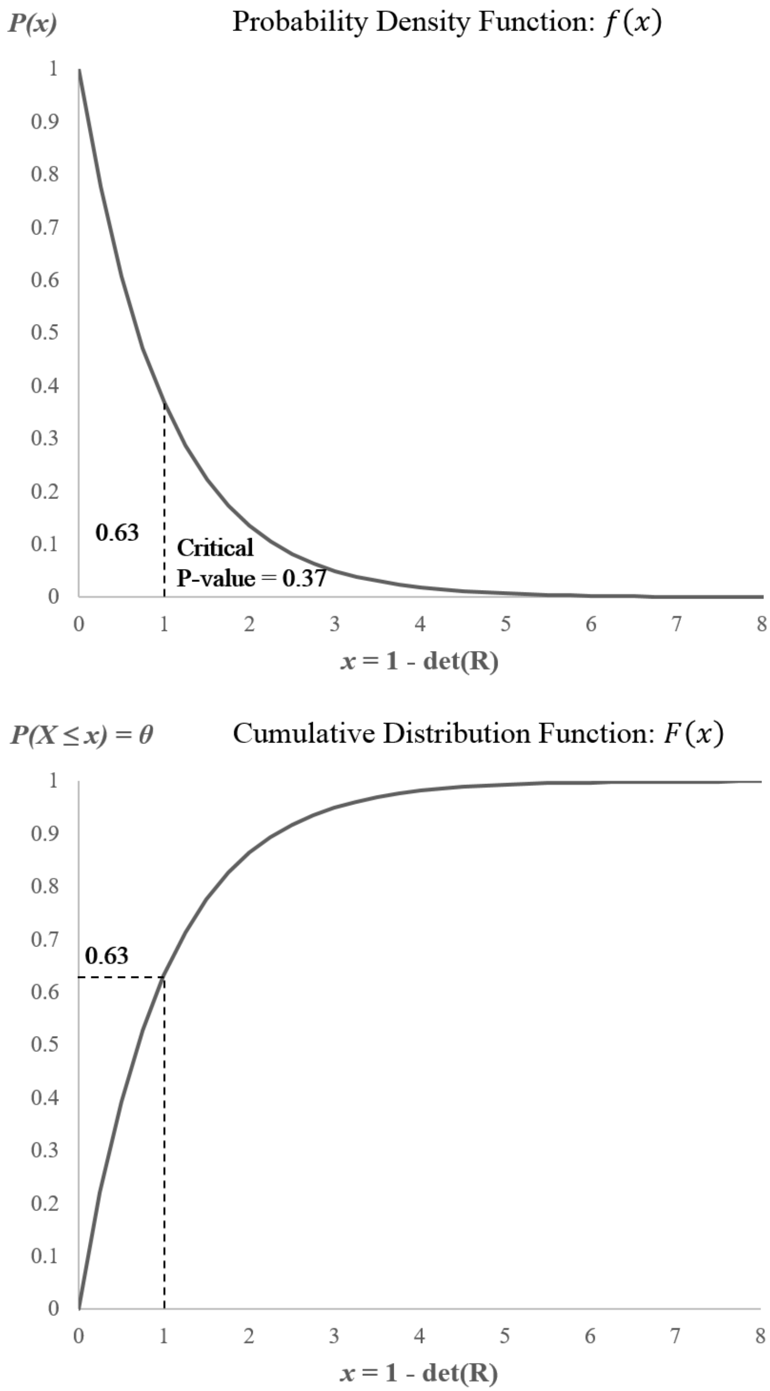

Figure 3. Hypothesis Test for the Rivalry Index