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ARTICLE

Quantifying Tariff Equivalents of Tariff Rate Quota on Grains in Korea

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ABSTRACT

This study quantifies the tariff equivalents of Tariff Rate Quotas (TRQs) for soybeans, corn, and rice in Korea using an import demand models with Poisson Pseudo Maximum Likelihood estimation. The research calculates Ad Valorem Equivalents (AVEs) to reveal the trade-restrictive effects of TRQs. The analysis reveals significant variations in TRQ impacts across different grains. Rice demonstrates the most pronounced trade-restrictive effects, with an AVE of 102.59%, compared to 92.34% for soybeans and 57.33% for corn. These findings highlight the complex interplay between trade policies, domestic market conditions, and import dynamics. Notably, the model-estimated AVEs are consistently lower than traditional Uruguay Round calculations, reflecting the importance of considering in-quota tariff allowances. The analysis found that the AVE of the TRQ for each country and grain could be related to the fill rate, where a higher fill rate implies a higher AVE. The study underscores the critical need for strategic policy adjustments in Korea's agricultural trade, particularly for rice, which is characterized by mandatory imports under Minimum Market Access policies. By providing a comprehensive quantitative assessment of TRQs, this research contributes valuable insights into agricultural trade policy, offering a sophisticated approach to understanding non-tariff barriers in international grain markets. The research critically reveals how these non-tariff barriers significantly impact food security and economic efficiency in Korea, offering important implications for stabilizing supply and demand.

Keywords: Tariff Rate Quotas; Ad Valorem Equivalents; Non-Tariff Barriers; Rice; Soybeans; Corn; Agricultural Policy

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1. Introduction

The Uruguay Round negotiations of 1994 abolished non-tariff measures on agricultural products, replacing them with tariffs, but allowed Tariff Rate Quotas (TRQs) for sensitive products requiring domestic protection [1]. TRQs are a two-tiered tariff system enabling high tariffs on imports exceeding a specific quota (out-of-quota tariffs) while offering lower tariffs within quotas (in-quota tariffs) to ensure market access [2–4]. Defined based on average import volumes from 1986–1988, TRQs are classified into Minimum Market Access (MMA) for limited import volumes (3–5% of domestic consumption) and Current Market Access (CMA) for higher import levels [5].

Under the agreement, developed countries were required to reduce tariffs by 36% over six years (1995–2000), while developing countries, including South Korea, were granted a 24% reduction over ten years [6]. MMA quotas were also mandated to increase to 5% by the end of the implementation period [7]. Approximately 43 WTO member countries now implement TRQs, covering around 1,425 agricultural products globally [8].

South Korea's 1994 implementation plan reflected the Uruguay Round principles and bilateral agreements. As a developing country, Korea adopted a gradual market opening, setting the base period as 1988–1990 [9]. Of the TRQ-covered agricultural products, 39 items, such as rice, garlic, and onions, fell under MMA due to negligible imports (<3% of domestic consumption) during the base period. Conversely, 24 items, including soybeans and corn, were subject to CMA due to higher import levels [9].

Rice was classified under MMA, with tariff imposition deferred until 2004. During this period, the MMA quota increased from 1% (51,307 tons) to 4% (205,229 tons) of domestic consumption [9]. In 2004, a renegotiation extended the tariff exemption to 2014, raising the MMA quota from 225,575 tons (4.4% of consumption) to 408,700 tons (8%) by 2014 [10]. In 2015, rice tariffs were implemented, with a mandatory import of 408,700 tons at a 5% tariff, while imports exceeding this quota faced a 513% tariff [11]. Soybeans, under CMA, were subject to an annual increase in quota from 1.03 million tons in the base period to 1.07 million tons by 2024. In 2018, the quota stood at 1.08 million tons, with in-quota imports subject to a 5% tariff and out-of-quota imports facing a tariff of 487%, which has been reduced over ten years (initially 541%) [9, 11]. Corn CMA quotas were similarly increased, from 6.1 million tons to 13.21 million tons by 2024. In 2018, the quota was 12.21 million tons. In-quota tariffs were reduced to 0% for feed and food by 2024, with out-of-quota tariffs falling from 365% to 328% over ten years [9, 11, 12].

In 2022, Korea's grain self-sufficiency rates for soybeans and corn were 7.7% and 0.8%, respectively, reflecting high import dependency. Annual imports of soybeans (1.23–1.32 million tons) and corn (10.16–11.80 million tons) from 2018 to 2023 underscored this reliance. Despite the substantial import demand for two grains, the in-quota volumes available at low tariff rates are constrained, with soybeans limited to 1.03 million tons and corn restricted to 6.1 million tons. Such a structured TRQ system creates significant challenges by constraining accessibility for domestic processing companies, feed industries, and consumers, thereby acting as a factor that elevates production costs and consumer prices. This mechanism can be viewed as potentially undermining food security by creating artificial market barriers that limit the efficient flow of agricultural commodities. By contrast, rice achieved near or full self-sufficiency, with a 2022 rate of 104.8% [13, 14]. From 2018 to 2023, rice imports averaged 410,000 tons annually, highlighting the critical role of TRQs in balancing supply and demand [15–17]. Consequently, rice TRQ MMA policy, which requires rice imports of 400,000 tons, inevitably presents challenges in managing surplus or oversupply.

This study quantifies the impact of TRQs as non-tariff barriers in Korea's soybean, corn, and rice import markets. By converting TRQs into tariff equivalents, the research critically reveals how these non-tariff barriers significantly impact food security and economic efficiency in the country. While extensive research exists on tariff equivalents of non-tariff measures, studies on TRQs specific to major grains in Korea remain limited. This research aims to fill this critical knowledge gap, offering comprehensive insights into TRQ effects on import market dynamics, fill rates, and grain prices, which are pivotal for understanding food security challenges and evaluating trade policy effectiveness.

2. Literature Review

The estimation of ad valorem equivalents (AVEs) for non-tariff measures (NTMs) has been approached using various methodologies, broadly categorized into price-based and quantity-based measures. These methods aim to quantify the trade-restrictive effects of NTMs, enhancing understanding of their implications under World Trade Organization (WTO) rules. Price-based methods include the Handicraft Price Gap Method and the Price-based Econometric Method, both of which assume that NTMs lead to price differentials.

The Handicraft Price Gap Method directly calculates AVEs by comparing prices in the presence of NTMs with those without them. Since such comparisons are often impractical, domestic market prices of imported goods are compared with international prices. For instance, Bradford [18], using OECD data, calculated AVEs for 124 products in eight countries, estimating averages of 57% for Japan, 48–55% for the EU, and 12% for the U.S. Similarly, Chemingui et al. [19] found that while Syria's average tariff rate was 8.2%, AVEs for 18 products averaged 22.1%. Although this method facilitates direct comparison with tariff rates, challenges such as limited data availability, product quality differences, and incomplete cost breakdowns restrict its applicability across products and countries [20].

An extension of the Handicraft Price Gap Method is the Price-based Econometric Method, which employs econometric techniques to estimate AVEs. For example, Andriamananjara et al. [21] analyzed price data for 14 products across 18 countries, finding high AVEs for products like clothing (EU 66%, Japan 190%), paper (Southeast Asia 67%, Japan 199%), and vegetable oils (South Africa 90%). Similarly, Dean et al. [22] identified average AVEs of 44% for fruits and vegetables, 54% for beef, and 50% for clothing. This approach enables broader analyses across products and regions, but it faces limitations, such as difficulty in accounting for country-specific characteristics and product quality differences [20].

Quantity-based measures analyze the impact of NTMs on trade volumes, with the Import Demand Model by Kee et al. [23] being a prominent example. This model incorporates variables from the gravity model (e.g., economic size, distance) alongside NTMs, tariffs, and subsidies. Kee et al. [23] applied the model to over 4,000 products in 78 countries, estimating an average AVE of 12%, with NTMs being 87% more restrictive than tariffs. Subsequent studies expanded on this model. For instance, Kim et al. [24] found AVEs of 35.9% for steel products in Indonesia, significantly exceeding the 12.5% tariff. Similarly, Shin [25] reported AVEs for EU products such as petroleum (11.6–77.2%), mobile phones (96.8%), and diesel cars (12–89.3%). Kim et al. [26] also estimated the AVEs of NTMs on kimchi products exported to China, finding that the AVE for 2012 was approximately 11.6%. Kee et al. [27] analyzed 5,000 products, concluding that NTMs had an average AVE of 11.5%, higher than the average tariff rate of 7.1%. They also highlighted issues like trade misreporting linked to NTMs.

Additional studies used the Import Demand Model to assess AVEs in specific contexts. For example, Nguyen [28] estimated rice import AVEs in 75 countries at 111%, nearly ten times the average tariff. Sanjuán López et al. [29] reported AVEs of 1–14% for products traded under the African Continental Free Trade Area (AfCFTA), while Mao et al. [30] calculated AVEs for agricultural NTMs, finding an average of 15.4% and noting their impact on welfare and carbon emissions. Ferrantino [20] pointed out that the advantage of Quantity-based Measures is that trade volume data are more standardized and readily available across countries and products, enabling country- and product-specific analysis. However, he also noted that the results could vary depending on the estimation model used, and converting the results into AVEs requires additional assumptions and calculations. Meanwhile, Fontagne et al. [31] used the Global Trade Analysis Project (GTAP) dataset and applied a gravity model with fixed effects to estimate the AVEs of NTMs across 65 countries and nine service sectors, concluding that the average protection provided by NTMs was approximately 75%.

Alternative approaches to estimating the effects of NTMs include Frequency-based and Survey-based measures. Frequency-based measures involve quantifying

NTMs by counting their occurrences or calculating trade coverage ratios. While easy to implement, they do not estimate AVEs, limiting their analytical depth [32]. Survey-based measures, by collecting stakeholder insights, provide qualitative assessments of NTMs. For example, European Commission [33] compiled an annual report on U.S. trade barriers based on survey data, and the U.S. Trade Representative [34] used this report to identify industries facing export restrictions. The OECD [35] surveyed companies in the U.S., Japan, the U.K., and Germany to identify trade barriers. Chen et al. [36] used World Bank survey data to assess the impact of Technical Barriers to Trade (TBT) on businesses. While insightful, surveys risk biases and lack quantitative rigor [36].

This study employs the Import Demand Model to estimate the AVEs of NTMs imposed by Korea on key agricultural products. Unlike previous research focusing on Korea's exports, this study examines NTMs applied by Korea as an importer, providing granular analysis of TRQs on grains. By linking AVEs to product-specific fill rates, the study elucidates the trade-restrictive effects of TRQs. Furthermore, the research validates the AVEs estimated through quantity-based measures by comparing them with price-based methods, contributing to the broader understanding of TRQs under WTO frameworks.

3. Theoretical Model and Estimation Methods

3.1. Import Demand Function

Following Kee et al. [23], the import demand function for each grain is formulated as follows in Equation (1). The dependent variable, Q_{ni} represents the quantity of grain, n imported by country i from the world in 2018. The independent variables include factors influencing import demand. TRQ_{ni} is a dummy variable that indicates whether a TRQ (Tariff Rate Quota) is applied to grain n by country i, and t_{ni} represents the tariff rate applied to the imported grain. The variables GDP_{ni}, pop_{ni}, $land_{ni}$, and $island_{ni}$ capture the economic and geographical characteristics of the importing country, including GDP, population relative to GDP, land area relative to GDP, and whether the country is an island nation.

The initial equation is:

$$\begin{aligned} \ln Q_{ni} &= \beta_n + \beta_{ni}^{TRQ} TRQ_{ni} \\ &+ \epsilon_{ni} \ln(1+t_{ni}) + \beta_{n1} \ln GDP_{ni} + \beta_{n2} \ln pop_{ni} \\ &+ \beta_{n3} \ln land_{ni} + \beta_{n4} island_{ni} + \varepsilon_{ni} \end{aligned} \tag{1}$$

As discussed in Trefler [37] and Lee et al. [38], there could be an endogeneity issue between t_{ni} and TRQ_{ni} with the dependent variable Q_{ni}. However, by utilizing the pre-estimated import demand price elasticity $\hat{\epsilon}_{ni}$ from previous studies, the endogeneity problem of t_{ni} can be addressed. Equation (1) is transformed into Equation (2) as follows, while acknowledging that heteroskedasticity could arise due to the substitution process in estimating the tariff elasticity, which is resolved by applying the Poisson Pseudo Maximum Likelihood (PPML) estimation method [39, 40]. PPML assumes that the conditional variance is proportional to the conditional means, and this can control for endogeneity caused by unobserved heterogeneity of countries [41, 42]:

$$\begin{aligned} \ln Q_{ni} - \hat{\epsilon}_{ni} \ln(1+t_{ni}) &= \beta_n \\ &+ \beta_{ni}^{TRQ} TRQ_{ni} + \beta_{n1} \ln GDP_{ni} + \beta_{n2} \ln pop_{ni} \\ &+ \beta_{n3} \ln land_{ni} + \beta_{n4} island_{ni} + \varepsilon_{ni} \end{aligned} \tag{2}$$

Due to the potential increase in the number of variables to be estimated across countries, degrees of freedom may be constrained. Hence, Equation (3) aggregates the term β_{ni}^{TRQ} across countries into two components: β_{ni}^{TRQ} as the common component across products and β_n^{share}, which captures country-specific differences based on market share. The impact of non-tariff barriers on imports can be divided into parts that are uniform across countries and parts that differ due to variations in market power by country [24–27]:

$$\beta_{ni}^{TRQ} = \beta_n^{TRQ} + \beta_n^{share} \cdot share_{ni} \tag{3}$$

Substituting Equation (3) into Equation (2), we get Equation (4):

$$\begin{aligned} \ln Q_{ni} - \hat{\epsilon}_{ni} \ln(1+t_{ni}) &= \beta_n + \\ \left(\beta_n^{TRQ} + \beta_n^{share} \cdot share_{ni}\right) & TRQ_{ni} \\ + \beta_{n1} \ln GDP_{ni} &+ \beta_{n2} \ln pop_{ni} + \\ \beta_{n3} \ln land_{ni} &+ \beta_{n4} island_{ni} + \varepsilon_{ni} \end{aligned} \tag{4}$$

To address the endogeneity of TRQ_{ni}, a fitted value for TRQ is obtained using instrumental variables through a probit model, and the inverse Mills ratio (IMR) is incorporated into Equation (4). The probit model is formulated in Equation (5), where X_{ni} represents the instrumental variables, including export quantity ex_{ni}, changes in import quantities de_im_{ni}, and the GDP-weighted TRQ of three neighboring countries $\overline{TRQ}_{ni}$, following Trefler[37] and Lee et al.[38]:

$$\begin{aligned} P_r\left(TRQ_{ni}=1\right) &= \Phi(\alpha_{n0}+\alpha_{n1}\ln ex_{ni} \\ &+\alpha_{n2}\ln de\_im_{ni}+\alpha_{n3}\overline{TRQ}_{ni}+e_n) \\ &= \Phi\left(X_{ni}\alpha\right) \end{aligned} \tag{5}$$

Using the estimated α values, the IMR is calculated through the ratio of the probability density function (ϕ) to the cumulative distribution function (Φ) as shown in Equation (6):

$$IMR_{ni}=\frac{\phi\left(X_{ni}\hat{\alpha}\right)}{\Phi\left(X_{ni}\hat{\alpha}\right)} \tag{6}$$

Finally, incorporating the IMR into Equation (4) transforms the model into the final form for PPML estimation, as seen in Equation (7):

$$\begin{aligned} \frac{Q_{ni}}{\exp[\hat{\epsilon}_{ni}\ln(1+t_{ni})]} &= exp[\beta_n+ \\ &(\beta_n^{TRQ}+\beta_n^{share}\cdot share_{ni})TRQ_{ni} \\ &+\beta_{n1}\ln GDP_{ni}+\beta_{n2}\ln pop_{ni}+\beta_{n3}\ln land_{ni} \\ &+\beta_{n4}island_{ni}+\beta_{n5}IMR_{ni}+\varepsilon_{ni}] \end{aligned} \tag{7}$$

3.2. Ad Valorem Equivalent of TRQ

The formula to calculate the ad valorem equivalent of the TRQ is derived using the coefficients estimated from the import demand model and the method employed during the 1994 Uruguay Round, which converted non-tariff measures into tariff equivalents for agricultural products. The AVE of the TRQ for grain n in importing country i is defined by the first identity in Equation (8) as the percentage change in the domestic price p_{ni}^d of grain n in country i, resulting from the presence or absence of the TRQ. However, due to the difficulty of obtaining comprehensive domestic price data for all importing countries, the formula is adjusted using import quantity Q_{ni} and import demand elasticity $\hat{\epsilon}_{ni}$, as shown in the second and third identities of Equation (8). The term $\frac{\partial \ln Q_{ni}}{\partial TRQ_{ni}}$ represents the percentage change in import quantity due to the TRQ.

$$\begin{aligned} AVE_{ni} &\equiv \frac{\partial \ln p_{ni}^d}{\partial TRQ_{ni}} = \\ \frac{\partial \ln p_{ni}^d}{\partial \ln Q_{ni}}\frac{\partial \ln Q_{ni}}{\partial TRQ_{ni}} &= \frac{1}{\epsilon_{ni}}\frac{\partial \ln Q_{ni}}{\partial TRQ_{ni}} = \\ &\frac{1}{\epsilon_{ni}}\frac{Q_{ni,TRQ=1}-Q_{ni,TRQ=0}}{Q_{ni,TRQ=0}} \end{aligned} \tag{8}$$

Once Equation (7) is estimated, the values of $\beta_n^{TRQ}+\beta_n^{share}share_{ni}$ are obtained, which correspond to the coefficient β_{ni}^{TRQ}. This allows us to express the change in import quantity caused by the presence or absence of the TRQ, as shown in Equation (9), using the logarithmic properties:

$$\begin{aligned} &\beta_n^{TRQ}+\beta_n^{share}\cdot share_{ni} = \\ &\ln Q_{ni,TRQ=1}-\ln Q_{ni,TRQ=0} = \\ &\ln\left(\frac{Q_{ni,TRQ=1}-Q_{ni,TRQ=0}}{Q_{ni,TRQ=0}}+1\right) \end{aligned} \tag{9}$$

By exponentiating both sides of Equation (9) and rearranging, we derive Equation (10):

$$\begin{aligned} &\frac{Q_{ni,TRQ=1}-Q_{ni,TRQ=0}}{Q_{ni,TRQ=0}} = \\ &\exp\left(\beta_n^{TRQ}+\beta_n^{share}\cdot share_{ni}\right)-1 \end{aligned} \tag{10}$$

Finally, substituting Equation (10) into Equation (8) results in the final calculation for the AVE of the TRQ for country i and grain n, as shown in Equation (11). Using the estimated coefficients from Equation (7) and the pre-determined elasticity ϵ_{ni} from prior studies, the AVE for each grain and country-specific TRQ can be calculated:

$$\begin{aligned} AVE_{ni} &\equiv \frac{\partial \ln p_{ni}^d}{\partial TRQ_{ni}} = \\ &\frac{\exp\left(\beta_n^{TRQ}+\beta_n^{share}\cdot share_{ni}\right)-1}{\epsilon_{ni}} \end{aligned} \tag{11}$$

Additionally, during the 1994 Uruguay Round, the AVE for agricultural products under TRQs was calculated by comparing the domestic price p_{ni}^d and the international price p_{ni}^w, divided by the international price, as shown in Equation (12). The domestic price is a representative wholesale price in the domestic market, and the international price is the CIF import price. Both prices were averaged for the 1988–1990 period during the Uruguay Round negotiations[6]:

$$AVE_{ni} = \frac{p_{ni}^d - p_{ni}^w}{p_{ni}^w} \tag{12}$$

4. Data

This section provides an overview of the variables used in the estimation model and their data sources, as shown in **Table 1**. The subscript n refers to the three types of grains—soybean, rice, and corn—corresponding to HS 4-digit codes 1201, 1006, and 1005, respectively. The subscript i represents the importing country, which includes 100 countries for each grain. The data primarily covers the year 2018, except for the import demand elasticity ϵ_{ni}, which references data from Kee et al. [43] and Grübler et al. [44]. These studies used the GDP function approach to estimate the import demand elasticity for specific products by analyzing how the share of imports in GDP changes when the import price changes by 1%. Data coverage up to 2018 is to construct a balanced panel dataset utilizing lagged tariff and WTO-notified country-specific TRQ reports from as many countries as possible. Although the unavailability of the latest data imposes constraints on the information, the fact that there are no significant year-to-year differences in TRQ-related policy variables ensures the validity of the empirical analysis.

Moreover, while AVE values can be sensitive to elasticity estimates, conducting comprehensive sensitivity analyses with various elasticity values presented practical challenges due to the limited number of existing studies. The referenced studies by Kee et al. [43], which analyzed 117 countries and 4,625 products over the period 1998–2002, and Grübler et al. [44], which examined 167 countries and 5,124 products over the period 1996–2014, calculated import demand elasticities by country and product using panel data based on the HS 6-digit level. Consequently, these datasets are considered relatively reliable for cross-country comparisons at the detailed product level. Furthermore, given the relatively stable nature of agricultural product demand, the import demand elasticity is unlikely to experience substantial variations.

Table 1. Definitions of variables and data sources.

Variable	Definition	Source of Data
Q_{ni}	Import volume of grain n from the world for importing country i	Trade Map [14]
t_{ni}	Tariff on grain n for importing country i	World Trade Organization (WTO) [45], Market Access Map [46]
$\hat{\epsilon}_{ni}$	Import demand price elasticity for grain n in importing country i	Kee et al. [43], Grübler et al. [44]
TRQ_{ni}	Dummy variable indicating whether importing country i has a TRQ for grain n (1 = TRQ, 0 = otherwise)	WTO [45]
$share_{ni}$	Market share based on import volume of import country i in the world import market for grain n	Author calculation based on Trade Map [14]
GDP_{ni}	Nominal GDP of importing country i for grain n	World Bank [47]
pop_{ni}	Population relative to GDP for importing country i for grain n	Author calculation based on World Bank [47]
$land_{ni}$	Agricultural land area relative to GDP for importing country i for grain n	Food and Agriculture Organization of the United Nations (FAO) [48]
$island_{ni}$	Dummy variable indicating whether importing country i is an island for grain n (1 = island, 0 = otherwise)	Wikipedia [49]
ex_{ni}	Export volume of grain n for importing country i	Trade Map [14]
de_im_{ni}	Year-over-year change in import volume for grain n in importing country i	Author calculation based on Trade Map [14]
$\overline{TRQ}_{ni}$	GDP-weighted average TRQ of the three neighboring countries of importing country i for grain n	Author calculation based on WTO [45], World Bank [47], CEPII [50]

For t_{ni} in-quota tariff rates were used for countries with TRQs, while MFN-applied tariffs were used for countries without TRQs. The environmental variables pop_{ni} and $land_{ni}$ are population over GDP and agricultural land areas over GDP, respectively. They were included to reflect relative factor endowment, in line with Ricardo [51]'s comparative advantage theory. Additionally, $\overline{TRQ}_{ni}$ was calculated as the GDP-weighted average TRQ status of the three closest neighboring countries for each importing country.

Summary statistics for these variables are provided in **Table 2**. The average values of Q_{ni} are highest for corn, followed by soybeans and rice. In terms of market concentration, the maximum value of $share_{ni}$ for soybeans is 0.60, indicating that the import market for soybeans is highly concentrated (e.g., China). In contrast, corn and rice exhibit more distributed market shares, with maximum values of 0.23 and 0.07, respectively. The average values of TRQ_{ni} and $\overline{TRQ}_{ni}$ are lower for soybeans compared to corn and rice, as fewer countries apply TRQs to soybeans.

Table 2. Summary Statistics.

Variable	Unit	Mean	Std. Dev.	Minimum	Maximum
		Soybean			
Q_{ni}	ton	1,465,541	8,954,923	42	88,000,000
t_{ni}	-	0.04	0.07	0.00	0.45
$\hat{\epsilon}_{ni}$	-	−0.87	0.20	−1.52	−0.12
TRQ_{ni}	-	0.02	0.14	0.00	1.00
$share_{ni}$	-	0.01	0.06	0.0000003	0.60
GDP_{ni}	billion US$	835	2,948	0.81	20,529
pop_{ni}	million persons/billion US$	0.13	0.18	0.006	1.13
$land_{ni}$	thousand hectare/billion US$	57.13	82.95	0.001	520.43
$island_{ni}$	-	0.20	0.40	0.00	1.00
ex_{ni}	ton	1,526,211	9,536,543	0	83,600,000
de_im_{ni}	ton	1,163	893,422	−7,503,218	4,545,415
$\overline{TRQ}_{ni}$	-	0.02	0.11	0.00	0.74
		Rice			
Q_{ni}	ton	432,463	575,355	26,157	3,029,190
t_{ni}	-	0.11	0.14	0.00	0.75
$\hat{\epsilon}_{ni}$	-	−2.18	3.53	−25.50	−0.32
TRQ_{ni}	-	0.09	0.29	0.00	1.00
$share_{ni}$	-	0.01	0.01	0.0001	0.07
GDP_{ni}	billion US$	791	2,946	0.82	20,529
pop_{ni}	million persons/billion US$	0.19	0.21	0.01	0.97
$land_{ni}$	thousand hectare/billion US$	94.43	178.84	0.002	1379.93
$island_{ni}$	-	0.22	0.42	0.00	1.00
ex_{ni}	ton	133,650	529,880	0	3,194,384
de_im_{ni}	ton	17,367	291,484	−1,012,893	1,948,095
$\overline{TRQ}_{ni}$	-	0.20	0.37	0.00	1.00
		Corn			
Q_{ni}	ton	1,586,971	4,505,628	11,137	36,200,000
t_{ni}	-	0.07	0.10	0.00	0.50
$\hat{\epsilon}_{ni}$	-	−1.93	2.32	−18.00	−0.01
TRQ_{ni}	-	0.14	0.35	0.00	1.00
$share_{ni}$	-	0.01	0.03	0.00003	0.23
GDP_{ni}	billion US$	814	2,949	1.46	20,529
pop_{ni}	million persons/billion US$	0.15	0.22	0.01	1.59
$land_{ni}$	thousand hectare/billion US$	75.23	167.56	0.002	1379.93
$island_{ni}$	-	0.18	0.39	0.00	1.00
ex_{ni}	ton	1,430,166	7,788,182	0	70,100,000
de_im_{ni}	ton	156,670	692,932	−798,407	5,919,835
$\overline{TRQ}_{ni}$	-	0.20	0.37	0.00	1.00

5. Results and Discussion

5.1. Model Estimation Results

The estimation results from **Table 3** show that, concerning country-specific factors, an increase in GDP by 1% leads to an increase in soybean, rice, and corn imports by 1.32%, 7.15%, and 0.25%, respectively. Moreover, when the population relative to GDP increases by 1%, soybean and rice imports rise by 1.20% and 1.64%, respectively. This indicates that larger economies or countries with a higher population-to-GDP ratio have higher food demand, resulting in greater imports. Conversely, when the land-to-GDP ratio increases by 1%, soybean, rice, and corn imports decrease by 0.34%, 1.69%, and 0.13%, respectively, reflecting the availability of domestic agricultural resources in each country.

Table 3. The Estimation Results

Variable	Soybean [1] PPML	Rice [1] PPML with IMR	Corn [1] PPML with IMR
lnGDP_{ni}	1.32*** (0.13)	7.15*** (0.65)	0.25** (0.09)
lnpop_{ni}	1.20*** (0.33)	1.64** (0.70)	0.06 (0.17)
ln$land_{ni}$	−0.34** (0.16)	−1.69*** (0.29)	−0.13* (0.07)
$island_{ni}$	−0.56* (0.30)	−8.96*** (0.68)	−0.10 (0.51)
TRQ_{ni}	−2.19*** (0.60)	−2.61*** (0.48)	0.66 (0.51)
$TRQ_{ni} \cdot share_{ni}$	1.94*** (0.50)	−2.68*** (0.13)	−12.27*** (3.12)
IMR_{ni}	-	−16.43*** (2.35)	−3.07*** (0.39)
constant	9.61*** (0.95)	−1.04 (6.83)	17.74*** (0.75)

[1] ***, **, and * indicate significance levels at 1%, 5%, and 10%, respectively. Standard errors are reported in parentheses.

For the island dummy variable, the coefficient for soybeans and rice translates into a 43.2% and 90.9% reduction in imports, respectively, compared to non-island countries. These figures are obtained by $(\exp(\beta) - 1) \times 100$ [52, 53]. This suggests that island nations face trade barriers due to geographic isolation, making imports more difficult.

The significantly larger coefficients for rice compared to soybeans and corn indicate that rice is primarily used for human consumption, unlike soybeans and corn, which are largely used for feed and industrial purposes. According to FAO [48] data (2018–2021), feed demand accounts for about 77% of soybean consumption and 75% of corn consumption, while rice has no feed demand.

The IMR_{ni} variable was added only to the rice and corn models, as the model specification test revealed endogeneity with the TRQ variable in these cases. The significant coefficient of IMR_{ni} indicates that endogeneity is well-controlled, and the parameter estimates are consistent, as described by Heckman [54]. The policy variables TRQ_{ni} and $TRQ_{ni} \cdot share_{ni}$ are used to estimate the ad valorem equivalent (AVE) of the TRQ. Since these variables are statistically significant, the AVE for each grain and country can be calculated by substituting the relevant values for the coefficients, market shares, and the respective import demand elasticities into Equation (11).

5.2. Comparison with AVE of UR in Korea

The AVE (ad valorem equivalent) of the TRQ for each grain estimated by the model can be compared with the AVE calculated using the Uruguay Round method, allowing us to observe the differences between the model-estimated AVE and the policy-based AVE. The analysis focuses on Korea's soybean, rice, and corn import markets. First, looking at the process by which the AVE is estimated in the model, as shown in **Table 4**, when we compare the impact of TRQ on each country's imports, represented by $\beta_n^{TRQ} + \beta_n^{share} \cdot share_{ni}$ for each grain, rice has the largest absolute value. This result is consistent with the fact mentioned earlier: rice is more responsive to factors affecting supply, such as TRQ, because it is used more as a staple food compared to soybeans or corn.

Table 4. AVE estimated using model

	β_n^{TRQ}	β_n^{share}	$share_{ni}$	$\beta_n^{TRQ} + \beta_n^{share} \cdot share_{ni}$	ϵ_{ni}	$AVE = \frac{exp\left(\beta_n^{TRQ} + \beta_n^{share} \cdot share_{ni}\right) - 1}{\epsilon_{ni}}$
Soybean	−2.19	1.94	0.009	−2.18	−0.96	92.34
Rice	−2.61	−2.68	0.010	−2.64	−0.91	102.59
Corn		−12.27	0.064	−0.79	−0.95	57.33

Additionally, due to the Minimum Market Access (MMA) policy in Korea, rice's sensitivity to import prices is low, which results in a lower import demand price elasticity, ϵ_{ni}, further raising the AVE of the TRQ, making it the highest among the three grains. In other words, while soybeans and corn do face pressure from the TRQ due to demand exceeding the TRQ quota, rice, as a staple food and due to the compulsory imports under the TRQ MMA, experiences a much greater burden from the TRQ.

Next, when comparing the AVE estimated by the model with the AVE calculated using the Uruguay Round tariff equivalent conversion method, the results are shown in **Table 5**. Using the Uruguay Round conversion method, the AVE was calculated based on the average domestic and international prices from 1988–1990 and the domestic and international prices from 2018, respectively. The reason for using the 2018 domestic and international prices is that the data analyzed in this paper is based on 2018, making it appropriate for comparison with the model-estimated AVE. For clarity, the AVE calculated based on the average domestic and international prices from 1988–1990 is denoted as $AVE_{'88-'90}$, the AVE based on the 2018 domestic and international prices is denoted as AVE_{2018}, and the AVE estimated by the model is denoted as AVE_{Model}.

Table 5. Comparison among AVEs of Korea.

	Soybean			**Rice**			**Corn**		
	UR		**Model**	**UR**		**Model**	**UR**		**Model**
	1988-'90 [1]	**2018** [2]		**1988-'90** [1]	**2018** [2]		**1988-'90** [1]	**2018** [2]	
p_{ni}^d(won/kg)	1,270	4,937	-	1,724	2,224	-	436	1,677	-
p_{ni}^w(won/kg)	198	523	-	281	786	-	93.7	234	-
AVE_{ni}(%)	541	843	92.3	513	183	102.6	365	616	57.3

[1] The data of p_{ni}^d and p_{ni}^w from 1988 to 1990 was referred from Lim et al. [4], Lim et al. [55], and WTO [45].
[2] The data of p_{ni}^d in 2018 was referred from KAMIS [56], KREI OASIS [57] and that of p_{ni}^w in 2018 was referred from Trademap [14].

First, in the case of $AVE_{'88-'90}$, the domestic price p_{ni}^d was the dominant wholesale price in the domestic market, and the international price p_{ni}^w was the CIF import price. Based on this, the AVE of the TRQ was calculated as 541% for soybeans, 513% for rice, and 365% for corn, which corresponds to the out-of-quota tariffs set during the Uruguay Round in 1994.

When comparing AVE_{Model} with $AVE_{'88-'90}$, AVE_{Model} appears lower for all three grains. This difference arises because $AVE_{'88-'90}$, as a policy formula, often reflected a higher domestic price to protect the national market. Additionally, $AVE_{'88-'90}$ was merely a tariff equivalent based on the price gap between domestic and international prices. In contrast, AVE_{Model} accounts for not only the out-of-quota tariff but also the TRQ's in-quota allowance, where imports are permitted at a lower tariff rate within the quota. This results in a lower AVE_{Model} compared to $AVE_{'88-'90}$.

When comparing AVE_{2018} and $AVE_{'88-'90}$, the results show that for soybeans and corn, AVE_{2018} is larger than $AVE_{'88-'90}$. This is because the domestic price increased more sharply than the import price due to supply shortages, which widened the price gap compared to the baseline years. On the other hand, for rice, $AVE_{'88-'90}$ is larger than AVE_{2018}, indicating that the price gap between domestic and international prices decreased, as the rise in domestic prices was not as steep due to oversupply in the domestic market.

Lastly, when comparing AVE_{Model} with AVE_{2018}, AVE_{Model} is lower for all three grains. Particularly for rice, even though the price gap between domestic and international prices decreased in 2018, AVE_{Model} was still smaller than AVE_{2018}. This demonstrates that calculating the tariff equivalent based solely on the domestic-international price difference does not capture the full tariff equivalent of the TRQ, especially when lower in-quota tariffs are considered. Thus, using the model, which accounts for various factors such as elasticity and in-quota low tariffs, provides a more realistic and accurate estimation of the TRQ's tariff equivalent.

5.3. AVE of TRQ by Country

The AVE of the TRQ for various countries can also be derived using the model and compared with in-quota and out-of-quota tariffs. **Figures 1–3** illustrate the AVE for soybean, rice, and corn, respectively, across countries with active TRQ systems. Only countries where TRQs are functioning are included in the analysis; for instance, countries where the Most Favored Nation (MFN) applied tariff is lower than the in-quota tariff are excluded, as in those cases, imports occur under the MFN tariff rather than through the TRQ system. And, in figures, the values in parentheses are the fill rates (%) for each country and were referred from WTO [45].

For soybeans (**Figure 1**), countries such as Korea and Thailand have high fill rates, each at 100%. A high fill rate indicates a demand for imports that exceeds the quota, leading to a higher AVE as a result of the TRQ acting as a significant trade barrier. Although the fill rate is officially capped at 100%, it can surpass this figure in reality.

For rice (**Figure 2**), similar trends are observed, with most countries maintaining fill rates close to or exceeding 100%. However, differences in the TRQ administrative methods may cause variation in how fill rates correlate with the AVE, as noted by previous studies [4, 8, 58].

For corn (**Figure 3**), Korea's AVE stands out at 57.3%, corresponding to its over fill rates beyond 100%. Conversely, countries like the Philippines and Venezuela, despite high fill rates, have AVEs closer to their in-quota tariffs. This discrepancy may be due to the absence of fill rate data, requiring estimation based on import volumes and quotas. For other countries, such as China, Guatemala, Switzerland, and India, where the fill rate remains below 50%, the AVE is also closer to the in-quota tariff, indicating that import demand remains below the quota limit.

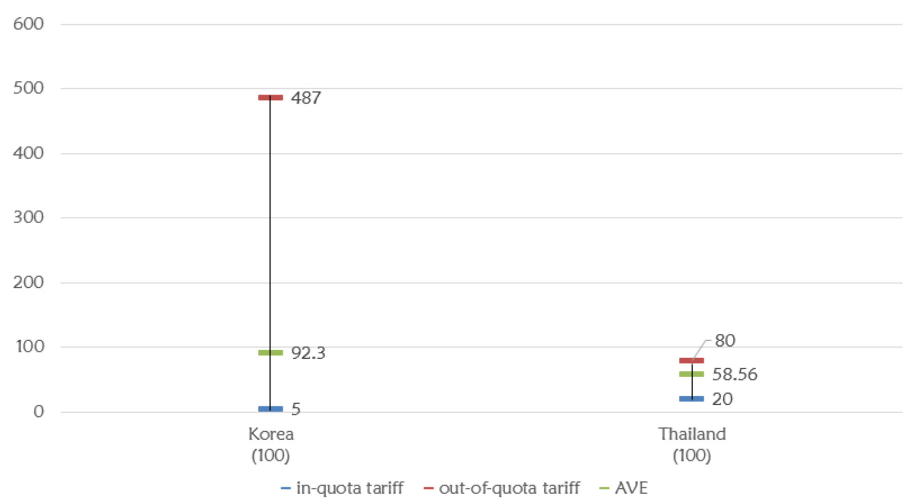

Figure 1. AVE for Soybean TRQ (%).

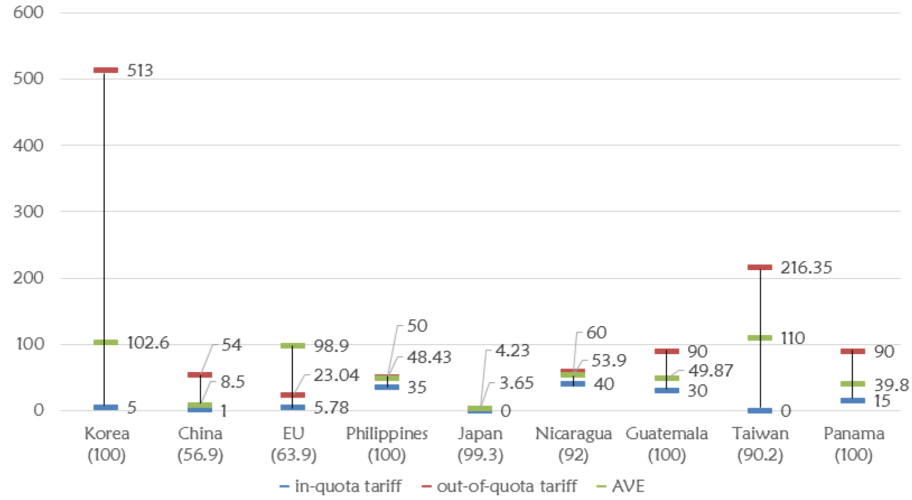

Figure 2. AVE for Rice TRQ (%).

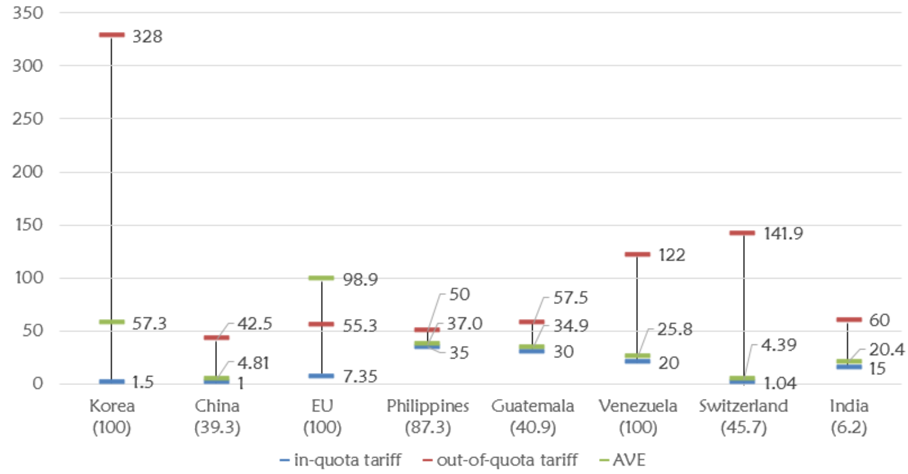

Figure 3. AVE for Corn TRQ (%).

6. Conclusions

In estimating the import demand function using PPML, this study found that environmental and policy variables were generally statistically significant and aligned with theoretical expectations. By utilizing coefficient values for each grain, along with market share and import demand price elasticity, the ad valorem equivalent (AVE) of the tariff rate quota (TRQ) was calculated. The study highlighted that quantity-based measures for calculating the AVE are more realistic than price-based methods, as they better reflect market conditions such as import demand price elasticity, in-quota low tariffs, and market share for each grain. A comparison between the Uruguay Round method and model-estimated AVEs for Korea's soybean, rice, and corn markets revealed that the model-derived AVE was lower, as it accounts for in-quota low tariffs, unlike the Uruguay Round method, which is based on price differences between domestic and international markets.

The analysis found that the AVE of the TRQ for each country and grain could be related to the fill rate, where a higher fill rate implies a higher AVE, though administrative factors may influence this relationship. The overfilled quotas signify that import demand surpasses the allocated quota, reflecting a pronounced non-tariff barrier effect of the TRQ, which in turn results in a higher AVE. In the opposite case, the AVE may be lower.

Korea's rice market, governed by Minimum Market Access (MMA), faces a heavier TRQ burden than soybeans and corn due to mandatory imports despite declining domestic demand [59, 60]. Strategic preparations for potential renegotiations of WTO agreements are needed, particularly for rice [61]. The study proposes proactive policies to manage rice supply and stimulate demand. To mitigate structural oversupply and promote optimal production, the government should implement targeted incentives for crop diversification, including comprehensive support for agricultural facilities, specialized equipment, and strategic financing mechanisms [60]. Moreover, expanding rice market potential necessitates strategic investment in R&D focused on developing high-quality, export-competitive rice varieties [59].

For soybeans and corn, effective managing excess demand requires dynamic adjustment of low-tariff quotas based on comprehensive annual demand surveys. Domestic policies to enhance self-sufficiency should be more proactively implemented, including strategic promotion of newly developed domestic crop varieties and targeted support for agricultural production technologies resilient to climate-related challenges [62].

In conclusion, this study's estimates of TRQ AVEs provide valuable insights into Korea's grain trade, offering important implications for stabilizing supply and demand. While Korea initially implemented TRQs to protect domestic staple grain industries, these measures have inadvertently created trade barriers and exacerbated supply-demand imbalances due to evolving domestic consumption patterns. The research findings are anticipated to generate valuable perspectives not only for Korea as an importing country but also for major grain-exporting countries, illuminating the current landscape of Korean agriculture and its potential future trajectories.

Future research could benefit from directly estimating import demand elasticities and conducting analyses of TRQ impacts on import volumes, subsequently leveraging these insights to evaluate potential changes in producer and consumer welfare through an integrated approach combining gravity and partial equilibrium models [63].

Author Contributions

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Conflicts of Interest

The authors declare no conflict of interest.

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