Interrelationships Among the U.S. and Global Rice Markets: A Time-Series Approach

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Abstract

Combining the monthly f.o.b. (free on board) prices of long and medium grain rice of Arkansas, Louisiana, Texas (Houston), and California and the rice export prices of India, Thailand and Vietnam, this study examined the price linkages within the U.S. rice markets and between the U.S. and international rice markets. In the process, the study relied on monthly f.o.b. price data sourced from United States Department of Agriculture (USDA) from August 1997 to February 2023. Employing the Prais-Winsten and Autoregressive Distributive Lag (ARDL) model estimation processes, this study demonstrated that the U.S. domestic rice markets are spatially strongly interlinked, and the medium grain rice export price of Arkansas is the leader, followed by the medium grain rice price of Louisiana. Furthermore, this study confirmed that both long and medium grain rice markets of the U.S. are strongly cointegrated with the global rice market, and there is a two-way relationship exists between the U.S. rice market and the global rice market in which the global rice market and the U.S. rice market influence each other. The findings of this study indicate that despite the fact that the U.S. is not the top rice exporter, the U.S. rice export dynamics significantly influence global rice prices. Many food-insecure, poverty-stricken developing countries rely on imported rice from the global market to meet their demand. Rice price volatility can generate severe negative impacts on global food security. Based on the findings, this study suggests to ensure sustainable rice production in the U.S. to ensure stable exports, which can contribute to keep the interntional rice market stable. Furthermore, the findings of this study suggest to monitor the U.S. rice exports and specifically the medium grain rice prices of Arkansas and Louisiana to better forecast rice prices in the global market.

Keywords: rice, price, export, domestic, long-grain, medium-grain, market linkage

JEL Classifications: C13, C32, C51, C54, F14

1. Introduction

The U.S. is the 13th largest rice producing country, but in terms of export, the country is the fifth largest rice exporting county in the world (USDA, 2024a). In 2022/23, the U.S. exported 2.7 million metric tons (MMT) of rice, which was 4.6% of the total global rice exports (USDA, 2024a). The major domestic rice markets and exporting ports of the U.S are Arkansas, Louisiana Texas (Houston), and California, and the major importing countries of the U.S. rice are Mexico, Haiti, Canada, Japan, Colombia, and Honduras (Childs & Lebeau, 2023). Questions arise as to are the domestic rice export markets of the U.S. spatially integrated? What types of price relationships exist between the U.S. and the global rice markets?

Examining the level of market integration and price transmission is important, because the effectiveness of both macro and micro level policies critically rely on the level of market integration and price transmission of a commodity market (Barrett, 2008). This is why, market integration and price transmission are important research topics in market analysis. A greater degree of market integration leads to a greater degree of price transmission among markets, which encourages producers to specialize based on comparative advantages (Baulch, 1997a, 1997b). However, based on the net trade status, the benefits of market integration and price transmission can be different. For any commodity, for a net exporting country, greater market integration and a higher level of price transmission ensure a higher price of that commodity, in which the net exporting country can respond to global shocks rapidly (Alam et al., 2012). It benefits the farmers and suppliers by ensuring higher market prices. For a country with a net importing status of a commodity, a greater market integration and a higher level of price transmission ensure a lower price of that commodity, which ensures a higher level of consumer welfare (Alam et al., 2012). In addition, greater market integration can minimize the supply shock impacts, as international markets can respond to domestic market shocks rapidly.

Currently, rice is cultivated on 879 thousand ha of land in the U.S. in which more than 5,000 households are engaged in rice cultivation (USA Rice, 2020). Altogether rice industry contributes US $34 billion to the economy and the sector has created job opportunities for 125,000 people in the country (USA Rice, 2020). Research on market integration and price transmission for assessing market efficiency is directly related to farm level efficiency, as farms receive information about prices from the markets. The price information is used to plan production and input usage. If the rice markets in the U.S. are efficient, farms will be efficient, because farms will plan their production decision based on accurate price information. The findings of the present research thus can significantly contribute to develop effective policies to ensure welfare of the rice farmers and people who are working in the rice sector for their livelihoods.

Globally, rice is the staple food of half of the world's population (USDA, 2024a), and many countries rely on imports to fill in the gap between domestic production and aggregate demand. For example, in 2022, at least 144 countries imported rice to meet their demand (United Nations, 2023). As the fifth largest rice exporting country in the world, the U.S. supplied rice to at least 138 countries in 2022, including Haiti, Guatemala, El Salvador, Cameroon, Congo, Niger, Nepal, Benin, Mali, Madagascar, Mozambique, and Rwanda (United Nations, 2023). In many of the rice importing countries, food security situation is already precarious. Thus, the speed of market response of the U.S. as well as other rice exporting countries is crucially important to ensure food security of the rice important dependent countries. The speed of market response relies on the level of market integration. As the U.S. is the fifth largest rice exporting country, an assessment of market integration and price transmission between the U.S. domestic rice markets and global markets can provide deep insights into the ability of the U.S. rice markets to respond to global shocks in the case of emergency.

On the issues of market integration and price transmission in the U.S. rice market, three strands of literature have emerged. The first strand of literature has examined the extent of spatial market integration in the U.S. rice markets (e.g., Brorsen & Grant, 1985; Djunaidi et al., 2001; Kim et al., 2016, 2017). The second strand of literature examined the relationship of the U.S. rice export prices with rice export prices of other countries (Chen & Saghaian, 2016; John, 2014; Weber & Lee, 2006). The third strand of literature examined the relationships of the U.S. rice prices both domestic and international contexts (Taylor et al., 1996). Since 2007-08 global food crisis, structural changes have taken place in the global rice market, for example, now, replacing Thailand, India has emerged as the largest exporter of rice in the world, and Vietnam has emerged as the third largest exporter. Also, large rice consuming countries, such as Bangladesh and Indonesia, have emerged as almost self-sufficient in rice production. Existing studies have never considered the structural change in the analysis. Also, the influence of Indian rice export price on the U.S. rice export prices has never been explored.

Using monthly milled f.o.b. rice export prices of both long and medium grain rice in Arkansas, Louisiana, Texas (Houston), and California, and rice export prices of India, Thailand, and Vietnam sourced from USDA from August 1997 to February 2023, this study examined the spatial as well as international price relationships of the U.S. rice. The novelty of the study is that this study examined the presence of structural breaks in each price series and included appropriate measures to tackle the presence of structural breaks in the series. The study explicitly examined the influences of the rice export prices of India, Thailand, and Vietnam on the rice export prices of the U.S. Finally, this study examined both short and long-run spatial and global relationships of the U.S. rice export prices applying the Prais-Winsten and Autoregressive Distributive Lag (ARDL) model estimation process The findings of the study can provide valuable information to the policymakers in two different ways. Firstly, this study intends to provide information on the level of spatial integration of the U.S. domestic rice markets, which can indicate the level of market efficiency and effectiveness of the rice policies in the country. Secondly, this study also intends to provide information on the influence of the U.S. rice prices on the global market by examining the direction of market information between the U.S rice prices and global prices. The findings can be useful for donor agencies, market monitoring agencies, and policymakers to provide early warning messages based on the price movement in the international market.

The rest of the study is organized as follows. Section 2 presents the literature review and Section 3 presents the materials and methods. Section 4 presents major findings and Section 5 includes conclusions and policy implications.

2. Literature review

A few empirical studies have examined the issue of rice market integration of the U.S. Taylor et al. (1996), applying the error correction model (ECM) estimation process and using weekly prices during 1987-1991 of Texas cash rough rice price, the Chicago Rice and Cotton Exchange rough futures price, the USDA weekly-announced world market price (WMP), and Thai milled rice price, demonstrated that there exists a long-run equilibrium relationship among Texas cash rough rice price, the Chicago Rice and Cotton Exchange rough futures price, and Thai milled rice price. The USDA weekly-announced world market price (WMP), however did not enter into a long run equilibrium condition (Taylor et al., 1996). The study of Taylor et al. (1996), however, did not consider prices of other major exporting countries prices, such as India and Vietnam, and did not consider the grain type in the analysis. Using weekly milled rice price data of Arkansas, Louisiana, Texas, and California, from August 1966 to July 1983, and applying the autoregressive estimation process, Brorsen & Grant, (1985) investigated the impacts of a shift in the U.S. government rice farm program on market price adjustments and efficiency. The study concluded that all domestic rice markets were inefficient in all periods as price adjustments were not instantaneous (Brorsen & Grant, 1985). Using monthly milled rice price information of long, medium, and short grain rice from 1980 to 2014 and applying the Vector Error Correction Model (VECM) estimation process, Kim et al., (2016) demonstrated that Arkansas medium grain price simultaneously leads Arkansas long grain and Louisiana long grain market. The long gain price of Arkansas, on the other hand, leads Texas long grain and Louisiana long grain rice markets. The short grain rice of California tends to move along (Kim et al., 2016). The study of Kim et al., (2016), however, did not consider any structural break in the price series.

Chen & Saghaian (2016), considering Thailand, Vietnam, and the U.S. rice export prices as a case, and applying the threshold Vector Error Correction model (TVECM) estimation process, concluded that there is a long run cointegration among the rice export prices of these three countries, in which the U.S. is the price leader. Moreover, the rice export price of Vietnam converges in the long run, in relation to the prices of Thailand and the U.S. In the study for the search of market leaders, John (2014) considered the monthly rice export prices from January 2000 to May 2013 in Argentina, Thailand, Pakistan, the U.S., and Vietnam and applied the Vector Autoregressive (VAR) model estimation process. The study was inconclusive on which country is the leader in the rice export market, but indicated that Vietnam's rice export price is highly related to other export markets. A major limitation of Chen & Saghaian's (2016) study is that it did not consider the prices of other major rice exporters, such as India, Pakistan, and Brazil. Also, the study did not include the prices of the U.S. rice exports by grain type and by exporting ports. In addition, only reliance on the Granger causality test in searching for the price leader is problematic, as the Granger causality test can be seriously affected by the number of lags (Thornton & Batten, 1985). In a recent study, Mottaleb et al. (2024) examined the price leader in the rice export market and demonstrated that the U.S. long grain rice export price is the most related price among the sampled eleven price series. The study, however, did not consider the export prices of the U.S. by the export location and ignored the rice grain type of the U.S. in the analysis.

The present study considered the grain types in the estimation process and employed both short and long run model estimation processes, in explaining the interrelationships among f.o.b. prices of milled long and medium grain rice of Arkansas, Louisiana, Texas (Houston), and California. To examine the direction of market relationship, the study also included the rice export prices of India, Thailand, and Vietnam. Finally, this study specifically examined the presence of structural breaks in the price series and attempted to comply with the presence of structural breaks.

3. Materials and methods

3.1 Data

This study relied on data sourced from USDA online data portal on the U.S. rice production, supply, disappearance, trade, and price data (USDA, 2024b). Specifically, the study used data on f.o.b. prices of milled rice from August 1997 to February 2023 in the U.S., milled 5% broken rice export price quotes of India, milled f.o.b. 5% broken rice price of Thailand and milled 5% broken rice export price quotes of Vietnam (USDA, 2024b).

In the case of India and Vietnam, price information for some months was missing. For example, during August 2001- March 2002 the export price information of 5% broken rice of India was missing. We have used information of 5% parbolied rice in such a case. In the case of Vietnam, for example, the price information for November to December 2005 and December 2006 to February 2007 were missing. We filled in the gap by taking the average of the previous three months' prices. All price data are transformed into real using the U.S. CPI (RateInflation, 2023) setting January 2000=100. The descriptive statistics of the variables used in this study are presented in Table 1.

[Insert Table 1 here]

3.2 Model specifications and estimation techniques

3.2.1 Test for unit root and selecting lag length

For any time series estimation process, it is necessary to find out whether each data series follows *I(0)* or *I(1)* process. Furthermore, it is also necessary to define the optimal lag lengths of each data series that will be used as distributed lags to avoid serial correlation in the error term. An examination of the trend of the data series, suggests that the real f.o.b. prices of rice in the U.S. and in the countries sampled have some trends (Figure 1).

[Insert Figure 1 here]

The test results for stationarity of the sampled price series are presented in Table 2. In the process, we have used generalized least-squares regression based modified Dicky-Fuller t-test

(DFGLS) for a unit root, Kwiatkowski-Phillips-Schmidt-Shin test (KPSS)(Kwiatkowski et al., 1992), Phillips-Perron (PP) test (Phillips & Perron, 1988), and a test (DKW) suggested by Ditzen et al., (2021) to examine multiple unknown structural breaks in the data series. For the DF-GLS test, with a single lag, the critical value of the test statistics at a 5% level is -2.986. A DF-GLS tau value greater than the 5% critical value, which is -2.986, indicates that the series is stationary. In the case of the PP test, the 5% critical value of the test statistics is -3.446. A Z(t) value greater than -3.446 indicates that the series is stationary. In the case of the KPSS test, the 5% critical value is 0.146. A value of test statistics less than 0.146 indicates that the series is stationary.

For all data series, all test statistics suggest that the first difference of the natural log follows the *I(1)* process (Table 2). Interestingly, the DF-GLS test shows that the real export price of Vietnam follows *I(0)* process (Table 2), however the PP and KPSS tests indicate that the price series follows *I(1)* process (Table 2). The test for structural breaks (DKW) suggested by Ditzen et al. (2021) suggests at least five structural breakpoints for all data series in various time periods (Table 2).

In selecting the optimal lag length for each data series, we applied the *varsoc* command in Stata and followed the Akaike information criterion (AIC). The optimal lag length for each price series is presented in Table 3.

[Insert Table 3 here]

3.2.2. Model specifications

To examine the interrelationship among rice export prices within the U.S. and between the U.S. and India, Thailand, and Vietnam rice export prices, this study employed the Prais-Winsten and Autoregressive Distributive Lag (ARDL) model estimation processes. Although the Prais-

Winsten method only captures the short-run average relationships, it is highly preferred due to its simplicity and techniques in handling autocorrelation (Bottomley et al., 2023).

To capture the dynamism in the analysis, this study also employed the ARDL model estimation process. The ARDL model is also frequently used in the time series estimation process mainly due to its flexibility in identifying the presence of cointegration in a data series, and its flexibility in handing both *I(0)* and *I(1)* series in a single equation. The ARDL model also allows to use different lag length for each variable. In this study, we thus employ both Prais-Winsten and ARDL estimation processes.

In the empirical estimation process, the Prais-Winsten model is specified as follows:

$$\ln(Y_{t,i}) = \alpha_{0i} + ln\left(Y_{t,i-1}\right)\beta_{1i-1} + \sum_{sb=1}^{5} \Upsilon_{sb}(SBD)_b + \varepsilon_{t,i} \qquad (1)$$

Where,

$\ln(Y_{t,i})$: a vector of dependent variables include the natural log of nine real rice export prices of the U.S. and India, Thailand and Vietnam (i= 1----9), in time t (t=August 1997-February 2023);

$(SBD)_b$: dummies for structural breaks (yes=1)

In Eq.(1), α_{0i} is the constant, β_{1i-1}, and α_{sb} are the parameters to be estimated, ε_{ti} $=\rho\epsilon_{t-1} + e_t \mid \rho \mid<1$, and e_t is white noise.

To capture the influence of the identified structural breaks reported in Table 2; dummy variables were generated and included in Eq.(1).

The empirical ARDL model is specified in this study following Kripfganz & Schneider (2016) as follows:

$$\ln(Y_{i,t}) = \delta_0 + \sum_{p=1}^{P} \emptyset_p \ln(Y_{1t-p}) + \sum_{k=1}^{M} \sum_{j=0}^{Qk} \beta_{k,j} \ln(X_{k,t-j}) + \sum_{sb=1}^{5} \Upsilon_{sb} (SBD)_b + \epsilon_{i,t}$$

(2)

Where,

$\ln(Y_{it})$ = The natural log of the rice export price of series i (i=1---9) in month t;

$\ln(X_{k,t-j})$ = The exogenous regressors in natural log form, which are the rice prices of other grains and countries excluding the price series that has already been treated as a dependent variable $\ln(Y_{i,t})$;

P denotes the optimal number of lags of the dependent variable, and Q denotes the optimal number of lags for the dependent and exogenous regressors, respectively. δ_0 is the constant term, $\emptyset_p$, $\beta_{k,j}$ and Υ_{sb} are the parameters to be estimated. ϵ_t is the error term, which follows the White Noise process. Eq.(2) is estimated for nine sampled price series separately in the empirical estimation process. After estimating Eqs. (1) and (2), several diagnostic tests were run to examine the fitness of the estimated models.

In searching for the most influential price series within the U.S., this study counted the number of times a price series significantly influences other rice export prices, and the number of times other prices significantly influenced the reference price series. For example, assume that the estimated function explaining the medium grain rice export price of California shows that the export prices of Arkansas and Louisiana medium grain rice and the rice export price of Thailand statistically significantly influence the California medium grain rice price. In contrast, the California medium grain rice price significantly impacts the export prices of Arkansas and Louisiana medium grain prices and export prices of Thailand. In such a case, the total number of interactions for the California medium grain rice price is 6 (3+3) and the leadership score is 0 (3-

3). In this study, after combining the number of statistically significant influences from both Prais-Winsten and ARDL model estimation processes, the price with the highest leadership scorer is considered the price leader.

4.0 Findings and discussions

Despite the fact that the U.S. is the fifth largest rice exporting country in the world, rice is not a major crop of the U.S. In 2021, total cropland of the U.S. was 160.3 million ha, but rice was cultivated only on 1.0 million ha (FAOSTAT, 2022a). Rice is mainly cultivated in Arkansas, California, Louisiana, Mississippi, and Texas (Table 4). Interestingly, long grain rice is mostly cultivated in Arkansas, Louisiana, and Texas, the medium grain rice is cultivated in California, Arkansas, and Louisiana. The short grain rice on the other hand, is mainly cultivated in California (Table 4).

[Insert Table 4 here]

A structural change in the U.S. rice economy can be observed in terms of grain type. Over the period, rice cultivation in the U.S is mostly shifted towards long grain by abandoning short and medium grain rice. For example, in 1965, out of total 3.9 million metric tons of total rice production, 43% was long grain, nearly 46% was medium grain, and a little more than 11% was short grain rice (USDA, 2024b). In 2022, out of total 8.1 MMT of total rice, 80% was long grain, and nearly 19% was medium grain (USDA, 2024b).

Rice is not a major food of the U.S. as rice supplies daily only 2% of dietary energy per person, on average(FAOSTAT, 2022b), however, rice imports in the U.S. has been increasing over the years. In 2010/11, total rice import was 0.59 MMT and mostly imported from Thailand and India (USDA, 2024b). In 2022/23, rice import increased to 1.27 MMT, of which is mostly imported from Thailand, India, and China (USDA, 2024b). The imported rice is mainly aromatic *jasmine* from Thailand and *basmati* from India.

The U.S. is the fifth largest rice exporting country in the world, and the U.S. rice exports is dominated by regular milled white rice. In 2021/22, total rice export by the U.S. was 3.06 MMT of which 44% was regular milled white rice (USDA, 2024b). Rough rice is also a part of the U.S. rice exports (USDA, 2024b). In 2021/22, 42% of total rice exported was rough rice (USDA, 2024b). Haiti, Mexico, Canada, Iraq, Japan, Columbia, Honduras, Nicaragua, Panama, and Guatemala are the top rice export markets of the U.S. (USDA, 2024b). The major rice exporting ports of the U.S. are New Orleans in Louisiana, Los Angeles, and Oakland in California, Arkansas, and Houston, Texas.

Whether or not the f.o.b. export prices of long and medium grain rice of the U.S. are interrelated with each other, and whether or not rice export prices of other major rice exporting countries influence the U.S. f.o.b. prices or the prices of the U.S. influence the export prices of other major exporting countries are econometrically presented in Tables 5 and 6.

4.1 Findings from the Prais-Winsten model

Table 5 presents the estimated functions explaining the f.o.b. prices of the U.S. long and medium grain rice by the major ports and rice export prices of India, Thailand, and Vietnam, applying the Prais-Winsten estimation procedure.

[Insert Table 5 here]

The estimated function explaining the long grain f.o.b. rice price of Arkansas demonstrated that the f.o.b. prices of Lousiana long grain and Texas long grain positively and significantly influence the price of Arkansas long grain rice ($p<0.01$). The f.o.b. price of medium grain rice of Arkansas also positively and statistically significantly ($p<0.05$) influence the price of Arkansas long grain (Table 5). The coefficients of the structural break dummies indicated that the real f.o.b. price of Arkansas long grain rice has actually declined from May 2001 to May 2005 (Table 5).

The estimated function explaining the long grain f.o.b. price of Lousiana demonstrated that the prices of Arkansas and Texas long grain positively and statistically significantly influence the price of long grain rice of Lousiana ($p<0.01$). On the other hand, the price of Arkansas medium grain rice negatively and weakly ($p<0.10$) and the price of Lousiana medium grain rice strongly and positively ($p<0.05$) influence the price of Lousiana medium grain rice (Table 5). Importantly, the rice export price of India weakly but positively influences the price of Lousiana long grain f.o.b. rice price (Table 5).

The estimated function explaining the long grain f.o.b. price of Texas demonstrated that the prices of Arkansas and Louisiana long grain positively and significantly influence the f.o.b. price of Texas long grain rice ($p<0.01$). The coefficients of the structural breaks dummies indicated that the real f.o.b. price of Texas long grain rice has actually declined after November 2014 (Table 5).

The estimated function explaining the medium grain f.o.b. rice price of Arkansas demonstrated that the prices of Arkansas long grain, and Lousiana and California medium grain f.o.b. rice prices positively and significantly influence the f.o.b. price of Arkansas medium grain rice ($p<0.01$). The coefficients of the structural break dummies indicated that the real f.o.b. price of Arkansas medium grain rice has actually increased consistently after August 2008 (Table 5).

The estimated function explaining the medium grain f.o.b. rice price of Lousiana demonstrated that the prices of Lousiana long grain and Arkansas medium grain positively highly statistically significantly influence the f.o.b. price of Lousiana medium grain rice ($p<0.01$). The price of California medium grain also positively and significantly influences the price of Lousiana medium grain ($p<0.05$). Importantly, among the international market prices, the export price of Thailand positively and significantly affects the price of Lousiana medium grain rice ($p<0.05$). The coefficients of the structural break dummies indicated that the real f.o.b. price of Lousiana medium grain rice has actually increased consistently from May 2001 to January 2013 (Table 5).

The estimated function explaining the medium grain f.o.b. rice price of California demonstrated that the prices of Arkansas medium grain influence the price of California medium grain rice positively at 1% level, and the price of Lousiana medium grain rice positively influence at 5% level (Table 5). Interestingly, among the international market prices, the export price of Thailand negatively and significantly affects the price of California medium grain rice ($p<0.05$). It shows that a 1% increase in the price of Thai rice reduces the price of California medium grain rice by 0.14% (Table 5). The coefficients of the structural break dummies indicated that the real f.o.b. price of California medium grain rice has actually increased after November 2017, when we control for the influence of other prices (Table 5).

The estimated function explaining the rice export price of India demonstrated that the price of Lousiana long grain positively and significantly influences the export price of India ($p<0.05$). It shows that a 1% increase in the long grain rice of Lousiana increases the export price of India by 0.20% (Table 5). The coefficients of the structural break dummies indicated that the real export price of India has declined during May 2001 to October 2010 (Table 5).

The estimated function explaining the rice export price of Thailand demonstrated that the price of Lousiana medium grain positively and significantly and the California medium grain rice significantly and negatively influence the export price of Thailand ($p<0.05$). It shows that a 1% increase in the long grain rice of Louisiana increases the export price of Thailand by 0.22%, and a 1% increase in the medium grain price of California decreases the export price of Thailand by 0.14% (Table 5). The export price of Vietnam, on the other hand, positively and significantly ($p<0.05$) influences the rice export price of Thailand (Table 5). The coefficients of the structural break dummies indicated that the real export price of Thailand has increased during December 2001 to August 2009 (Table 5).

The estimated function explaining the export price of Vietnam demonstrated that the price of Arkansas medium grain rice positively and weakly ($p<0.10$) influences the export price of Vietnam (Table 5). The export price of Thailand, however positively and highly significantly ($p<0.01$) influences the export price of Vietnam (Table 5). It shows that a 1% increase in the export price of Thailand can increase the rice export price of Vietnam by 0.61% (Table 5).

4.2 Finding from the ARDL model

Table 6 presents the estimated functions explaining the rice export prices of the U.S. long and medium grain rice by the major ports and the rice export prices of India, Thailand, and Vietnam, applying the ARDL model estimation procedure.

The estimated function explaining the long grain export price of Arkansas demonstrated that the price is cointegrated with the sampled prices with a long-run relationship ($p<0.01$). It shows that in the long-run, the long grain export price of Arkansas converges with the existing rice market at a speed of 29% per month. In other words, every month the long grain rice export price of Arkansas adjusts towards the market equilibrium price at a speed of 29% per month (Table 6). An examination of the long-run elasticities reveals that both long ($p<0.01$) and medium grain ($p<0.10$) rice export prices of Louisiana positively influence the long grain rice export price of Arkansas (Table 6). In the short-run, the Texas long grain price ($p<0.05$), Arkansas medium grain price ($p<0.01$), and Louisiana medium grain price ($p<0.10$) influence the long grain rice export price of Arkansas. Importantly, in the short-run, the rice export price of Thailand influences the long grain rice export price of Arkansas (Table 6)

The long grain rice export price of Louisiana is also strongly cointegrated with the global as well as domestic rice market in the long run ($p<0.01$). It shows that in the long-run, the long grain export price of Louisiana converges to the market equilibrium at a speed of 26% per month. It shows that the long grain rice export price of Arkansas significantly and positively ($p<0.01$) influcence the long grain rice export price of Louisiana both in the long run and short run (Table 6). In the short run, the Texas long grain rice positively and Arkansas medium grain rice negatively influcence ($p<0.01$) the long grain rice export price of Lousiana (Table 6). Thailand's rice export price plays a significant and positive role ($p<0.05$) on the long grain rice export price of Louisiana in the short run (Table 6). The coefficients of the structural break dummies indicated that the real long grain rice export price of Lousiana has increased after April 2019 (Table 6).

The long grain rice export market of Texas is also strongly cointegrated with the global as well as domestic rice market ($p<0.01$). It shows that in the long-run, the long grain export price of Texas converges toward market equilibrium at a speed of 18% per month. It shows that the long grain rice export market of Texas is completely free of influence from any other sampled market in the long run (Table 6). However, the long grain rice prices of Arkansas and

Louisiana, and the medium grain rice price of California and the rice export prices of India and Thailand plays role on Texas long grain rice price in the short run (Table 6).

The medium grain rice export market of Arkansas is very strongly co-integrated with domestic as well as global rice market. It shows that in the long run the medium grain rice market of Arkansas adjust to market equilibrium at a speed of 16% per month (Table 6). In the long run, the long grain rice export price of Arkansas and Louisiana and the medium grain rice price of Louisiana play a statistically significant role ($0.05<p<0.10$) on the medium grain rice price of Arkansas (Table 6). In the short run, the long grain rice prices of Arkansas and Louisiana, and the medium grain rice prices of Lousiana and California and the rice export prices of India and Thailand play a role on Arkansas medium grain rice price (Table 6).

The medium grain rice export market of Luosiana is very strongly co-integrated with the domestic as well as global rice market. It shows that in the long run the market adjusts to the equilibrium by 18% per month (Table 6). In the long run, the medium grain rice price of Arkansas plays a statistically significant role ($p<0.01$) on the medium grain rice price of Lousiana (Table 6). In the short run, the long grain rice prices of Lousiana, and the medium grain rice prices of Arkansas play statistically significant role on the medium grain rice price of Lousiana (Table 6).

The medium grain rice export market of California is very strongly co-integrated with domestic as well as global rice market. It shows that in the long run the market adjusts towards equilibrium by 12% per month (Table 6). In the long run, the medium grain rice price of California is influenced by Lousiana long grain rice, and the export price of Thailand (Table 6).

The rice export price of India is very strongly co-integrated with the U.S. and international rice markets. It shows that in the long run the Indian rice export price adjusts to the global rice market at a speed of 17% per month (Table 6). In the long run, the medium grain rice price of California ($p<0.05$) and the export of Thailand ($p<0.05$) positively and significantly influence the rice export price of India (Table 6). In the short run, the long grain rice export price of Arkansas and Louisiana, and the medium grain rice prices of Arkansas and Louisiana influence the rice export price of India (Table 6). The coefficients of the structural break dummies indicated that the real rice export price of India has been declining over the period sampled (Table 5).

The rice export price of Thailand is very strongly co-integrated with the U.S. and international rice markets. It shows that in the long run the Thailand rice export price adjusts to the global rice market at a speed of 26% per month (Table 6). In the long run, the long grain rice price of Arkansas ($p<0.01$) and Lousiana ($p<0.05$) and the export of Vietnam ($p<0.01$) significantly influence the rice export price of Thailand (Table 6). In the short run, the long grain rice export price of Arkansas, Texas, and the medium grain rice prices of California, and the export price of Vietnam influence the rice export price of Thailand (Table 6). The coefficients of the structural break dummies indicated that the real rice export price of Thailand has been increasing over the period sampled (Table 5).

The rice export price of Vietnam is very strongly co-integrated with the U.S. and international rice market. It shows that in the long run the Vietnam rice export price adjusts to the global rice rice market at a speed of 32% per month (Table 6). In the long run, the long grain and medium grian rice prices of Arkansas ($p<0.01$), the long grain rice price of Lousiana ($p<0.01$) and Texas ($p<0.05$) and the export price of Thailand statistically significantly influence the rice export price of Vietnam (Table 6). In the short run, the long grain rice export price of Arkansas, Louisiana, and the medium grain rice price of California plays a significant role on the rice export price of Vietnam (Table 6).

The summary of the findings of Tables 5 and 6 are presented in Table 7. Table 7 was constructed considering how many times a price series plays a role in explaining other rice export prices, and how many times other prices play roles in explaining the reference price series. In the process, we have excluded self-impact (impacts of own lags on own prices) in the case of the ARDL model (Table 6). It shows that in terms of total interactions, the long grain rice export price of Louisiana is the most related price, which has interacted 21 times altogether with other prices (Table 7). The second most related price is the medium grain rice price of Arkansas, which has interacted 19 times altogether (Table 7). In terms of leadership score, the medium grain rice export price of Arkansas is the leader, which was influenced by other prices eight times but influenced other prices a total of 11 times. The medium grain rice price of Louisiana is the second leader in the U.S. rice market (Table 7).

[Insert Table 7 here]

5. Conclusion and policy implications

The U.S. is the fifth largest rice exporting country in the world. Many developing countries such as Haiti, Guatemala, El Salvador, Cameroon, Congo, Niger, Nepal, Benin, Mali, Madagascar, Mozambique and Rwanda, where food security situation is already precarious, rely on imported rice from the U.S. This study demonstrated that the rice prices of the U.S. are spatially strongly related, and secondly the U.S. rice prices are strongly cointegrated with the global market. As the rice prices within the U.S. are strongly spatially connected, it confirms the efficiency of the rice related macro policies of the country.

The findings of the study confirm that the U.S. rice prices is strongly cointegrated with the global rice market in which, the global prices are not only influencing the U.S. rice export prices, but also the U.S. rice prices influencing the global rice export prices. The strong market integration of the U.S. rice market with the global rice market ensures higher prices for the farmers in the U.S.. The findings of the study also indicate that the U.S. plays a significant role in the global rice market. Specifically, the medium grain rice export prices of Arkansas and Louisiana are the most influential rice markets to influence the global rice market. The information can be useful for the policy markers and rice market monitors to formulate early warning messages.

Finally, the findings of this study confirm that the rice prices of the U.S. significantly influence the global rice prices, as well as the prices of the major exporting countries also affect the rice export prices of the U.S. Based on the findings, to keep the global rice market less volatile and stable, this study suggests to ensure sustainable rice production not only in the U.S., but also in other major rice exporting countries, such as in India, Vietnam, and Thailand. As the rice export prices of the major exporting countries are strongly interlinked, sustaining domestic production in the major exporting countries can ensure export prices are less volatile, which can contribute to the food security of the rice importing developing countries. Policies and strategies must be formulated to sustain future rice production in the face of increasingly warming global climate and population pressure.

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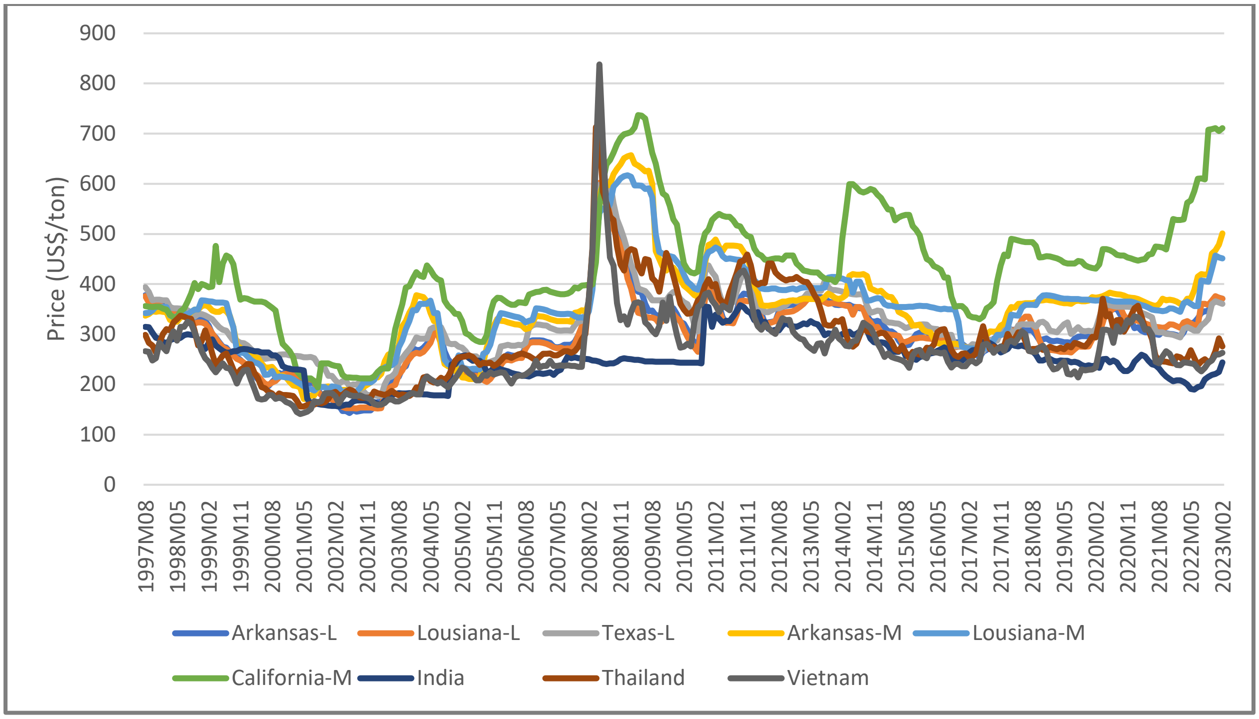

Figure 1: Co-movement of f.o.b. prices of milled rice of the U.S. and India, Thailand and Vietnam's rice export price during August 1997- February 2023.

Source: Authors based on (USDA, 2024b).

Notes: All monetary values are converted into real using the U.S. CPI setting January 2000=100. L-long grain, M= medium grain.

Table 1: Descriptive statistics

Price (US$/ton/barrel)	No. of observations	Mean	Standard deviation	Minimum	Maximum
Arkansas-long grain	307	300.6	73.4	143	591
Luisiana-long grain	307	296.9	70.2	152	602
Texas (Houston)-long grain	307	322.7	67.5	177	605
Arkansas-medium grain	307	348.9	96.7	171	657
Luisiana-medium grain	307	350.4	89.5	183	617
California-medium grain	307	431.6	117.0	194	737
India %	307	250.7	45.5	156	358
Thailand 5%	307	293.2	88.4	156	713
Vietnam 5%	307	264.3	78.2	141	838

Note: all monetary

Notes: All monetary values are converted into real using the U.S. CPI setting January 2000=100.

Source: Authors based on (USDA, 2024b).

Table 2: Stationarity test results.

Variables (ln)	DFGLS		PP		KPSS		DKW	Summary
	Level	1st dif.	Level	1st dif.	Level	1st dif.	MB	
Arkansas-Long grain	-2.11	-7.45***	-2.65 (0.25)	-8.84*** (0.00)	0.41*** (0.00)	0.07 (0.34)	2001m5, 2005m5, 2009m3, 2013m4, 2017m2	I(1) S. break
Luisiana-long grain	-2.07	-7.86***	-2.76 (0.21)	-9.3*** (0.00)	0.38*** (0.00)	0.07 (0.36)	2001m8, 2005m6, 2009m4, 2015m1, 2019m4	I(1), S. break
Texas-Long grain	-2.17	-8.98***	-2.67 (0.24)	-10.4*** (0.00)	0.47*** (0.00)	0.07 (0.41)	2002m9, 2006m10, 2011m1, 2014m11, 2018m9	I(1) S. break
Arkansas-medium grain	-2.12	-7.91***	-2.23 (0.47)	-10.2*** (0.00)	0.45*** (0.00)	0.07 (0.40)	2001m8, 2005m8, 2009m8, 2013m6, 2017m4	I(1) S. break
Luisiana-medium grain	-2.02	-8.60***	-2.17 (0.50)	-10.9*** (0.00)	0.53*** (0.00)	0.07 (0.34)	2001m5, 2005m5, 2009m3, 2013m1, 2016m11	I(1) S. break
California-medium grain	-2.15	-8.24***	-2.39 (0.39)	-12.4*** (0.00)	0.34*** (0.00)	0.05 (0.55)	2001m5, 2005m7, 2009m8, 2014m1, 2017m11	I(1) S. break
Thailand	-2.28	-9.55***	-2.14 (0.52)	-11.5*** (0.00)	0.68*** (0.00)	0.07 (0.41)	2001m12, 2005m10, 2009m8, 2013m7, 2017m10	I(1) S. break
India	-1.59	-11.2***	-2.35 (0.41)	-15.8*** (0.00)	0.54*** (0.00)	0.09 (0.19)	2001m5, 2005m8, 2010m10, 2015m2, 2019m4	I(1) S. break
Vietnam	-3.08**	-9.90***	-2.95 (0.14)	-11.9*** (0.00)	0.53*** (0.00)	0.03 (0.86)	2001m7, 2005m7, 2009m5, 2013m9, 2018m12	I(1) S. break

Source: Authors.

Notes: DFGLS: Modified Dickey-Fuller unit-root test for stationarity transformed by a generalized least square regression. PP: Phillips-Perron unit-root test for stationarity. KPSS: Kwiatkowski-Phillips-Schmidt-Shin test for stationarity DKW: Sequential test for multiple breaks at unknown breakpoints, suggested by Ditzen, Karavias and Westerlund test allowing for multiple breaks in a series. S. break: Presence of multiple structural breaks.

Table 3: Selection of optimal lag length of distributed lagged variables

Variable	Optimal lag length
ln(Arkansas-LG)	2
ln(Luisiana-LG)	2
ln(Houston-LG)	2
ln(Arkansas-MG)	2
ln(Luisiana-MG)	2
ln(California-MG)	4
ln(India)	1
ln(Thailand)	2
ln(Vietnam)	2

Source: Authors calculation.

Table 4: Rice area and production by states and grain type in 2022/23 year.

	Area (1000 ha)	Yield (ton/ha)	Total production (1000 tons)
Long grain			
Arkansas	400.6	8.3	3736.9
California	2.8	7.1	22.4
Louisiana	148.1	7.5	1242.1
Mississippi	34.0	8.3	314.5
Missouri	59.1	8.9	589.7
Texas	73.2	7.4	605.1
Medium grain			
Arkansas	37.6	8.1	342.1
California	88.2	10.1	999.0
Louisiana	19.8	7.3	162.6
Mississippi	0.4	0.0	0.1
Missouri	1.2	8.4	11.4
Texas	2.0	4.4	9.9
Short grain			
Arkansas	0.4	5.6	2.5
California	11.7	8.3	109.0
Total/average	879.1	9.27	8147.3

Source: Authors based on (USDA, 2024b).

Table 5: Estimated functions applying Prais-Winsten model estimation procedure explaining milled rice export prices long and medium grain rice of the U.S.

	ln(Price of long grain rice in)			ln(Price of medium grain rice in)			ln(International prices of)		
	AR-LG$_t$	LU-LG$_t$	Texas-LG$_t$	AR-MG$_t$	LU-MG$_t$	CA-MG$_t$	India	Thai	Viet Nam
ln(Arkansas-LG)$_t$		0.65***	0.36***	0.28***	-0.060	0.018	-0.20	0.28	-0.027
		(0.05)	(0.08)	(0.10)	(0.10)	(0.15)	(0.12)	(0.17)	(0.22)
ln(**Luisiana**-LG)$_t$	0.64***		0.33***	-0.16	0.29***	0.14	0.20**	-0.086	0.15
	(0.06)		(0.08)	(0.11)	(0.11)	(0.15)	(0.10)	(0.18)	(0.23)
ln(Texas-LG)$_t$	0.24***	0.24***		0.046	-0.043	0.030	0.23	0.14	0.20
	(0.05)	(0.06)		(0.07)	(0.07)	(0.09)	(0.23)	(0.12)	(0.15)
ln(Arkansas-MG)$_t$	0.13**	-0.12*	0.033		0.60***	0.34***	0.033	-0.017	0.16*
	(0.05)	(0.06)	(0.06)		(0.05)	(0.11)	(0.07)	(0.09)	(0.08)
ln(Luisiana-MG)$_t$	-0.027	0.18**	-0.019	0.61***		0.17**	-0.037	0.22**	-0.16
	(0.06)	(0.07)	(0.07)	(0.10)		(0.08)	(0.07)	(0.11)	(0.10)
ln(California-MG)$_t$	0.0010	0.035	0.017	0.16***	0.071**		0.0058	-0.14**	-0.0044
	(0.03)	(0.03)	(0.03)	(0.04)	(0.03)		(0.04)	(0.06)	(0.06)
ln(India)$_t$	-0.037	0.053*	0.070	0.015	-0.0084	0.016		0.081	0.0083
	(0.02)	(0.03)	(0.06)	(0.03)	(0.03)	(0.05)		(0.07)	(0.07)
ln(Thailand)$_t$	0.054	-0.025	0.037	-0.011	0.062**	-0.14**	0.032		0.61***
	(0.03)	(0.04)	(0.03)	(0.04)	(0.03)	(0.06)	(0.05)		(0.06)
ln(Vietnam)$_t$	-0.0018	0.019	0.045	0.031	-0.022	0.012	0.013	0.41***	
	(0.03)	(0.04)	(0.03)	(0.02)	(0.02)	(0.05)	(0.04)	(0.06)	
First structural break	-0.035***	-0.0050	-0.0035	0.063***	0.045***	0.025	-0.017	0.069**	0.025
dummy (yes-1)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.03)	(0.01)	(0.03)	(0.03)
Second structural	-0.018*	-0.00091	0.00098	0.12***	0.063***	0.035	-0.034*	0.12**	0.033
break dummy (yes-1)	(0.01)	(0.01)	(0.01)	(0.03)	(0.02)	(0.04)	(0.02)	(0.05)	(0.04)
Third structural break	-0.016	-0.013	-0.025	0.090**	0.081***	0.012	-0.051**	0.11**	0.038
dummy (yes-1)	(0.01)	(0.02)	(0.02)	(0.04)	(0.02)	(0.04)	(0.02)	(0.05)	(0.04)
Fourth structural	-0.0068	-0.0063	-0.038*	0.079**	0.079***	0.054	-0.048*	0.056	0.057
break dummy (yes-1)	(0.01)	(0.02)	(0.02)	(0.03)	(0.02)	(0.05)	(0.03)	(0.05)	(0.04)
Fifth structural break	-0.022	0.0094	-0.040*	0.090***	0.011	0.13**	-0.051	0.040	0.023
dummy (yes-1)	(0.01)	(0.03)	(0.02)	(0.03)	(0.02)	(0.05)	(0.03)	(0.05)	(0.05)
Constant	-0.052	-0.22	0.85**	0.059	0.60***	2.61***	3.93***	0.68	0.16
	(0.18)	(0.26)	(0.38)	(0.28)	(0.23)	(0.53)	(1.07)	(0.74)	(0.50)
Observations	307	307	307	307	307	307	307	307	307
F	143.9	102.1	36.7	56.2	70.5	11.24	1.55	8.03	37.57
Prob>F	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00
R2	0.98	0.98	0.97	0.95	0.96	0.80	0.77	0.89	0.89
Rho	0.78	0.85	0.86	0.92	0.89	0.97	0.97	0.90	0.80
Durbin–Watson statistic (original)	0.65	0.64	0.38	0.38	0.49	0.24	0.48	0.49	0.59
Durbin–Watson statistic (original)	1.96	2.02	1.90	1.87	1.87	1.79	1.83	1.76	1.78

Note: Numbers in parentheses are robust standard errors. *Significant at the 10% level. **Significant at the 5% level. ***Significant at the 1%.

Table 6: Estimated functions applying the ARDL model estimation procedure explaining prices in different market in the U.S. and in India, Thailand and Vietnam

	ln(Price of long grain rice in)			ln(Price of midium grain rice in)			ln(export price of)		
	Arkansas$_t$	Luisiana$_t$	Texas$_t$	Arkansas$_t$	Luisiana$_t$	California$_t$	India	Thailand	Viet Nam
Adjustment factor	-0.29***	-0.26***	-0.18***	-0.16***	-0.18***	-0.12***	-0.17***	-0.26***	-0.32***
	(0.05)	(0.04)	(0.04)	(0.04)	(0.03)	(0.02)	(0.03)	(0.04)	(0.04)
ln(Arkansas-LG)t		1.09***	0.52	0.86*	0.048	-0.24	0.27	1.28***	-1.49***
		(0.11)	(0.32)	(0.47)	(0.35)	(0.79)	(0.61)	(0.42)	(0.38)
ln(**Luisiana**-LG)$_t$	0.74***		0.29	-0.72*	0.15	1.01	-0.66	-0.94**	1.31***
	(0.08)		(0.32)	(0.41)	(0.32)	(0.71)	(0.55)	(0.37)	(0.34)
ln(Texas-LG)$_t$	0.11	-0.19		-0.15	-0.086	-0.66	0.26	-0.15	0.48**
	(0.10)	(0.13)		(0.27)	(0.22)	(0.50)	(0.38)	(0.25)	(0.23)
ln(Arkansas-MG)$_t$	-0.025	-0.039	-0.077		0.77***	1.39***	-0.27	-0.079	0.53***
	(0.10)	(0.10)	(0.17)		(0.12)	(0.36)	(0.30)	(0.21)	(0.19)
ln(Luisiana-MG)$_t$	0.19*	-0.047	-0.081	0.66***		-0.41	-0.010	0.14	-0.32
	(0.10)	(0.10)	(0.17)	(0.15)		(0.42)	(0.30)	(0.21)	(0.19)
ln(California-MG)$_t$	0.0073	0.0041	0.090	0.070	-0.0024		0.36**	-0.12	-0.14
	(0.04)	(0.05)	(0.09)	(0.10)	(0.09)		(0.15)	(0.10)	(0.10)
ln(India)$_t$	0.011	0.012	0.056	-0.087	-0.074	0.065		0.13	0.029
	(0.04)	(0.05)	(0.09)	(0.10)	(0.09)	(0.19)		(0.08)	(0.10)
ln(Thai5%)$_t$	0.049	-0.054	0.035	0.059	0.13	-0.18	0.46**		0.63***
	(0.06)	(0.07)	(0.12)	(0.16)	(0.12)	(0.29)	(0.20)		(0.10)
ln(Vietnam)$_t$	-0.022	0.088	0.072	0.090	-0.050	0.045	0.029	0.77***	
	(0.06)	(0.07)	(0.12)	(0.15)	(0.12)	(0.29)	(0.22)	(0.09)	
SR									
ln(Arkansas-LG)$_t$		0.31***	0.15*	0.14*	-0.060	0.11	-0.28**	0.023	0.44***
		(0.06)	(0.08)	(0.09)	(0.08)	(0.12)	(0.13)	(0.13)	(0.16)
ln(Arkansas-LG)$_{t-1}$	0.14**	-0.051	0.055	-0.18**	-0.000065	0.014	0.0017	-0.29**	0.39**
	(0.06)	(0.06)	(0.08)	(0.08)	(0.08)	(0.12)	(0.13)	(0.13)	(0.15)
ln(Lusiana-LG)$_t$	0.35***		0.24***	-0.13	0.27***	-0.024	0.29**	0.091	-0.36**
	(0.06)		(0.07)	(0.08)	(0.08)	(0.12)	(0.12)	(0.13)	(0.15)
ln(Lusiana-LG)$_{t-1}$	0.071	0.058	0.049	0.084	-0.14*	-0.34***	0.20*	-0.0011	-0.14
	(0.06)	(0.06)	(0.07)	(0.08)	(0.08)	(0.11)	(0.12)	(0.12)	(0.15)
ln(Texas-LG)$_t$	0.13**	0.26***		0.070	-0.017	0.12	0.11	0.21*	0.041
	(0.05)	(0.05)		(0.07)	(0.07)	(0.10)	(0.11)	(0.11)	(0.13)
ln(Texas-LG)$_{t-1}$	0.00093	0.032	0.074	0.032	0.065	0.038	-0.051	-0.030	-0.21*
	(0.05)	(0.05)	(0.06)	(0.07)	(0.06)	(0.09)	(0.10)	(0.10)	(0.12)
ln(Arkansas-MG)$_t$	0.16***	-0.14***	0.040		0.39***	0.011	0.082	0.042	-0.0032
	(0.05)	(0.05)	(0.05)		(0.05)	(0.09)	(0.09)	(0.09)	(0.11)
ln(Arkansas-MG)$_{t-1}$	-0.0091	-0.012	-0.037	0.11*	0.023	0.12	0.17*	-0.072	-0.043
	(0.05)	(0.05)	(0.06)	(0.06)	(0.06)	(0.09)	(0.09)	(0.10)	(0.12)
ln(Lusiana-MG)$_t$	-0.083*	0.21***	-0.0011	0.47***		0.069	-0.031	0.11	0.11
	(0.05)	(0.05)	(0.06)	(0.06)		(0.09)	(0.09)	(0.10)	(0.12)
ln(Lusiana-MG)$_{t-1}$	-0.060	0.026	0.00010	-0.016	0.16***	0.14	-0.19**	0.059	-0.091
	(0.05)	(0.05)	(0.06)	(0.06)	(0.06)	(0.09)	(0.09)	(0.10)	(0.12)
ln(California-MG)$_t$	0.022	0.023	-0.0040	0.079*	0.00017		-0.023	-0.14**	0.051
	(0.03)	(0.03)	(0.04)	(0.04)	(0.04)		(0.06)	(0.06)	(0.08)
ln(California -MG)$_{t-1}$	-0.0029	-0.018	0.060*	0.073*	-0.019	0.11*	0.031	-0.17***	0.057
	(0.03)	(0.03)	(0.04)	(0.04)	(0.04)	(0.06)	(0.06)	(0.06)	(0.08)
ln(California -MG)$_{t-2}$	-0.020	0.049	-0.067*	0.15***	-0.047	0.048	-0.090	-0.027	0.0022
	(0.03)	(0.03)	(0.04)	(0.04)	(0.04)	(0.06)	(0.06)	(0.06)	(0.08)
ln(California -MG)$_{t-3}$	0.019	-0.023	0.036	0.025	0.041	-0.0015	0.0049	0.017	-0.13*
	(0.03)	(0.03)	(0.04)	(0.04)	(0.04)	(0.06)	(0.06)	(0.06)	(0.07)
ln(India)$_t$	-0.048	0.042	0.058*	0.040	-0.0028	0.033		0.018	0.049
	(0.03)	(0.03)	(0.04)	(0.04)	(0.04)	(0.06)		(0.06)	(0.08)
ln(Thai5%)$_t$	0.069**	-0.024	0.045	-0.0077	0.036	-0.12**	0.0091		0.34***
	(0.03)	(0.03)	(0.03)	(0.04)	(0.04)	(0.05)	(0.06)		(0.07)
ln(Thai5%)$_{t-1}$	-0.049*	0.076**	-0.067*	0.051	-0.041	0.13**	-0.036	0.19***	0.15**
	(0.03)	(0.03)	(0.03)	(0.04)	(0.04)	(0.06)	(0.06)	(0.06)	(0.07)
ln(Vietnam)$_t$	0.0023	-0.012	0.036	0.033	0.013	-0.0073	0.047	0.17***	
	(0.02)	(0.02)	(0.03)	(0.03)	(0.03)	(0.04)	(0.05)	(0.05)	
ln(Vietnam)$_{t-1}$	0.011	-0.0087	0.033	0.010	-0.023	0.034	-0.062	-0.013	0.19***
	(0.02)	(0.02)	(0.03)	(0.03)	(0.03)	(0.04)	(0.05)	(0.05)	(0.06)
First structural break	-0.0024	-0.0068	0.0053	-0.0084	0.0015	0.011	-0.046***	0.021*	0.0023
dummy (yes-1)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)

Second structural break dummy (yes-1)	-0.0024 (0.01)	0.00100 (0.01)	0.0053 (0.01)	0.0065 (0.01)	0.0071 (0.01)	0.0035 (0.01)	-0.045*** (0.01)	0.035*** (0.01)	0.0020 (0.01)
Third structural break dummy (yes-1)	-0.0070 (0.01)	0.0066 (0.01)	-0.0041 (0.01)	0.0028 (0.01)	0.0079 (0.01)	-0.0013 (0.01)	0.00019 (0.01)	0.036*** (0.01)	-0.0020 (0.02)
Fourth structural break dummy (yes-1)	-0.0039 (0.01)	0.0000017 (0.01)	-0.012* (0.01)	-0.0023 (0.01)	0.015** (0.01)	0.020** (0.01)	-0.017* (0.01)	0.0058 (0.01)	0.026** (0.01)
Fifth structural break dummy (yes-1)	-0.0053 (0.00)	0.010* (0.01)	-0.0061 (0.01)	0.0081 (0.01)	-0.0019 (0.01)	0.0088 (0.01)	-0.039*** (0.01)	0.018* (0.01)	0.0024 (0.01)
Constant	-0.093 (0.08)	0.20** (0.08)	0.11 (0.10)	0.19* (0.10)	0.11 (0.11)	0.017 (0.15)	0.52*** (0.17)	-0.053 (0.14)	-0.092 (0.19)
No. of observations	303	303	303	303	303	303	303	303	303
R^2	0.79	0.79	0.68	0.66	0.66	0.44	0.23	0.53	0.53
Log likelihood	794.4	789.2	739.2	706.3	723.5	601.7	574.0	547.1	516.9
Durbin–Watson d-statistic(39, 303)	2.05	1.97	1.95	1.92	2.01	1.95	1.82	1.94	2.07
Breusch–Godfrey LM test for autocorrelation (Chi^2)	4.04 (0.13)	1.88 (0.39)	9.51 (0.01)	8.06 (0.02)	0.27 (0.87)	3.24 (0.51)	2.79 (0.10)	14.9 (0.00)	5.80 (0.06)
White's test for heteroskedasticity	303.0 (0.47)	303.0 (0.47)	302.0 (0.47)	302.0 (0.47)	302.0 (0.47)	303.0 (0.47)	302.0 (0.47)	302.0 (0.47)	302.0 (0.47)
Bound test-based decision: LR	Y	Y	ID	Y	Y	Y	Y	Y	Y
Model stability test	F	F	F	P	F	P	P	F	P

Note: Numbers in parentheses are robust standard errors. *Significant at the 10% level. **Significant at the 5% level. ***Significant at the 1%.

Table 7: Summary of the findings of Table 5 and 6.

Country	Plays role on other countries' price (number)		Influenced by other countries' prices (number)		Total interactions	Leadership score
	a	b	c	d	e=a+b+c+d	f=(a+b)-(c-d)
	Prais-Winsten	ARDL	Prais-Winsten	ARDL		
Arkansas-long grain	3	6	3	5	17	0
Louisiana- long grain	4	7	5	5	21	-3
Texas-long grain	2	4	2	5	13	0
Arkansas-medium grain	5	6	3	5	19	1
Louisiana- medium grain	4	4	4	2	14	1
California- medium grain	3	4	3	3	13	-1

Source: Authors based on Tables 8 and 9.