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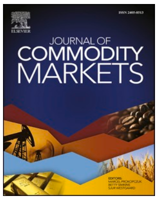

The asymmetric impact of global economic policy uncertainty on international grain prices

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ABSTRACT

Using monthly data from January 1998 to May 2021, this study investigates the asymmetric impact of global economic policy uncertainty (GEPU) on international grain prices by using nonlinear autoregressive distribution lag (NARDL). We find that there is a positive, asymmetric relationship between GEPU and international grain prices. Specifically, GEPU has a greater negative than positive impact on wheat and maize prices, and the positive impact on soybean price is more pronounced than the negative one. We have also observed that the asymmetric impact of GEPU on rice price is not significant in the long run. The findings have important implications to formulate targeted and differentiated international grain price regulatory policies.

1. Introduction

The increase in global economic policy uncertainty (GEPU) caused by the outbreak of COVID-19 in 2019 may have a significant impact on the rise of international grain prices. In fact, the volatility in international grain prices has always been the focus of concern among academics, policymakers, investors, farmers, and consumers. International grain prices significantly impact grain security, and are related to the vital interests of local residents (Amolegbe et al., 2021). International grain prices not only directly affect food prices, but also affect overall price stability through upstream and downstream chain transmission. Since 1998, international grain prices have experienced long-term and drastic fluctuations, especially during the global grain crisis in early 2008 and the outbreak of the COVID-19 in 2019. The continuous volatility of international grain prices has brought immense uncertainty to the international grain market, threatening not only global grain security but also economic and social stability (Gilbert and Mugera, 2014; Marktanner and Noiset, 2013). Thus, countries worldwide attach great importance to the changing trend of international grain prices, and consider stabilizing grain prices as a crucial goal of economic and social policies.

In addition to being affected by factors such as supply and demand (Gohin and Chantret, 2009), financial speculation, production costs, and natural disasters (Santeramo and Lamonaca, 2019), international grain prices are also affected by GEPU. Generally speaking, when the world faces major events such as wars, economic and financial crises, terrorist attacks, sudden health crisis, natural disasters, etc., it is possible for governments to adjust their economic policies more frequently and significantly, thereby exacerbating the uncertainties and risks faced by various market players around the world (Baker et al., 2016). Changes in GEPU will also affect the supply

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and demand of global grain markets. For example, the COVID-19 pandemic has led to a significant increase in global economic risks, and many grain exporting countries have restricted exports in order to ensure their own grain security, resulting in a reduction in the international grain supply. On the other hand, grain importing countries in the pandemic are in the need of stockpiles. There is an incentive to increase grain imports to ensure domestic grain security. Therefore, with the backdrop of the continued COVID-19 pandemic and high global economic risks, it is of great practical significance to explore the impact of GEPU on international grain prices.

Economic policy uncertainty was difficult to directly observe until Baker et al. (2016) constructed an economic policy uncertainty index based on the newspaper coverage frequency method; it is currently one of the most widely used methods to measure the overall level of economic policy uncertainty. Fig. 1 shows the changes in the GEPU index and main international grain prices from January 1998 to May 2021. During periods of severe fluctuations in GEPU, there are greater fluctuations in international grain prices as well, indicating there is a strong linkage between GEPU and international grain prices. For example, during the period of violent fluctuations in GEPU around July 2008, after the outbreak of the international financial crisis, international grain prices (wheat, maize, soybean, and rice) also fluctuated sharply. Similarly, in the recent fluctuations in GEPU since 2018, international grain prices have also shown large fluctuations. Therefore, GEPU may have an impact on international grain prices, and this impact seems to be positively correlated. Moreover, from the perspective of fluctuations, the impact of the rise and fall of GEPU on the rise and fall of international grain prices is inconsistent, which shows that the impact of GEPU on international grain prices may be nonlinear and asymmetrical.

However, the previous literature focusing on the impact of GEPU on international grain prices is quite limited, and most of it focuses on the effects of economic policy uncertainty on energy prices, cryptocurrency prices or other commodity prices (Long et al., 2022). In addition, although a few studies that have examined the impact of uncertainty on international grain prices, they have not delved into the long- and short-run asymmetric effects of GEPU on international grain prices (Wen et al., 2021). Therefore, in order to fill this gap, this paper uses monthly data from January 1998 to May 2021, and employs the nonlinear autoregressive distributed lag model (NARDL) to investigate the asymmetric impact of GEPU on main international grain prices.

This paper makes two valuable contributions to the existing literature. First, we employ the nonlinear autoregressive distributed lag model (NARDL) developed by Shin et al. (2014) to capture the asymmetric impact of GEPU on international grain prices. This will enrich the literature on the asymmetric relationship between GEPU and international grain prices (wheat, maize, soybean, and rice) in the long and short run. Second, the conclusions of this research have important reference value for making policies to stabilize international grain prices. We accurately distinguish the heterogeneous impacts of GEPU on various international grain prices. That is to say, the asymmetric effects of GEPU on different kinds of grain prices are clearly distinct, and there is a difference in the degree of influence of the rise and fall of GEPU on the price of the same grain. This helps to formulate more accurate and differentiated grain

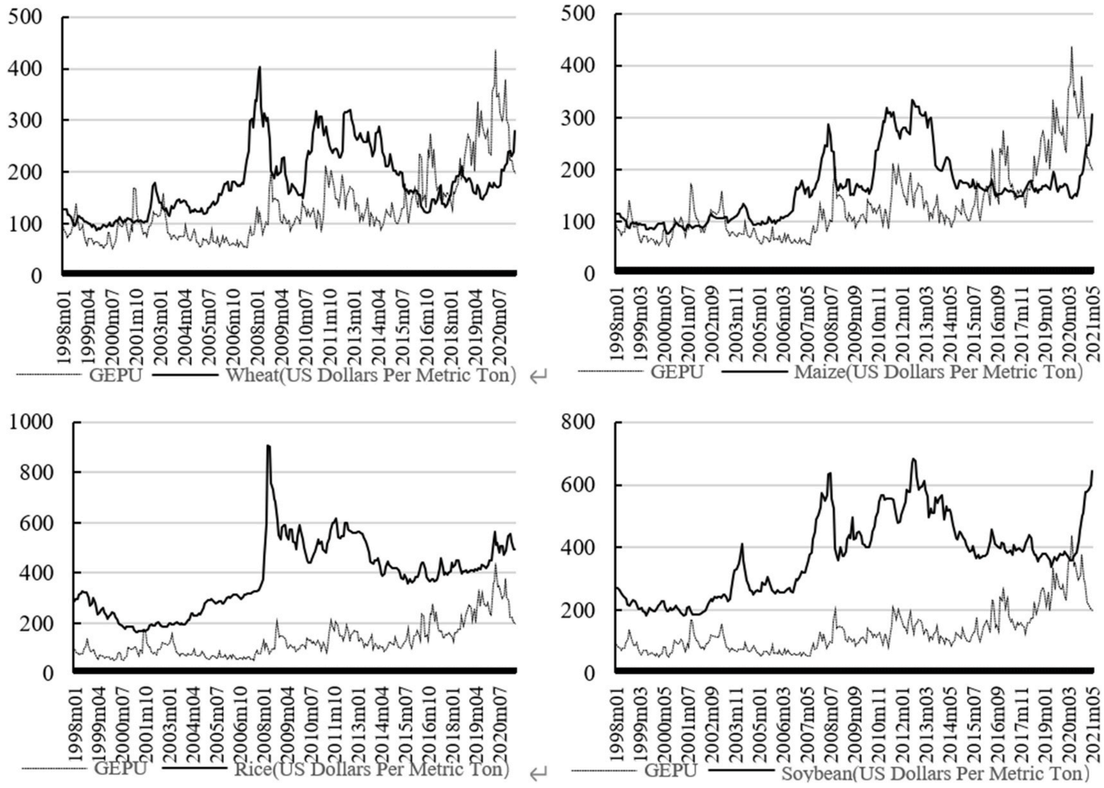

Fig. 1. Trends of global economic policy uncertainty and major international grain prices.

price regulator policies when facing the same GEPU rising and falling.

The empirical results of this study reveal two findings. First, the impact of GEPU on international grain prices, are asymmetric in the long and short run. Therefore, when facing a rising or falling in GEPU, differentiated price regulatory policies are essential to ensure the effectiveness of policy implementation. Second, there are variations in the asymmetric impact of GEPU on international grain prices. For wheat and maize, the decline in price caused by a decline in GEPU is greater than the increase in price caused by a rise in GEPU; for soybean, the increase in price caused by a rise in GEPU is greater than the decline in price caused by a decline in GEPU. However, the rising and falling of GEPU have no significant asymmetric impact on rice price in the long run.

The remainder of this paper is organized as follows: Section 2 provides the relevant theoretical background of the impact of GEPU on international grain prices. Section 3 introduces the variables used in this research and the source of data. Section 4 outlines the empirical approach used for investigating the asymmetric impact of GEPU on international grain prices. Section 5 discusses the results of the empirical analysis. Section 6 summarizes the main findings and proposes corresponding suggestions.

2. Background

International grain prices have experienced violent fluctuations, and the price formation of grains is affected by a variety of macroeconomic factors. First, the changes in international grains' prices can be explained by changes in supply and demand. Regional grain production and its annual changes have important implications for international grain prices (Zelingher et al., 2021), and demand shocks are also principal sources of price changes of several agricultural commodities (Gilbert, 2010). Second, energy prices may have significant spillover effects on agricultural prices, i.e., agricultural commodities are sensitive to movements in energy commodities (Qiang et al., 2018). The impact of the rising production costs such as oil prices (Headey and Fan, 2008), and the development of biofuels (Gilbert and Mugera, 2014) on grain prices have also been confirmed. Third, financial factors of international grain prices cannot be ignored either, such as dollar depreciation and financial speculation. On the one hand, when the dollar weakens, agricultural grain prices increase (Mitchel, 2008; Hernandez et al., 2014). On the other hand, there is some debate about whether financial investors have caused excessive increases on volatility of commodity grain prices (Irwin and Sanders, 2011; Dwyer et al., 2012). Fourth, some studies observe strong commodity price co-movement among various markets in recent years (Dorfman and Karali, 2014; Adhikari and Putnam, 2020). For instance, in the grain market, there is substitutability between rice and wheat, and there is a corresponding linkage in their prices. In addition, in the feed market, there is a complementary relationship between corn and soybeans, and their prices may have a certain linkage.

Since Bloom (2009) proposed a pioneering study on uncertainty, research on the impact of economic policy uncertainty on macroeconomic variables has continuously emerged (Baker et al., 2016; Bloom et al., 2018). GEPU has an impact on macroeconomic fluctuations and the behavior of market participants. For example, GEPU has a wide range of impacts on investment, consumption, and imports and exports (Bloom, 2014; Guvenen et al., 2014). In addition to the supply and demand shocks, economic policy uncertainty shocks have a significant and continuous positive impact on the prices of commodities, such as energy, agricultural products and precious metals (Bakas and Triantafyllou, 2018; Joëts et al., 2017; Long et al., 2021). Thus, GEPU is likely to cause fluctuations in global grain prices, and may cause a redistribution of benefits between grain producers and consumers.

The main impact mechanism of GEPU on international grain prices is as follows: First, GEPU affects the behaviors and decision-making of various participants in the international grain market by influencing individual behavior characteristics and preferences (Kim and kung, 2017). GEPU may increase the uncertainty of the total grain supply and total grain demand, which impacts the behavior of grain producers and consumers and will increase the volatility of international grain prices (Bakas and Triantafyllou, 2018).

Second, GEPU will also change market speculators' expectations for the future, and have a certain impact on international grain speculation and demand (Stokey, 2016). When the future value of currency is unreliable, commodities, including grain, are regarded as safe physical assets (Cooper and Lawrence, 1975); commodity investment not only hedges against inflation, but may also increase the return of investors' asset and financial derivatives portfolio, and reduce portfolio risk (Gorton and Rouwenhorst, 2006). Thus, in theory, the uncertainty of global economic policy has a significant impact on international grain prices.

Empirically, related literature shows the impact of economic policy uncertainty on commodity prices such as grain (Bakas and Triantafyllou, 2018). It is worth noting that in reality, the economic and financial variables, including GEPU and international grain prices, are not simply linear, but rather nonlinear. Since the linear relationship assumptions of traditional econometric models are too strict and cannot capture a real nonlinear relationship well, it is more appropriate to use nonlinear econometrics to describe them (Shin et al., 2014). In fact, the nonlinear characteristics of economic uncertainty on international prices of oil and agricultural products exist (Van, 2016; Mobeen et al., 2019). Literature studying the asymmetric impact of GEPU on international grain prices is scant. Xiao et al. (2019) find that economic policy uncertainty has less influence on wheat futures price than on maize and soybean, and the Chinese government interventions may be the reason for this difference. Wen et al. (2021) suggest that negative shocks of uncertainty have a deeper effect than positive shocks on grain prices in China.

It is clear existing studies have shown that economic policy uncertainty has a significant impact on the prices of international commodities. However, few studies have focused on the special nonlinear relationship between the long run and short run asymmetric effects of different international grain prices when GEPU rises and falls. This nonlinear and asymmetric relationship is of great significance for clarifying the heterogeneity transmission mechanism of economic policy uncertainty to different international grain prices, and for formulating asymmetric and differentiated grain price control policies. To this end, this paper uses the NARDL model to study the long run and short run asymmetric effects of rising and falling GEPU on the prices of major international grains (wheat, corn, soybean, and rice), so as to provide relevant departments with targeted and non-symmetrical measures.

3. Data

This study employs monthly data from January 1998 to May 2021 for the empirical analysis. Monthly data for empirical analysis are selected due to the high-frequency and the availability of variable data. Generally speaking, high-frequency data have more information than low-frequency data. For example, compared with annual or quarterly data, monthly data are abundant and informative, helping to ensure a large enough data sample and more reliable results. In addition, the highest frequency of explained variable, key explanatory variables, and most control variables are provided in the form of monthly data; the daily or weekly data for international grain prices, GEPU, and global economic activity index are not available.

3.1. Main variables

We select the four main international grains (wheat, maize, soybean, and rice) as the samples to investigate the asymmetric effects of GEPU on different international grain prices; these grains are the four most important global staple crops in the world (Haile et al., 2014), and they constitute a substantial share of world food production (Roberts and Schlenker, 2009). Moreover, in order to strengthen world food security, the Food and Agriculture Organization of the United Nations (FAO) mainly focuses on the production and supply of wheat, corn, soybeans, and rice, monitoring and tracking their price changes. The international grain prices regularly published by the FAO on its official website are limited to these four kinds, highlighting their importance in comparison to other grains.[1] In addition, scholars' attention to global grain is also mainly focused on these four staple food crops (Stevens, 1991; Roberts and Schlenker, 2013; Gutierrez, 2013).

International grain prices include wheat prices (*lnwheat*), maize prices (*lnmaize*), soybean prices (*lnsoybean*), and rice prices (*lnrice*), which are measured by U.S. No. 1 hard red winter wheat (USD per Metric Ton), U.S. No. 2, yellow maize (USD per Metric Ton), U.S. No. 2 yellow soybean (USD per Metric Ton) and white rice with 5% broken (USD per Metric Ton), respectively. International grain price data are all sourced from the statistical database of the FAO. We first use the US Consumer Price Index (base year: 2010) to deflate the international grain prices, and then seasonally adjust the data to take the logarithm. The US Consumer Price Index comes from the Bank for International Settlements (BIS) website.

GEPU (*lngepu*) is measured by the PPP-based GEPU index published on the Economic Policy Uncertainty website, and the GEPU index is seasonally adjusted to take the logarithm.[2] The GEPU Index is a GDP-weighted average of national economic policy uncertainty indices for 21 countries, which reflects the relative frequency of these countries' newspaper articles that contain a trio of terms pertaining to the economy, policy, and uncertainty.

3.2. Control variables

As stated in Section 2, the impact of international oil price and other factors on international grain prices needs to be considered. In order to make the measurement results more accurate, we choose international oil price, international oil price uncertainty, global economic activity index, the dollar index, and international grain speculation as control variables in this study.

International oil price and international oil price uncertainty. For oil price (lnoil), we obtain the monthly average international oil price data from the U.S. Energy Information Administration (EIA) and deflate them by the U.S. consumer price index (base year: 2010). We then seasonally adjust the data and take the logarithm. For oil price uncertainty (volaoil) data, we use a generalized autoregressive conditional heteroscedasticity model (GARCH (1,1)) to calculate the conditional volatility of international oil price (Pan et al., 2017; Ozge, 2019). The conditional variance equation of GARCH (1,1) is as follows:

$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \alpha_2 \sigma_{t-1}^2 \tag{1}$$

In Eq. (1), σ_t^2 represents the conditional variance, $a_t = \sigma_t \varepsilon_t$ and ε_t are independent and identically distributed in the standard normal distribution, and α_0、 α_1、 α_2 are the parameters to be estimated.

The estimation results of the variance equation for the international crude oil price are reported in Table 1. We find that the parameters of both ARCH (α_1) and GARCH (α_2) for this series are statistically significant at the 1% level, implying that the conditional variances of international oil price significantly depend on its lagged conditional variance and lagged squared error.

Global economic activity index. The global economic activity index is used to reflect the impact of economic activity-related demand on international grain prices. Kilian (2009) believes that global economic activity is the most important determinant of the demand for transportation services. The global economic activity index is derived from a set of global dry bulk freight charges denominated in U.S. dollars, which can be regarded as a proxy of the global industrial commodity market transportation volume. Kilian (2019) made amendments to the index in 2019 to make it measure global economic activity more accurately. We use this index instead of the global industrial production index or global real GDP to measure the global economic activity for three reasons (Kilian and Zhou, 2018). First, the global industrial production index cannot measure global economic activity well because of the continuous change of the economic structure of different countries around the world. Second, the statistics of global GDP indicators only have quarterly data and no monthly data, which is not suitable for this study. Third, Kilian's index, when compared with global real GDP or

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[1] http://www.amis-outlook.org/indicators/prices/en/.

[2] The data come from: http://www.policyuncertainty.com/.

Table 1
Variance equation results.

Variable	Model	α_0	α_1	α_2
Oil	GARCH(1 , 1)	0.0010*** (0.0004)	0.5370*** (0.000)	0.4429*** (0.000)

Notes:(1) ***, **, and * indicate the significance at the 1%, 5%, and 10% levels, respectively; (2) Numbers in () are p-values.

global industrial production indicators, is a leading indicator of potential global actual output changes and takes its expected effect on the business cycle into account. Therefore, it is more suitable than other indicators to capture changes and fluctuations in the global business cycle and the economic activities. The data of Kilian's global economic activity index come from the official website of Kilian.[3]

The Dollar Index. The dollar index also has an impact on international grain prices. Since international commodity prices are generally priced in U.S. dollars, the strength or weakness of the U.S. dollar directly affects international grain prices. The data come from Wind financial database.

International grain speculation. The U.S. Commodity Futures Trading Commission (CFTC) publishes data on commercial and non-commercial positions in the commodity market every Friday. Commercial positions are generally held by commodity producers and spot merchants, and are mainly used for hedging, while non-commercial positions are generally regarded as fund positions held by speculators and have investment or speculative propensity.

We use the non-commercial long positions of international grain minus the number of non-commercial short positions to quantify international grain speculation (Mayer, 2012; Etienne et al., 2018). In addition, we refer to Sanders and Irwin (2010) using the net long percentage to measure the trader's position in the market, and calculate the average monthly net long percentage of non-commercial international grain holdings to measure the financial speculative demand for international grains, as follows:

$$Spec = \frac{NCL_t - NCS_t}{NCL_t + NCS_t} \tag{2}$$

In Eq. (2), NCL_t represents the number of non-commercial long positions held in the international commodity futures market at time t, and NCS_t represents the number of non-commercial short positions held in the international commodity futures market at time t. *Spec* index is used to capture the potential impact of traders' speculation on international grain prices.

The international grain speculation index calculated in this study includes the wheat speculation index (*Specwheat*), the maize speculation index (*Specmaize*), the soybean speculation index (*Specsoybean*), and the rice speculation index (*Specrice*). The original data are from the website of the United States Commodity Futures Trading Commission (CTFC).[4]

Dummy Variable. During the period from January 1998 to May 2021, the world experienced two severely impactful situations, namely the financial crisis in 2008 and the emergence of the COVID-19 pandemic in 2020, which have had an significant impact on global economic activities and grain prices. In order to control for the impact of these two situations in the regression, we establish two dummy variables (dum2008 for the financial crisis and dum2020 for the pandemic).

Because the 2008 financial crisis event affects different economic variables at different speeds and degrees, there are varying ranges set for it in the relevant literature regarding the impact of the crisis on different economic variables (Dungey and Gajurel, 2014; Su et al., 2020; Long et al., 2022). Therefore, we analyze the sharp fluctuation interval of major international grains since January 2007, and determine the range of the 2008 financial crisis to be from January 2007 to June 2008. Thus, we set the values of January 2007 to June 2008 of dum2008 as 1, and the others as 0.

The COVID-19 virus was first discovered at the end of December 2019, and the subsequent pandemic broke out in early 2020, significantly impacting the global economy including international grain prices. Therefore, referring to the existing literature (Long et al., 2022; Sun and Wang, 2021; Najaf et al., 2022), we set the period of the COVID-19 pandemic from January 2020 to the end of the sample. Thus, we set the values of January 2020 to the end of the sample of dum2020 to 1 and set other values to 0.

Since the earliest statistics of the global economic activity index began in January 1998, we selected the longest data interval available and use monthly data from January 1998 to May 2021 to analyze the relationship between GEPU and international grain prices.

Table 2 shows the descriptive statistics of each variable. During the sample period, the standard error of the GEPU index and international grain prices are relatively large, and the maximum and minimum values deviate from their average value, which shows the significant changes in GEPU and international grain prices. Kurtosis shows that the values of the GEPU index and international grain prices are less than 3, which conforms to the characteristics of lean tail distribution; the values of skewness are greater than 0, conforming to the characteristics of right-skewed distribution. The Jarque-Bera tests also show that the GEPU index and international grain prices do not follow a normal distribution (except for the international rice price). This also indicates that GEPU may have an asymmetric impact on the prices of wheat, maize, and soybean, while the impact on rice prices may be symmetrical.

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[3] The data come from : https://sites.google.com/site/lkilian2019/.

[4] The data comes from : https://www.cftc.gov/.

Table 2
Descriptive statistics.

Variable	Mean	Median	Min	Max	Std.Dev.	Skewness	Kurtosis	Jarque-Bera	Prob
lngepu	4.762	4.718	3.964	6.096	0.470	0.482	2.608	12.68	0.0018***
lnwheat	5.158	5.092	4.720	6.038	0.282	0.712	2.690	24.86	0.0000***
lnmaize	5.039	4.970	4.591	5.761	0.293	0.840	2.854	33.28	0.0000***
lnsoybean	5.891	5.856	5.418	6.460	0.257	0.283	2.162	11.98	0.0025***
lnrice	5.902	5.890	5.315	6.803	0.296	0.121	2.788	1.214	0.5451
lnoil	3.905	3.929	2.656	4.837	0.517	−0.269	2.276	9.524	0.0085***
volaoil	0.011	0.006	0.002	0.159	0.018	5.825	42.23	20,000	0.0000***
act	5.519	−6.634	−159.5	190.8	69.81	0.611	2.874	17.64	0.0002***
lnusdi	4.57	4.583	4.389	4.735	0.090	−0.213	1.991	14.04	0.0009***
specwheat	−0.022	−0.033	−0.403	0.536	0.189	0.725	3.393	26.39	0.0000***
specmaize	0.222	0.193	−0.548	0.776	0.308	−0.061	2.010	11.66	0.0029***
specsoybean	0.255	0.310	−0.662	0.772	0.344	−0.409	2.104	17.23	0.0002***
specrice	0.055	0.031	−0.907	0.938	0.450	0.074	2.076	10.26	0.0059***
dum2008	0.064	0	0	1	0.245	3.561	13.68	1929	0.0000***
dum2020	0.060	0	0	1	0.239	3.687	14.59	2210	0.0000***

Notes: ***, **, and * indicate the significance at the 1%, 5%, and 10% levels, respectively.

4. Methodology

In the complex world, the relationship between macroeconomic variables tends to be nonlinear and asymmetric (Rather, 2019; S. Long et al., 2021), and the nonlinear models can more accurately capture the relationship between these variables. Some recent literature finds nonlinear relationships between international grain prices and GEPU (Wen et al., 2021). Therefore, if our empirical research on GEPU and international grain prices is conducted only within a linear framework, it may not be able to accurately capture the true relationship between them; thus, we give priority to using nonlinear methods.

While studying the nonlinear relationship between GEPU and international grain prices, we mainly focus on the difference impact of the rise and fall of GEPU on international grain prices so that investors and policymakers can adopt varying magnitudes of hedging or regulating strategies. In this study, we employ the nonlinear autoregressive distributed lag model (NARDL) developed by Shin et al. (2014) to investigate the nonlinear and asymmetric effects of GEPU on the four major international grain prices.

The NARDL model is an extension of the symmetric autoregressive distributed lag model (ARDL) (Pesaran et al., 2001). By decomposing the variables into their positive and negative partial sum processes and jointly modeling the long-run equilibrium relationship and the short-run dynamic adjustments, the NARDL model has the advantage to capture asymmetric effects both in the short and long run. Moreover, unlike models requiring all the time series to be I (1), the NARDL allows the time series of the variables to be I (0), I (1) or a mix of both (Arize et al., 2017; Jareno et al., 2020; Long et al., 2022). In addition, since the ARDL model estimates both the long- and short-run components, it can overcome the serial correlation and the endogeneity problems by choosing the appropriate lag period (Pesaran and Shin, 1998); the NARDL model inherits this advantage.

We first construct a traditional regression model of international grain prices and GEPU, as follows:

$$lny_t = \alpha_0 + \alpha_1 lngepu_t + \alpha_2 con_t + \varepsilon_t \tag{3}$$

where, *ln* represents the natural logarithm of the variable, y_t refers to the prices of the international grain (wheat, maize, soybean, and rice), and *gepu* denotes GEPU. Following Delatte and López-Villavicencio (2012) and Baharumshah et al. (2017), we include other control variables that affect the international grain prices into the model. *con* stands for control variables, including the international oil price (*lnoil*), international oil price uncertainty (*volaoil*), global economic activity index (*act*), dollar index (*lnusdi*), international grain speculation (*specwheat*, *specmaize*, *specsoybean*, *and specrice*) and two dummy variables (*dum*2008, *dum*2020). In addition, ε_t is the residual error, which is assumed to be independent and identically distributed. α_1 represents the coefficient of GEPU on international grain prices.

In order to obtain the short- and long-run impact of GEPU on international grain prices, we use the autoregressive distributed lag model (ARDL) for Eq. (3), which can be written as follows:

$$\Delta lny_t = \alpha_0 + \alpha_1 lny_{t-1} + \alpha_2 lngepu_{t-1} + \sum_{i=1}^{p} \varphi_i \Delta \ln y_{t-i} + \sum_{i=0}^{q} b_i \Delta lngepu_{t-1} + ccon_t + \varepsilon_t \tag{4}$$

In Eq. (4), *p* represents the number of lags of the dependent variable, *q* represents the number of lags of the regressor, and φ_i and b_i are the regression coefficients.

In order to capture the asymmetric effects of the rise and fall of GEPU on international grain prices in the long and short run, following the approach of Shin et al. (2014), we extend Eq. (4) to decompose *lngepu* into partial sums of positive and negative changes, as follows:

$$lngepu_t^+ = \sum_{j=1}^{t} \Delta lngepu_j^+ = \sum_{j=1}^{t} \max\left(\Delta lngepu_j, 0\right)$$

$$lngepu_t^- = \sum_{j=1}^{t} \Delta lngepu_j^- = \sum_{j=1}^{t} \min\left(\Delta lngepu_j, 0\right) \tag{5}$$

In Eq. (5), $lngepu_t^+$ and $lngepu_t^-$ represent the partial sum processes of the positive and negative changes of *lngepu*, respectively. By adding the decomposed partial sum processes to the ARDL model of Eq. (4), we obtain the error correction model of the nonlinear autoregressive distributed lag model (NARDL-ECM), as follows :

$$\Delta lny_t = \alpha_0 + \alpha_1 lny_{t-1} + \alpha_2^+ lngepu_{t-1}^+ + \alpha_2^- lngepu_{t-1}^- + \sum_{i=1}^{p} \varphi_i \Delta \ln y_{t-i} + \sum_{i=0}^{q} \left(b_i^+ \Delta \ln gepu_{t-i}^+ + b_i^- \Delta \ln gepu_{t-i}^-\right) + ccon_t + \varepsilon_t \tag{6}$$

In Eq. (6), $\theta^+ = -\alpha_2^+/\alpha_1$ and $\theta^- = -\alpha_2^-/\alpha_1$ are the long-run impact coefficients of the rising and falling of GEPU on international grain prices, respectively. $\sum_{i=0}^{q} b_i^+$ and $\sum_{i=0}^{q} b_i^-$ measure the rising and falling impacts of GEPU on international grain prices in the short run.

After estimation of the NARDL model, the existence of a long-term co-integration relationship needs to be tested. According to Shin et al. (2014), we use F_{PSS} and T_{BDM} statistics to perform the co-integration test. The null hypothesis and alternative hypothesis of F_{PSS} are respectively: $H_0^F : \alpha_1 = \alpha_2^+ = \alpha_2^- = 0$ and $H_1^F : \alpha_1, \alpha_2^+, \alpha_2^- \neq 0$. And the corresponding null hypothesis and alternative hypothesis T_{BDM} test are $H_0 : \alpha_1 = 0$ and $H_1 : \alpha_1 \neq 0$. If the null hypothesis of F_{PSS} test, or T_{BDM} test is rejected, which indicate there is a co-integration relationship between international grain prices and GEPU. The decision in support or against the null hypothesis is rooted in comparing F_{PSS} and T_{BDM} with the critical values of the upper bound tests. If the values of the tests are greater than the critical values of the bounds tests, the null hypothesis is rejected, and vice versa. However, if the values are in between the upper and lower bounds, the co-integration relationship is inconclusive.

Next, the Wald test can be applied to test the long-run asymmetric effect of GEPU on international grain prices. The null hypothesis is $H_0 : -\alpha_2^+/\alpha_1 = -\alpha_2^-/\alpha_1$, and the alternative hypothesis is $H_1 : -\alpha_2^+/\alpha_1 \neq -\alpha_2^-/\alpha_1$. If the null hypothesis is rejected, it means there is an asymmetric effect of GEPU on international grain prices.

It is also necessary to test whether there is a short-run asymmetric effect. The coefficients of the short-run effects of the rise and fall of GEPU on international grain prices in Eq. (6) are $\sum_{i=0}^{q} b_i^+$ and $\sum_{i=0}^{q} b_i^-$, respectively. We can also apply the Wald test to verify the existence of the short-run asymmetric effect, with the null hypothesis of $H_0 : \sum_{i=0}^{q} b_i^+ = \sum_{i=0}^{q} b_i^-$, and the alternative hypothesis of

Table 3
Stationarity test results of all variables.

Variables	ADF Test		PP Test	
	(i, t)	Test Values	(i, t)	Test Values
lngepu	(1,1)	−4.8092***	(1,1)	−4.4979***
Δlngepu	(0,0)	−13.0473***	(0,0)	−22.0047***
lnwheat	(1,0)	−2.2416	(1,0)	−2.3176
Δlnwheat	(0,0)	−14.1520***	(0,0)	−14.2142***
lnmaize	(0,0)	0.3884	(0,0)	0.3462
Δlnmaize	(0,0)	−13.6794***	(0,0)	−13.7631***
lnsoybean	(0,0)	0.2827	(0,0)	0.2627
Δlnsoybean	(0,0)	−13.8652***	(0,0)	−14.0750***
lnrice	(0,0)	−0.1104	(0,0)	−0.0380
Δlnrice	(0,0)	−11.269***	(0,0)	−10.9339***
lnoil	(1,0)	−2.1073	(0,0)	−0.0948
Δlnoil	(0,0)	−13.0030***	(0,0)	−12.7892***
volaoil	(1,0)	−7.5334***	(1,0)	−4.4930***
Δvolaoil	(0,0)	−13.143***	(0,0)	−29.1000***
act	(0,0)	−3.2184***	(0,0)	−2.4451***
Δact	(0,0)	−12.9206***	(0,0)	−12.8076***
lnusdi	(0,0)	0.0396	(0,0)	0.0440
Δlnusdi	(0,0)	−17.8343***	(0,0)	−17.8348***
specwheat	(1,1)	−5.3143***	(0,0)	−4.9824***
Δspecwheat	(0,0)	−14.9427***	(0,0)	−27.1446***
specmaize	(1,0)	−3.4303***	(1,1)	−5.7374***
Δspecmaize	(0,0)	−11.2720***	(0,0)	−24.0651***
specsoybean	(1,0)	−6.1241***	(1,0)	−6.0919***
Δspecsoybean	(0,0)	−12.8594***	(0,0)	−29.4131***
specrice	(1,0)	−5.0683**	(1,0)	−5.1662***
Δspecrice	(0,0)	−17.2252***	(0,0)	−19.6252**

Notes: (1) i and t in parentheses indicate whether the test is performed with an intercept term or a trend term, where $i = 0$ or 1 means no/with intercept term, and $t = 0$ or 1 means no/with trend; (2) ***, **, and * indicate the significance at the 1%, 5%, and 10% levels, respectively.

$H_1: \sum_{i=0}^{q} b_i^+ \neq \sum_{i=0}^{q} b_i^-$. Similarly, if the null hypothesis is rejected, we can infer that there is an asymmetric effect of GEPU on international grain prices in the short run.

In addition, using the asymmetric dynamic multipliers, the asymmetric dynamic adjustment trajectory of international grain prices to the rising and falling of GEPU shocks can be drawn intuitively and vividly. The rising and falling of the asymmetric dynamic multipliers are equal to the long-run asymmetric coefficients θ^+ and θ^-, and they can be expressed as follows:

$$M_h^+ = \sum_{j=0}^{h} \frac{\partial lny_{t+j}}{\partial lngepu_t^+}, M_h^- = \sum_{j=0}^{h} \frac{\partial lny_{t+j}}{\partial lngepu_t^-}, \quad \text{for} \quad \mathrm{h} = 0, 1, 2, \cdots \tag{7}$$

where, if $h \to \infty$, then $M_h^+ \to \theta^+ = -\alpha_2^+/\alpha_1$, and $M_h^- \to \theta^- = -\alpha_2^-/\alpha_1$. As mentioned above, the asymmetric responses of the grain prices to positive and negative shocks of GEPU is represented by the asymmetric dynamic multipliers. From the calculated multipliers, the asymmetric dynamic adjustment is noticeable from the initial equilibrium to the new equilibrium.

5. Empirical analysis

5.1. Stationarity tests

Before empirical estimation, it is necessary to verify whether all variables are eligible to be included in the NARDL model by performing the Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests. From the results in Table 3, it can be seen that at the significance level of 1%, each variable is I (0) or I (1), and no variable is I (2), which meets the requirements of data stationarity for the NARDL model.

Table 4

NARDL estimation results of the asymmetric impact of GEPU on international wheat price.

Panel A. Diagnostic Tests				
W_{LR}	11.97*** (0.001)			
W_{SR}	–			
F_{PSS}	24.0776***			
T_{BDM}	−8.4453***			
χ^2_{SC}	4.650 (0.5894)			
χ^2_{HET}	0.02(0.8842)			
χ^2_{Ramsey}	0.95(0.4195)			
Panel B. Long-Run Coefficients				
	Coefficient		**F-statistic**	**Probability**
L^+_{lngepu}	0.117**		3.87	0.050
L^-_{lngepu}	0.139**		4.733	0.031
Panel C. Estimated Coefficients				
Variable	**Coefficient**	**Std.Error**	**T-statistic**	**Probability**
$lnwheat_{t-1}$	−0.2390***	0.0283	−8.45	0.000
$lngepu^+_{t-1}$	0.0279*	0.0149	1.87	0.063
$lngepu^-_{t-1}$	0.0331**	0.0161	2.05	0.041
$\Delta lngepu_{t-1}$	0.1154933**	0.0565	2.04	0.042
$\Delta lngepu_{t-5}$	0.1858***	0.0537	3.46	0.001
lnoil	0.0622***	0.0137	4.56	0.000
volaoil	−0.5955**	0.2364	−2.52	0.012
lnusdi	0.4191***	0.0818	5.12	0.000
act	−0.00006	0.00007	−0.89	0.372
specwheat	0.1491***	0.0224	6.65	0.000
*dum*2008	0.0665***	0.0182	3.66	0.000
*dum*2020	0.0872***	0.0215	4.05	0.000
cons	2.9418***	0.4848	6.07	0.000

Notes: (1) ***, **, and * represent 1%, 5%, and 10% significance levels, respectively; (2) F_{PSS} indicates the Paseran–Shin–Smith F test, and following Shin et al.(2013), the conservative of critical values is adopted: k = 6, and the upper bound test statistics at 10%, 5% and 1% are 3.23 , 3.61, and 4.43, respectively; (3) T_{BDM} indicates the BDM test, and following Shin et al. (2013), the conservative of critical values is adopted: k = 6, and the upper bound test statistics at 10%, 5% and 1% are −4.04 , −4.38, and −4.99, respectively; (4) W_{LR} and W_{SR} refer to the Wald test for long- and short-run asymmetry, respectively; (5) χ^2_{SC} and χ^2_{HET} denote Breusch–Godfrey LM test for serial autocorrelation, and Breusch–Pagan test for heteroskedasticity, respectively; Ramsey is the Ramsey test of Misspecification; (6) Numbers in () are p-values.

5.2. Empirical results

This section shows the results of the impact of GEPU on international grain prices (wheat, maize, soybean, and rice). The NARDL approach is used to estimate the relationship, and the sample period is from January 1998 to May 2021, and the longest lag period selected is 12 periods. Following Krolzig and Hendry (2001), we apply the general-to-specific approach to eliminate insignificant lagged variables to obtain the optimal NARDL specifications.

5.2.1. The asymmetric impact of GEPU on international wheat prices

Table 4 shows the estimated results of the asymmetric impact of GEPU on international wheat prices. The statistical values of F_{PSS} and T_{BDM} are 24.0776 and −8.4453, respectively. There is no co-integration relationship at the 1% significance level, meaning there is a long-run co-integration relationship between GEPU and international wheat prices. The long-run impact of the rise of GEPU on international wheat prices has an elastic coefficient of 0.117, and it is significant at the 5% level; that is, if GEPU rises by 1%, wheat prices will rise 0.117%. The long-run effect of GEPU decline on wheat prices has an elastic coefficient of 0.139, which is significant at the 5% level. Thus, if GEPU decreases by 1%, wheat prices will decline 0.139%, indicating that GEPU has a positive correlation with wheat prices.

As the most important food ration of the world's population, wheat is directly related to the security of staple grains in various countries. According to data from the Food and Agriculture Organization (FAO), the total global wheat consumption in 2020 was 755 million tons, of which 527 million tons were used for human consumption, accounting for 70% of its total consumption. Therefore, countries worldwide attach great importance to the safety of wheat.

The mechanism of the positive impact of GEPU on international wheat prices is mainly as follows: On the one hand, considering factors such as grain ration security, the supply willingness and supply capacity of the world's major wheat-producing countries have declined. This has resulted in a reduction in the supply of wheat in the international market, which increases the international wheat

Table 5

NARDL estimation results of the asymmetric impact of GEPU on international maize price.

Panel A. Diagnostic Tests

W_{LR}	9.34*** (0.002)
W_{SR}	0.9737 (0.325)
F_{PSS}	19.6237***
T_{BDM}	−7.5771***
χ^2_{SC}	9.062 (0.1701)
χ^2_{HET}	6.11**(0.0134)
χ^2_{Ramsey}	1.14(0.3331)

Panel B. Long-Run Coefficients

	Coefficient	F-statistic	Probability
L^+_{lngepu}	0.411***	36.76	0.000
L^-_{lngepu}	0.431***	35.26	0.000

Panel C. Estimated Coefficients

Variable	Coefficient	Std.Error	T-statistic	Probability
$lnmaize_{t-1}$	−0.2027***	0.0267	−7.58	0.000
$lngepu^+_{t-1}$	0.0833***	0.0171	4.87	0.000
$lngepu^-_{t-1}$	0.0874***	0.0183	4.79	0.000
$\Delta lngepu^+_{t-1}$	−0.1096***	0.0322	−3.40	0.001
$\Delta lngepu^+_{t-2}$	−0.0569*	0.0335	−1.70	0.091
$\Delta lngepu^+_{t-3}$	−0.0703**	0.0316	−2.22	0.027
$\Delta lngepu^+_{t-9}$	−0.0658**	0.0277	−2.38	0.018
$\Delta lngepu^-_{t-1}$	−0.0992**	0.0410	−2.42	0.016
$\Delta lngepu^-_{t-2}$	−0.1176***	0.0380	−3.10	0.002
lnoil	0.0066	0.0104	0.64	0.522
volaoil	−0.1721	0.2092	−0.82	0.411
lnusdi	−0.4103***	0.0794	−5.16	0.000
act	−0.00008	0.00006	−1.41	0.160
specmaize	0.1174***	0.0135	8.68	0.000
*dum*2008	0.0372**	0.0150	2.48	0.014
*dum*2020	0.0269	0.0182	1.47	0.142
cons	2.8597***	0.4770	5.99	0.000

Notes: (1) ***, **, and * represent 1%, 5%, and 10% significance levels, respectively; (2) F_{PSS} indicates the Paseran–Shin–Smith F test, and following Shin et al.(2013), the conservative of critical values is adopted: k = 6, and the upper bound test statistics at 10%, 5% and 1% are 3.23，3.61, and 4.43, respectively; (3) T_{BDM} indicates the BDM test, and following Shin et al. (2013), the conservative of critical values is adopted: k = 6, and the upper bound test statistics at 10%, 5% and 1% are −4.04，−4.38, and −4.99, respectively; (4) W_{LR} and W_{SR} refer to the Wald test for long- and short-run asymmetry, respectively; (5) χ^2_{SC} and χ^2_{HET} denote Breusch–Godfrey LM test for serial autocorrelation, and Breusch–Pagan test for heteroskedasticity, respectively; Ramsey is the Ramsey test of Misspecification; (6) Numbers in () are p-values.

price. On the other hand, as a necessary survival ration, the major international wheat-consuming countries have also increased their demand for wheat stockpiles to prevent risks, thereby pushing up the international demand for wheat. Therefore, the demand for wheat in the international market is greater than the supply caused by the uncertainty of global economic policy, which has led to the rise of international wheat prices. In addition, international oil price shocks, geopolitical risks and rising GEPU manifested by natural disasters also have led to an increase in international wheat prices in terms of production, transportation costs and supply reductions. Conversely, when GEPU decreases, the supply willingness of global wheat producers will also be restored, and the international supply of wheat will also increase relatively. At the same time, the precautionary demand of consumers will decline, and the demand will also fall back to the previous normal level, which will bring down the price of international wheat. Moreover, with the decline of GEPU and risks, speculative funds in the international market may gradually flow to other markets such as stocks with higher returns, which eases the contradiction between the supply and demand of international wheat, thereby making international grain prices gradually decline.

The Wald test value W_{LR} is 11.97 in Table 5, which rejects the null hypothesis that GEPU has the same long-run impact on wheat prices at the 1% level. Therefore, GEPU has an asymmetric influence on international wheat prices in the long run. The results show that the decreases in wheat prices induced by GEPU decreases, are greater than the increases in wheat prices caused by GEPU increases.

Wheat is the most widely distributed grain crop in the world and is the staple food of about 35%–40% of the global population. Therefore, governments' intervention in precautionary buffer stockpiles of wheat may be more prominent than other grains, so as to better mitigate domestic wheat prices from various external shocks such as GEPU. In fact, compared with other grains, the global wheat inventory-to-consumption ratio has been at a relatively high level and has shown an upward trend, increasing year by year from 34.83% in 2015 to 42.75% in 2020, making it possible to buffer the pressure of price increases by releasing adequate inventory. Therefore, it makes the release of stockpiled inventories more effective in suppressing wheat price increases in the global markets (Tadesse et al., 2014). When the GEPU rises, in order to stabilize the grain market, wheat-consuming countries will increase their grain supply by releasing stockpiles, which suppresses the increase in international wheat price to a certain extent. This also inhibits the supply of wheat to a certain extent. When GEPU decreases, the global supply of wheat increases relatively, while the precautionary import demand of various countries decreases, thus bringing about a relatively large drop in international wheat prices. That is to say, a lower wheat price results due to higher wheat inventory in response to a rising GEPU. This finding may indicate an increase in the price responsiveness of storable goods under low inventory conditions (Wright, 2012), a finding that is also consistent with that of David (2017).

5.2.2. The asymmetric impact of GEPU on international maize price

Table 5 shows the estimated results of the asymmetric impact of GEPU on international maize prices. The statistical values of F_{PSS} and T_{BDM} are both significant at the 1% level, indicating that GEPU does have a long-term impact on international maize prices. Moreover, the long-term asymmetric Wald test statistic W_{LR} is significant at the 1% level, indicating that the long-term asymmetric impact of GEPU on international maize prices is significant. Moreover, the long-term impact elasticity coefficients of rising and falling GEPU on international maize prices are $L^{+}_{lngepu} = 0.411$ and $L^{-}_{lngepu} =0.431$, respectively, and are significant at the 1% level. This indicates that the effect of increasing GEPU is smaller than the effect of declining GEPU on international maize prices.

Unlike wheat, as a multifunctional grain crop, maize is not only one of the grain crops for human beings, but also the main raw material for the production of bioenergy such as bioethanol, and it is also used in animal husbandry and aquaculture. Therefore, the demand and price of international maize will be greatly affected by the overall economic activity in the world. That is to say, GEPU impacts maize prices through two channels. First, changes in GEPU directly affect the supply and demand of maize in the international market and then affect maize prices, which is the main channel of influence on maize price. Second, changes in GEPU affect global economic activities, and the level of economic activity is directly related to the demand for maize from industrial ethanol, agricultural breeding, etc., which indirectly affects the international maize price. This is a secondary channel effect and its effect is smaller. Since the impacts of GEPU on maize prices through the main channel and the secondary channel work in opposite directions, the final net effect is the primary channel effect minus the secondary effect.

Therefore, when GEPU rises, maize producing countries reduce maize exports to the international market for the purpose of increasing their domestic stockpiles to prevent risks, causing maize prices to rise. However, the decline in global economic activities will also cause downward pressure on the international demand for maize, thus restraining the rise of international maize prices to a certain extent, making the rise in international maize prices relatively small. Conversely, when GEPU declines, global maize producers will increase their export supply in the global market, thereby contributing to a fall in international maize prices. At this time, the decline in GEPU will also increase economic activity, which will lead to an increase in maize farming and industrial demand, thereby reducing the decline in international maize prices.

It is worth noting that, in general, when uncertainty or risk rises, market participants will have more pessimistic expectations about the economic outlook, and tend to significantly reduce economic activities such as production, investment, and consumption. However, when uncertainty or risk declines by the same amount, market players will only cautiously and slowly resume their economic activities (Florio, 2004). In other words, the rise and fall of uncertainty or risk has asymmetric effects on the behavior of market participants. The decline of GEPU improves economic recovery to a smaller extent than a rise in GEPU suppresses economic activity (Florio, 2004). Thus, the increase in GEPU has led to a significant decline in global economic activities, which has a relatively greater impact on the decline in maize prices, and has largely offset the increasing pressure on international maize prices from the direct channel. Therefore, the effect of an increase in GEPU on the rise of international maize price is relatively small ($L^{+}_{lngepu} =0.411$), while a decrease in GEPU has a smaller increase in global economic activities and impact on the rise in maize price. There is a smaller magnitude of offsets effect to the increase price of direct channel to the international maize; thus, the effect of decline in GEPU on international maize price is relatively large (L^{-}_{lngepu} =0.431). In sum, a rise in GEPU causes a smaller increase in international maize price than the effect of a decline in GEPU on maize price.

5.2.3. The asymmetric impact of GEPU on international soybean price

Table 6 shows the estimated results of the asymmetric impact of GEPU on international soybean price. The statistical values of F_{PSS} and T_{BDM} are 29.6182 and −9.3293, respectively. Both reject the null hypothesis that there is no co-integration relationship at the 1% significance level. This means that there is a long-run co-integration relationship between GEPU and international soybean price. The long-run impact of the rise of GEPU on soybean price has an elastic coefficient of 0.129, and it is significant at the 1% level, that is, if GEPU rises by 1%, international soybean price will rise 0.129%; while the long-run effect of GEPU decline on soybean price has an elastic coefficient of 0.12, which is significant at the 1% level, meaning if GEPU decreases by 1%, international soybean price will decrease 0.12%.

The Wald test value W_{LR} is 3.76, which rejects the null hypothesis that GEPU has the same long-run impact on soybean price at the 5% level. Therefore, GEPU has a long-run asymmetric influence on international soybean price. The results show that a decrease in soybean price induced by a GEPU decrease is greater than an increase in soybean price when GEPU increases.

Soybeans are the most liberalized crop in international trade, and its trade volume has increased during the past 20 years. Its main production and export countries are the United States, Brazil, and Argentina, and the three countries' soybean exports accounted for 81.2% of the world's soybean exports in 2020. Chongguang et al. (2020) find soybean price is more vulnerable to a rise in GEPU. An increase in GEPU will bring about a reduction in global soybean production and exports in the international market, leading to upward pressure on international soybean prices. Exporting countries give priority to ensuring domestic demand and protecting vulnerable consumers in their own countries, and soybean-exporting countries have intervened in storage markets and limited trade access (Wright, 2012). Due to the relatively high concentration of global soybean production and supply, producers have a greater monopoly power to increase prices by restricting supply for economic interests, which makes the international soybean price rise more sharply. When GEPU decreases, the international soybean supply will gradually recover. However, the high monopoly degree of the global soybean production and supply makes the export supply increase at a small speed and in a small range, thus making the international

Table 6

NARDL estimation results of the asymmetric impact of GEPU on international soybean price.

Panel A. Diagnostic Tests

W_{LR}	3.76** (0.054)
W_{SR}	6.509***(0.001)
F_{PSS}	29.6182***
T_{BDM}	−9.3293***
χ^2_{SC}	6.848 (0.3351)
χ^2_{HET}	18.85***(0.0000)
χ^2_{Ramsey}	2.23*(0.0848)

Panel B. Long-Run Coefficients

	Coefficient	F-statistic	Probability
L^{+}_{lngepu}	0.129***	9.013	0.003
L^{-}_{lngepu}	0.120***	6.815	0.010

Panel C. Estimated Coefficients

Variable	Coefficient	Std.Error	T-statistic	Probability
$lnsoybean_{t-1}$	−0.2576***	0.0276	−9.33	0.000
$lngepu^{+}_{t-1}$	0.0331***	0.0119	2.79	0.006
$lngepu^{-}_{t-1}$	0.0310**	0.0126	2.46	0.015
$\Delta lngepu^{+}_{t-1}$	−0.0534**	0.0257	−2.08	0.039
$\Delta lngepu^{-}_{t-2}$	−0.1005***	0.0290	−3.47	0.001
$\Delta lngepu^{-}_{t-4}$	−0.0702**	0.0287	−2.45	0.015
$lnoil$	−0.0009	0.0086	−0.11	0.912
$volaoil$	−0.0557	0.1678	−0.33	0.740
$lnusdi$	−0.4991***	0.0764	−6.53	0.005
act	0.0001***	0.0000	2.81	0.005
$specsoybean$	0.0926***	0.0100	9.25	0.000
$dum2008$	0.0177	0.0124	1.43	0.155
$dum2020$	0.0259*	0.0152	1.71	0.089
$cons$	3.7393***	0.4934	7.58	0.000

Notes: (1) ***, **, and * represent 1%, 5%, and 10% significance levels, respectively; (2) F_{PSS} indicates the Paseran–Shin–Smith F test, and following Shin et al.(2013), the conservative of critical values is adopted: k = 6, and the upper bound test statistics at 10%, 5% and 1% are 3.23 , 3.61, and 4.43, respectively; (3) T_{BDM} indicates the BDM test, and following Shin et al. (2013), the conservative of critical values is adopted: k = 6, and the upper bound test statistics at 10%, 5% and 1% are −4.04 , −4.38, and −4.99, respectively; (4) W_{LR} and W_{SR} refer to the Wald test for long- and short-run asymmetry, respectively; (5) χ^2_{SC} and χ^2_{HET} denote Breusch–Godfrey LM test for serial autocorrelation, and Breusch–Pagan test for heteroskedasticity, respectively; Ramsey is the Ramsey test of Misspecification; (6) Numbers in () are p-values.

soybean price fall relatively less. As a result, rising GEPU will result in a larger increase in soybean prices than a decline in GEPU. This shows that for soybeans, which have a high degree of trade liberalization, it is necessary to pay close attention to the unfavorable impact of the rise of GEPU on soybeans to prevent it from causing greater damage to related consumers such as the poor, the animal husbandry industry, and soybean processing industry.

5.2.4. The asymmetric impact of GEPU on international rice price

Table 7 shows the estimated results of the asymmetric impact of GEPU on international rice price. The statistical values of F_{PSS} and T_{BDM} are 10.825 and −5.279, respectively, which reject the null hypothesis that there is no co-integration relationship at the 1% significance level. This means that there is a long-run co-integration relationship between GEPU and rice price, and that GEPU has a positive correlation with rice price.

The Wald test value W_{LR} is 0.058, so the result accepts the null hypothesis that GEPU has the same long-run impact on international rice price. Therefore, there is no long-run asymmetric influence relationship between international rice price and GEPU. The Wald test value of W_{SR} is significant at the 5% level. That means the null hypothesis that the rising and falling in GEPU have the same short-run impact on international rice price is rejected. Therefore, GEPU has a short-run asymmetric influence on the international rice price.

Geographically, the rice production and consumption countries are mainly concentrated in Asia. In addition, the proportion of global trade of rice is relatively low, the global import and export of rice accounted for 9% of the total global production in 2020, and the characteristics of the high proportion of self-sufficiency in the major rice-consuming countries in the world are obvious. In addition, major rice-consuming countries have maintained high inventories to cope with the impact of uncertainty. From 2015 to 2021, the proportion of global rice inventories to consumption remained between 34.8% and 36.5%. When GEPU rises, it will push international rice prices higher. In order to stabilize the rice price in the domestic market, major rice-consuming countries in Asia will increase the supply of domestic rice by releasing relatively sufficient stockpiles, which restrained the increase in rice prices to a certain extent. In contrast, when GEPU decreases, in order to maintain the enthusiasm of rice producers, countries balance the relationship between rice supply and demand through governments' purchase and increasing inventories, which stabilizes the price of rice to a certain extent. In sum, since global rice inventories have been maintained at high levels to stabilize price fluctuations, the rise and fall of GEPU has no significant long-term asymmetric effect on the magnitude of the impact on international rice prices. It can be seen that

Table 7
NARDL estimation results of the asymmetric impact of GEPU on international rice price.

Panel A. Diagnostic Tests				
W_{LR}	0.058 (0.810)			
W_{SR}	5.836**(0.016)			
F_{PSS}	10.825***			
T_{BDM}	−5.279***			
χ^2_{SC}	2.948 (0.5666)			
χ^2_{HET}	0.03(0.8589)			
χ^2_{Ramsey}	2.37(0.0711)			
Panel B. Long-Run Coefficients				
	Coefficient		**F-statistic**	**Probability**
L^+_{lngepu}	0.373**		10.12	0.002
L^-_{lngepu}	0.370***		8.774	0.003
Panel C. Estimated Coefficients				
Variable	**Coefficient**	**Std.Error**	**T-statistic**	**Probability**
$lnrice_{t-1}$	−0.0946***	0.0179	−5.28	0.000
$lngepu^+_{t-1}$	0.0353***	0.0113	3.12	0.002
$lngepu^-_{t-1}$	0.0350***	0.0121	2.90	0.004
$\Delta lngepu_{t-1}$	0.3249***	0.0562	5.78	0.000
$\Delta lngepu_{t-3}$	−0.1621***	0.0551	−2.94	0.004
$\Delta lngepu^+_{t-6}$	0.0605**	0.0250	2.42	0.016
lnoil	−0.0125	0.0092	−1.36	0.176
volaoil	0.1629	0.1809	0.90	0.369
lnusdi	−0.3028***	0.0653	−4.64	0.000
act	0.00005	0.00006	0.75	0.455
specrice	0.0207**	0.0086	2.40	0.017
*dum*2008	0.0196	0.0132	1.48	0.140
*dum*2020	0.0002	0.0167	0.01	0.991
cons	1.9687***	0.3901	5.05	0.000

Notes: (1) ***, **, and * represent 1%, 5%, and 10% significance levels, respectively; (2) F_{PSS} indicates the Paseran–Shin–Smith F test, and following Shin et al.(2013), the conservative of critical values is adopted: k = 6, and the upper bound test statistics at 10%, 5% and 1% are 3.23 , 3.61, and 4.43, respectively; (3) T_{BDM} indicates the BDM test, and following Shin et al. (2013), the conservative of critical values is adopted: k = 6, and the upper bound test statistics at 10%, 5% and 1% are −4.04 , −4.38, and −4.99, respectively; (4) W_{LR} and W_{SR} refer to the Wald test for long- and short-run asymmetry, respectively; (5) χ^2_{SC} and χ^2_{HET} denote Breusch–Godfrey LM test for serial autocorrelation, and Breusch–Pagan test for heteroskedasticity, respectively; Ramsey is the Ramsey test of Misspecification; (6) Numbers in () are p-values.

the current rice stockpile and control policies of various countries generally balance the interests of producers and consumers well, which is conducive to the stability of international rice prices.

In addition, in order to obtain a more intuitive impression, we also use the asymmetric dynamic multipliers to obtain the trajectory of asymmetric effects of GEPU on international grain prices, as shown in Fig. 2. For wheat and maize, although the asymmetric curve (solid blue line) fluctuates in the short run, it is below the horizontal axis (0 axis) in the long run. This shows that the effect of a rise of GEPU on the prices of wheat and maize (positive change) is greater than the effect of a fall of GEPU on their prices (negative change). For soybeans, the asymmetric curve (solid blue line) is located above the horizontal axis (0 axis), which indicates that an increase in GEPU will have a greater impact on the rise of international soybean price than when GEPU falls. The results further verify the asymmetric influence of GEPU on international grain (wheat, maize, soybean) prices. Moreover, these asymmetric effects may fluctuate in the short run, but are relatively stable in the long run. However, for rice, GEPU will increase international rice price more than the decline in the short run, but in the long run, this asymmetry does not exist. The results graphically depicted by the asymmetric dynamic multipliers are clearly consistent with the estimated results of the previous regression equations.

6. Conclusion and implications

Since the outbreak of the COVID-19 pandemic, the volatilities of major international grain prices have increased significantly, and academia and authorities have focused more attention on the factors influencing the prices of grain. Previous studies have found that extreme changes in GEPU will affect commodity price fluctuations in the agricultural product market; however, these studies mainly focus on the linear relationship between them. In order to obtain more in-depth research results, we use the NARDL model to explore the asymmetric impact of GEPU on international grain prices (wheat, maize, soybean, and rice).

6.1. Conclusion

The empirical results showed the following: (1) There is a positive relationship between GEPU and international grain prices. A rise in GEPU will lead to an increase in international grain prices, and a decline in GEPU will lead to a fall in international grain prices. (2) The impacts of GEPU on international grain prices (wheat, maize, and soybean) are asymmetric in the long run. (3) The asymmetric impacts of GEPU on international grain prices vary. For wheat and maize, the decline in prices caused by a decline in GEPU is greater than the increase in prices caused by a rise in GEPU; for soybeans, the increase in price caused by a rise in GEPU is greater than the decrease in price caused by a decline in GEPU. Furthermore, the rise and fall of GEPU have no significant asymmetric impact on rice

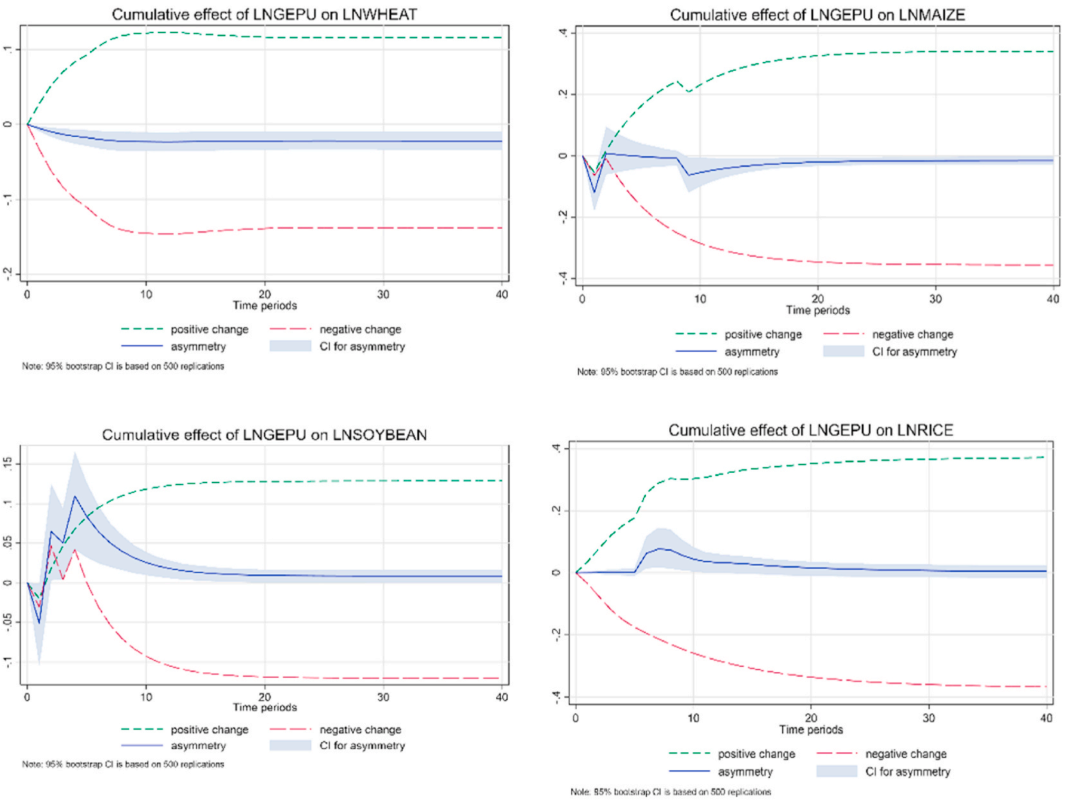

Fig. 2. The asymmetric cumulative effects of GEPU on international grain prices.

price in the long run, but have an asymmetric impact in the short run.

6.2. Policy implications

Taking the aforementioned conclusions into account, the following suggestions are provided for investors and policymakers to reduce the unfavorable impact of rising GEPU on international grain prices.

International organizations and governments should incorporate GEPU into the factors affecting international grain prices to ensure the stability of prices and enhance global grain security capabilities. Governments should strengthen the monitoring and forecasting of world macroeconomic and global economic policy risks and establish a global market risk warning system and emergency response mechanism to effectively reduce the adverse effects of GEPU on global grain price stability.

In addition, the governments should pay ample attention to the differential mechanisms of GEPU on different grain prices and adopt more precise and targeted grain price control policies. It is necessary to focus on the greater impact of falling GEPU on prices of international wheat and maize and the greater impact of rising GEPU on international soybean prices to formulate more precise and asymmetric grain price control policies.

Investors should focus their attention on the dynamic changes of GEPU and its differentiated influences on different grain prices. This will enable investors to formulate reasonable portfolio investment strategies in agricultural commodities markets to diversify risks from GEPU.

It should also be noted that our current research suffers from some limitations, specifically in the following two aspects: (i) This paper focuses on the main four international grain prices because of their special importance. In the future, we can conduct further comparative research on other international agricultural commodity prices to obtain more information and formulate a general conclusion that can be applied in a broader context. (ii) Due to the availability of data, we have no way to obtain higher-frequency data (e.g., GEPU index). If daily data can be obtained for related research in the future, it will likely be useful for investors in making more specific and timely decisions.

Author statement

Shaobo Long: Conceptualization, Methodology, Formal analysis, Writing – review & editing. **Jieyu Li** (Corresponding author): Data curation, Software, Writing – original draft preparation. **TianYuan Luo**: Conceptualization, Writing – review & editing.

Declaration of competing interest

There are no financial conflicts of interest to disclose.

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