On the Drivers of Global Grain Price Volatility : an empirical investigation

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Abstract

A vast number of studies examined the determinants of price volatility in agricultural markets. It is clear that the joint influence of several causes may generate market instability, but the partial contribution of different factors is still debated. We investigate how market-based drivers influence the global price volatility of three major grains: wheat, corn, barley. We adopt a Seemingly Unrelated Regression Equations model, in order to investigate potential common patterns and to control for the influence of external drivers. We compare inter-annual, intra-annual, and global volatility, to conclude on short-run and long-run dynamics of markets instability. We quantify the negative relationship linking (temporal)arbitrage and grain price volatility and conclude on the effects of supply movements on price volatility.

1. INTRODUCTION

During the last decades, the price volatility of agricultural markets has become a issue of utmost importance in the international debate. The reason of the particular attention of scholars and policymakers on price volatility lies in the instability characterizing agricultural markets, that causes serious uncertainty among stakeholders (Acosta et al., 2014; Brümmer et al., 2016). Starting from the food price crisis of 2007/2008, prices of staple food commodities (grain in particular) lost their partial stability in favor of an outstanding volatility. The growing volatility of prices has boosted the general atmosphere of uncertainty in agricultural markets, causing adverse effects (e.g. food emergency, political crisis, poverty, unbalanced conditions, etc.) (Wright, 2011). Understanding which factors drive price volatility in agricultural markets is a pressing issue that calls for specific attention. In particular, quantifying the effect of specific drivers on price volatility is an issue that merits deeper investigations: do they limit or amplify price volatility?

An extensive literature investigates price volatility in agricultural markets from theoretical and empirical perspectives: for example, Headey and Fan (2008) analyze the causes of price volatility from a theoretical point of view; Assefa et al. (2015) revise the literature on price volatility transmission. Baffes and Haniotis (2016) suggest that the most influential factors of volatility are the level of stocks and the trend in oil prices and exchange rates; Ott (2014) focuses on grain market; Tadesse et al. (2014) explore the quantitative importance of demand and supply shocks for price volatility, highlighting the amplifier effects of energy and financial markets; Brümmer et al. (2016) examine the effect of exogenous determinants (oil price, exchange rates, weather shocks, etc.), concluding that volatility drivers are market specific.

Other studies are focused on specific topics. A vast number of studies on price volatility pays particular attention to the theory of competitive storage: in particular, Cafiero et al. (2011), Bobenrieth et al. (2013), and Cafiero and Wright (2015) agree in considering stock data as indicators of vulnerability to shortages and price spikes; Mitra and Boussard (2012) find that storage contributes to the endogenous volatility of prices with mixed effects; Serra and Gil (2012) suggest that stock building reduces price fluctuations.

The literature has not fallen short in investigating the role of export restrictions on price volatility: some examples are Martin and Anderson (2011), Anderson (2012), Anderson and Nelgen (2012), Gouel (2013, 2016), Ivanic and Martin (2014), Rude and An (2015), Pieters and Swinnen (2016). The common idea is that trade policies intended to reduce level of exports increase price volatility at domestic and global level.

In addition to these causes, a major role is played by production levels: Goodwin et al. (2012) suggest that yield responds to significant price changes that occur early in the growing season; findings from Haile et al. (2014, 2015, 2016) reveal that price volatility is a disincentive to acreage allocation and yield response.

Among potential causes of price volatility, we distinguish market based drivers from external shocks. Market based drivers are generated by shocks in demand or supply (via levels of domestic consumption and production), or by spatial and temporal arbitrage (via trade and storage) (Santeramo et al., 2017). Examples of external shocks may be the dynamics of real and financial markets (e.g. trend in oil prices and exchange rates), the consequences of unforeseen natural events, and the influence of policy intervention (Tadesse et al., 2014). Interactions among market based drivers and external shocks may exist and determine different effects on price volatility within year (inter-annual volatility) and between years (intra-annual volatility). For instance, when stock-outs occur, demand becomes more inelastic so that (even thin) supply shocks are likely to determine great price instability in medium-long term (Mitra and Boussard, 2012). Large (low) trade volumes may reduce (increase) the consequence of shocks on price volatility: a suitable policy intervention may contribute to generate balanced spatial re-allocations. Weather shocks or natural events occurring in a crop year may affect inter-annual volatility, but also yields of the following crop year harvest: as a result, shocks in production levels may drive intra-annual volatility (Ott, 2014).

We assess the potential effects that market based and external drivers may generate on international price dynamics. In particular, our focus is on market based drivers: we investigate the contribution of spatial and temporal arbitrage (via trade and storage) and of determinants of supply and demand shocks (via harvested area, yield, and domestic consumption) on price volatility in grain market, controlling for the influence of external drivers. We expand the analysis of Ott (2014) as suggested by Brümmer et al. (2016), who suggest that determinants of price volatility are market specific. Ott (2014) focuses on cereal sector as a whole, while we derive commodity-specific conclusions, for wheat, corn and barley. We analyze global and country-level information from 1960 to 2015 adopting a Seemingly Unrelated Regression Equations (SURE) model.

As suggested by Mitra and Boussard (2012) and Ott (2014), the same drivers may determine different effects, depending on whether inter- or intra-annual volatility is investigated. We examine and compare inter-annual, intra-annual, and global volatility, to conclude on different effects of the drivers and on the short-run and long-run dynamics of markets instability. We propose a novel measure of global volatility (covering a wider timeframe) in order to capture the overall effect of each drivers.

Our contribution is twofold: we provide commodity-specific evidence on the effect of market based drivers, and separate the different effects of the drivers on intra-annual, on inter-annual, and on global volatility.

2. ON GRAIN MARKET FUNDAMENTALS

International grain market is characterized by a high concentration of production, trade, and consumption in few Countries, thus being far from the model of perfect competition. Such a feature may increase the vulnerability to food security problems, especially because of the large share of world's food energy consumption provided by grain markets (Tadesse *et al.*, 2014). As far as major grain (i.e. wheat, corn, and barley)[1] is concerned, the maximum share of production traded in the world is lower than the half, possibly due to restrictive domestic policies that discourage trade. Because grain markets are thin, even tiny changes in domestic markets may generate great international impacts and increase global instability. The long term patterns of stationary prices interspersed by severe growing spikes, that has characterized grain price during the last half century, reveal these problems (figure 1).

[FIGURE 1 ABOUT HERE]

Prices of major grain (i.e. wheat, corn, and barley) exhibit a stable growing trend over time, with several sharp peaks (figure 1). More important, it is notable the range existing between the minimum and the maximum level of price for each commodity (table 1).

[TABLE 1 HERE ABOUT]

Although trade in agri-food commodities is massive, demand from most emerging economies grows faster than domestic consumption. Despite significant declines, prices are still higher than pre-financial crisis levels and characterized by remarkable volatility (IMF, 2016). But simply, what is likely to have caused volatility? Several factors help explaining market instability: trade and storage, supply shocks, and demand shocks.

As for arbitrage, storage and trade are effective tools to achieve price stabilization (Bobenrieth *et al.*, 2013). The buffering function of prices operates through the incentives to arbitrage on price dynamics, and in particular to store when prices are low and trading when prices are high. This mechanism has been well described by competitive storage theory (Wright and Williams, 1982, 1984; Williams and Wright, 1991; Deaton and Laroque, 1992; Bobenrieth et al., 2013). Arbitrage mechanism reflects also the influence of agricultural trade policies, aiming at stabilizing price fluctuations and avoiding price spikes, but *de facto* they

[1] According to the official data on production of grain (USDA, 2016), wheat is the most produced grain worldwide, followed by corn and barley.

may cause supply shocks, amplifying price volatility (Martin and Anderson, 2011; Anderson, 2012; Anderson and Nelgen, 2012; Ivanic and Martin, 2014).

On the demand and supply sides, crop yields determine production levels but, differently from the planting decisions, are the result of noneconomic external drivers, which influence prices variability (e.g. weather conditions, pest infestations, environmental conditions and technological changes) (Goodwin et al., 2012; Fisher et al., 2012; Haile et al., 2014). For tradable commodities such as grain, yield shocks and harvest deficiencies may contribute to global price instability (Goodwin et al., 2012; Fisher et al., 2012; Haile et al., 2014, 2015).

Given this framework, we examine international price dynamics by taking into account the influence of market fundamentals.

3. METHODOLOGICAL FRAMEWORK

3.1 Data

In order to quantify the impact of market based and external drivers on prices volatility in grain market, we analyze global and country-level information from 1960 to 2015, considering three commodities: wheat, corn, and barley. Table 2 provides a detailed description of data used in the analysis and the source of adoption.

[TABLE 2 ABOUT HERE]

According to the World Bank's commodity price database (Pink Sheet)[2], barley, corn, and wheat are quoted as: 'Barley (United States) feed, no. 2, spot, 20 days To-Arrive, delivered Minneapolis from May 2012 onwards; during 1980-2012 April Canadian, feed, Western no. 1, Winnipeg Commodity Exchange, spot, wholesale farmers' price'; 'Maize (United States), no. 2, yellow, f.o.b.[3]. US Gulf ports'; 'Wheat (United States), no. 1, hard red winter, ordinary protein, export price delivered at the US Gulf port for prompt or 30 days shipment'. Prices (in US$/Mt) include monthly data and annual averages (obtained as simple averages of monthly values)[4]. Prices of commodities are the starting point to create measures of price volatility (*cfr.* Section 3.2)

Annual data for fundamentals of grain market are collected from the United States Department of Agriculture's Foreign Agricultural Service, Production, Supply, and Distribution Online (USDA FAS

[2] Available at www.worldbank.org/en/research/commodity-markets, accessed in April 2016.
[3] F.o.b. stands for free-on-board.
[4] The empirical model uses nominal world price. They have not been deflated due to the lack of a sufficiently accurate consumer price index (CPI) to deflate nominal prices at global level. This restriction is not able to capture price trend in real economy, but it is justifiable because macroeconomic conditions of the last decades, promoting global economic growth and leveling off differences between developed and developing Countries, have stopped the downfall of real prices and reduced the difference nominal-real prices (OECD, 2008).

PSDO)[5]. They proxy market based drivers of price volatility: harvested area (in 1,000 Mt) proxies planted area and, jointly with yield (in Mt/ha), indicates levels of production; domestic consumption (in 1,000 Mt) refers to food, seed, industrial, feed and waste consumption; exports (in 1,000 Mt) is a proxy of spatial arbitrage; ending stocks (in 1,000 Mt) informs on storage levels at the end of marketing year. According to the definition of USDA FAS[6], the marketing year ends in May for wheat and barley, and in August for corn.
In order to estimate the effect of external drivers on price volatility, we include a set of four control variables. The price of crude oil (in US$/bbl), collected from the World Bank's commodity price database (Pink Sheet) and quoted as 'Crude oil, average spot price of Brent, Dubai and West Texas Intermediate (WTI), equally weighed' is a proxy of real economy. The foreign exchange rates, collected from the Economic Research of Federal Reserve Bank of St. Louis[7], is a proxy of financial economy: we consider U.S. Dollar against Australian Dollar (USD/AUD) and Chinese Yuan against U.S. Dollar (CNY/USD); they were chosen to emphasize the weight of major producers in the international scenario[8]. The trade reduction index (TRI) (in percentage), specific for each commodity (i.e. barley, corn, rice, and wheat), which covers all tradable products from 1960 to 2011, collected from Anderson and Nelgen's dataset[9] is a proxy of the global impact of policy intervention. Data on natural disasters (in 1,000 US$), collected from the International Disaster Database (EM-DAT)[10], is a proxy of exogenous and unforeseen events.
Table 3 summarizes basic statistics of explanatory variables.

[TABLE 3 ABOUT HERE]

3.2 Volatility measurement

Volatility describes price movements in the medium-long term: it consists in intervals where sharp jumps in price follow steep falls back to the trend, or vice-versa. Price volatility, measured in terms of price dispersion around a central trend, is an indicator of how much and how quickly prices change over time (Tadesse et al., 2014).
It is useful to distinguish between inter-annual and intra-annual volatility of price. Inter-annual volatility is the dispersion of price between crop years and may influence decisions about long term investments of

[5] Available at apps.fas.usda.gov/psdonline/, accessed in April 2016. Annual data for production, yield, harvested area, domestic consumption, export, import, and ending stock at world level were obtained by performing the sum of the values for each Countries included in the USDA original database.
[6] Available at apps.fas.usda.gov/export-sales/myfi_rpt.htm, accessed in April 2016. The USDA Marketing Year Final Reports reflects the accumulated exports for the previous two marketing years and the quantity of outstanding sales not exported and carried over to the next marketing year.
[7] Available at research.stlouisfed.org/fred2/categories/95, accessed in April 2016. Series of exchange rates are discontinued: USD/AUD covers 1971-2015; INR/USD covers 1973-2015; CNY/USD covers 1981-2015.
[8] According to USDA FAS PSDO (2016), China and India are leading producers of wheat and corn; Australia is the major producer of barley; the United States are great and producer and exporter of the analyzed commodities.
[9] The database is a product of the World Bank's research project "Distortions to Agricultural Incentives", led by Kym Anderson, and is available at siteresources.worldbank.org/INTRES/Resources/469232-1107449512766/UpdatedTRI_WRI_Database_0613.xls.
[10] Available at www.emdat.be/advanced_search/index.html, accessed in April 2016.

farmers, storers, and traders. It is measured as the standard deviation ($\sigma_y^{y,i}$)[11] of logarithmic changes in annual price of commodity *i* from a central trend, computed on five years[12]:

$$\sigma_y^{y,i} = \sqrt{\left(\Delta P_y^{y,i} - \Delta_5 P_y^{y,i}\right)^2} \tag{1}$$

where $\Delta P_y^{y,i} = ln\left(\frac{P_y^{y,i}}{P_{y-1}^{y,i}}\right)$ is the year-by-year variance, computed on average annual prices of commodity *i* and $\Delta_5 P_y^{y,i} = \frac{1}{5} ln\left(\frac{P_{y+2}^{y,i}}{P_{y-2}^{y,i}}\right)$ is the proportional annual change in prices of commodity *i*, computed on a five years moving average.

Intra-annual volatility is the dispersion of price within the crop year and affect planting decisions of farmers. In line with Ott (2014), we measure intra-annual as the standard deviation ($\sigma_m^{y,i}$) of logarithmic changes in monthly price of commodity *i* within the crop year from the annual average price:

$$\sigma_m^{y,i} = \sqrt{\frac{1}{10}\sum_{m=2}^{12}\left(ln\left(P_m^{y,i} \big/ P_{m-1}^{y,i}\right) - \mu_y^{y,i}\right)^2} \tag{2}$$

where $P_m^{y,i}$ is the price of commodity *i* in month *m* of crop year *y* and $\mu_y^{y,i} = \frac{1}{11} ln\left(\frac{P_{12}^{y,i}}{P_1^{y,i}}\right)$ is the proportional monthly change in prices of commodity *i*, computed as a moving average on twelve months.

In order to capture both monthly and yearly volatility in a single indicator, we measure global volatility as the standard deviation ($\sigma_m^{3y,i}$) of logarithmic changes in monthly price of commodity *i* from a central trend, computed using a moving average on 36 months:

$$\sigma_m^{3y,i} = \sqrt{\frac{1}{34}\sum_{m=2}^{36}\left(ln\left(P_m^{y,i} \big/ P_{m-1}^{y,i}\right) - \mu_y^{3y,i}\right)^2} \tag{3}$$

where $\mu_y^{3y,i} = \frac{1}{35} ln\left(\frac{P_{36}^{y,i}}{P_1^{y,i}}\right)$ is the proportional monthly change in prices of commodity *i*, computed on a three years moving average.

[11] Using the root of the squared variances between annual price change and annual average price change allows to obtain symmetric, robust, and unvarying results, with respect to outcomes of other volatility measurements.
[12] Equation (2) is an adaptation of formula used in Ott (2014). Using our specification allows to improve coherence among all measurements of volatility (see also Equations (2) and (3)).

The three indicators are used to measure volatility of grain prices and to capture variability in price of crude oil and in trend of exchange rates, so to have explanatory variables expressed with the same frequencies of dependent variables.

3.3 Model specification

In order to quantify the impact of different drivers on inter-annual, intra-annual, and global volatility of grain prices, we suppose that volatility (σ) is a function of a set of market based variables and of a set of variables of external shocks:

$$\sigma = f(market\ based\ drivers, external\ drivers) \tag{4}$$

The set of market based drivers includes commodity-specific variables referred to arbitrage and fundamentals of grain market (demand and supply): i.e. storage levels, trade flows, harvested area, yield, and domestic consumption[13]. We involve market based variables in the model to test if and how spatial (via exports) and temporal (via ending stock) arbitrage, shocks of demand (via trend in domestic consumption), and shocks of supply (via trend in harvested area and yields) influence volatility of grain price. The set of external drivers is common for each commodity and involves price volatility of energy commodities (crude oil) as proxy of real economy, volatility of exchange rates (U.S. Dollar/Australian Dollar, Chinese Yuan/U.S. Dollar) as proxy of financial economy, the Trade Reduction Index (TRI) as proxy of policy intervention, and natural disasters as proxy of unpredictable and exogenous events. External drivers are involved in the model in progressive steps and compared with a basic specification that includes only market based drivers.

In order to capture potential common patterns among commodities, the empirical model is estimated as a SURE system[14]. For each equation in the system, we consider commodity-specific variables, as well as variables common for each commodity and no simultaneity is assumed: although there are no explicit relationships among single equations, cross-equations relationships are likely to occur, due to the correlation among simultaneous error terms (Zellner, 1962). Because of the correlation among the disturbances, the estimation of an equation of the system improves the estimation of the others, and vice-versa. Assuming that cross-equations covariance is constant, the most asymptotically efficient, linear, and unbiased estimator is the Generalized Least Squares (GLS): regression coefficients are more efficient than those estimated (equation-by-equation) using a standard Ordinary Last Squares (OLS) estimator.

Equations (5), (6), and (7) express in matrix form the SURE model for inter-annual, intra-annual, and global volatility:

[13] The empirical model captures different dynamics not endogenously determined, because dependent variables and explanatory variables have different frequencies. In addition, volatilities, expressed as changes from a central trend, are a function of market based variables in level.

[14] The existence of a close conceptual relationship among dependent variables is realistically possible for the analyzed commodities, which may be substitute goods: farmers may easily substitute different grain during planting decisions, and buyers may choose the most affordable grain among them.

$$\begin{bmatrix}\sigma_y^{y,B}\\ \sigma_y^{y,C}\\ \sigma_y^{y,W}\end{bmatrix} = \begin{bmatrix}1 & S_y^{y,B} & EX_y^{y,B} & A_y^{y,B} & Y_y^{y,BA} & C_y^{y,B} & \sigma_y^{y,OIL} & \sigma_y^{y,USD/AUD} & TRI_{y-1}^{y,B} & Z_y^{y}\\ 1 & S_y^{y,C} & EX_y^{y,C} & A_y^{y,C} & Y_y^{y,CO} & C_y^{y,C} & \sigma_y^{y,OIL} & \sigma_y^{y,CNY/USD} & TRI_{y-1}^{y,C} & Z_y^{y}\\ 1 & S_y^{y,W} & EX_y^{y,W} & A_y^{y,W} & Y_y^{y,W} & C_y^{y,W} & \sigma_y^{y,OIL} & \sigma_y^{y,CNY/USD} & TRI_{y-1}^{y,W} & Z_y^{y}\end{bmatrix} \cdot \begin{bmatrix}\alpha\\ \beta_1\\ \beta_2\\ \beta_3\\ \beta_4\\ \beta_5\\ \gamma\\ \delta\\ \eta\\ \theta\end{bmatrix} + \begin{bmatrix}\varepsilon_y^{y,B}\\ \varepsilon_y^{y,C}\\ \varepsilon_y^{y,W}\end{bmatrix} \tag{5}$$

$$\begin{bmatrix}\sigma_m^{y,B}\\ \sigma_m^{y,C}\\ \sigma_m^{y,W}\end{bmatrix} = \begin{bmatrix}1 & S_m^{y,B} & EX_m^{y,B} & A_m^{y,B} & Y_m^{y,BA} & C_m^{y,B} & \sigma_m^{y,OIL} & \sigma_m^{y,USD/AUD} & TRI_{m-12}^{y,B} & Z_m^{y}\\ 1 & S_m^{y,C} & EX_m^{y,C} & A_m^{y,C} & Y_m^{y,CO} & C_m^{y,C} & \sigma_m^{y,OIL} & \sigma_m^{y,CNY/USD} & TRI_{m-12}^{y,C} & Z_y^{y}\\ 1 & S_m^{y,W} & EX_m^{y,W} & A_m^{y,W} & Y_m^{y,W} & C_m^{y,W} & \sigma_m^{y,OIL} & \sigma_m^{y,CNY/USD} & TRI_{m-12}^{y,W} & Z_m^{y}\end{bmatrix} \cdot \begin{bmatrix}\alpha\\ \beta_1\\ \beta_2\\ \beta_3\\ \beta_4\\ \beta_5\\ \gamma\\ \delta\\ \eta\\ \theta\end{bmatrix} + \begin{bmatrix}\varepsilon_m^{y,B}\\ \varepsilon_m^{y,C}\\ \varepsilon_m^{y,W}\end{bmatrix} \tag{6}$$

$$\begin{bmatrix}\sigma_m^{3y,B}\\ \sigma_m^{3y,C}\\ \sigma_m^{3y,W}\end{bmatrix} = \begin{bmatrix}1 & S_m^{y,B} & EX_m^{y,B} & A_m^{y,B} & Y_m^{y,BA} & C_m^{y,B} & \sigma_m^{3y,OIL} & \sigma_m^{3y,USD/AUD} & TRI_{m-12}^{y,B} & Z_m^{y}\\ 1 & S_m^{y,C} & EX_m^{y,C} & A_m^{y,C} & Y_m^{y,CO} & C_m^{y,C} & \sigma_m^{3y,OIL} & \sigma_m^{3y,CNY/USD} & TRI_{m-12}^{y,C} & Z_y^{y}\\ 1 & S_m^{y,W} & EX_m^{y,W} & A_m^{y,W} & Y_m^{y,W} & C_m^{y,W} & \sigma_m^{3y,OIL} & \sigma_m^{3y,CNY/USD} & TRI_{m-12}^{y,W} & Z_m^{y}\end{bmatrix} \cdot \begin{bmatrix}\alpha\\ \beta_1\\ \beta_2\\ \beta_3\\ \beta_4\\ \beta_5\\ \gamma\\ \delta\\ \eta\\ \theta\end{bmatrix} + \begin{bmatrix}\varepsilon_m^{3y,B}\\ \varepsilon_m^{3y,C}\\ \varepsilon_m^{3y,W}\end{bmatrix} \tag{7}$$

where B, C, and W indicate barley, corn, and wheat; *y* stands for year, *m* for month, and *3y* for a time span of 36 months. The left hand side (LHS) of equations (5)-(7) is the vector of inter-annual, intra-annual, and global volatilities of grain price: the elements of the vector are current volatilities of barley, corn, and wheat, expressed in logarithmic terms. The right side (RHS) of equations (5)-(7) includes the matrix of explanatory variables, where S, EX, A, Y, C indicate for each commodity (B, C, W) the logarithmic form of storage levels, export flows, harvested area, yield, and consumption at current time; σ^{OIL}, $\sigma^{USD/AUD}$, and $\sigma^{CNY/USD}$ are current volatilities of oil price and of exchange rates between U.S. Dollar (USD) and Australian Dollar (AUD), and Chinese Yuan (CNY) and USD; TRI is the Trade Reduction Index of the previous period, used as measure of levels of policy intervention[15]; Z is the loss in economic terms caused by natural disasters, used to proxy unpredictable events. The RHS also includes the vector of a constant term (α) and parameters of interest, referred to market based drivers (β_i, with *i* = 1, …, 5) and to external drivers (γ, δ, η, θ), and the vector of error terms specific for each equation of the system, with expected value zero and variance-covariance matrix which is non zero.

[15] We consider lagged TRI for each commodity to avoid endogeneity carried out by the introduction of restrictive trade measures, according to Trefler (1993).

We interpret estimated parameters β_i, γ, and δ as elasticities, because volatilities and market based variables are expressed in a logarithmic form: a percentage change in an explanatory variable causes a percentage change in volatility of the amount of the estimated parameter. As for the coefficients η and θ, an unitary variation in variables TRI or natural disasters determines a change in volatility equal to the 100% of the amount of the estimated coefficient.

4. RESULTS AND DISCUSSION

Tables 4, 5 and 6 show results of SURE estimates for inter-annual, intra-annual, and global volatility. The basic specification of the model (A) includes as regressors only market based drivers; External drivers are progressively involved in the model as control factor: specification (B) includes volatility oil price as proxy of real economy, specification (C) adds volatility of exchange rates as proxy of financial economy, specification (D) involves natural disasters as proxy of exogenous events, specification (E) further considers TRI as proxy of policy intervention. The model fits well for each commodity in each specification.

[TABLE 4 ABOUT HERE]

As regard temporal arbitrage, price volatility of grain is negatively correlated with ending stock, as also found in Serra and Gil (2012), Bobenrieth *et al.* (2013) and Ott (2014). This is true in particular for price volatility of wheat: the coefficients estimated for ending stock are negative and statistically significant in each specification of the model, regardless of the type of volatility under investigation. The stronger effect for wheat occurs in intra-annual volatility: we found that a 1% reduction in storage levels leads to an upsurge of price volatility of wheat ranging from 0.13% to 0.22% (table 4). Considering inter-annual and global volatilities, following a 1% decrease in ending stock volatilities increase by 0.02% on average (tables 5 and 6). A negative relationship also occurs between storage and price volatility of barley: a 1% increase of ending stock cause a reduction of 0.02% in three out of five cases for inter-annual volatility and ranging from 0.01% and 0.02% in global volatility (tables 5 and 6). Evidence support the idea that storage contributes to the endogenous volatility of prices: in particular, grain prices show less inter-annual variation compared to a situation that considers long-run dynamics of prices (Mitra and Boussard, 2012).

As far as spatial arbitrage is concerned, differences exist between short-run and long-run dynamics: an inverse relationship links intra-annual volatility of barley and trade flows in specification (E), while exports are positively correlated with inter-annual and global volatilities of barley, corn, and wheat (tables 4-6). In particular, the coefficients estimated for barley and corn are positive and statistically significant in all specifications of the model, while coefficients estimated for wheat are statistically significant in three out of five cases: a 1% increase in exports leads inter-annual and global volatilities of wheat to grow by 0.02% (tables 5 and 6). It is plausible that, following the Law of One Price, the price adjustment in the long-run neutralizes the buffering effect of greater exports on price volatility in the short-run. However, the nature of these relationships is not clear understanding and requires further investigation.

[TABLE 5 ABOUT HERE]

Regarding drivers of supply, variables that proxy production (i.e. harvested area and yield) are positively correlated with price volatility of grain, differently from previous evidence by Haile et al. (2015). The magnitude of the effects depends on whether volatility is intra-annual, inter-annual, or global. The stronger results occur for wheat: intra-annual volatility suffers an upward variation by 1.47% and by 0.23%, due to a 1% increase respectively in harvested area and in yield (table 4). Coefficients estimated for harvested area are positive and statistically significant for specification (D) when inter-annual and global volatility of wheat is under investigation (tables 5 and 6). Analyzing barley, harvested area and yield are always positively correlated (with statistical significance) with inter-annual and global volatilities: when a 1% upward variation occurs in variables of production side, volatilities of barley rise by an amount ranging between 0.06% and 0.12% due to changes in harvested area, and ranging from 0.02% to 0.05% due to changes in yield (tables 5 and 6). For corn, coefficients estimated for yields are always statistically significant for global volatility: a 1% growth in yield leads global volatility to increase by 0.05% on average (table 6).Coefficients estimated for harvested area are positively related (with statistical significance) with inter-annual volatility of corn in specification (E) and with global volatility of corn in all but one case (specification (D)) (tables 5 and 6).

As regard drivers of demand, coefficients estimated for domestic consumption show mixed evidence. In few cases, a positive correlation exists between domestic consumption and price volatility of grain: we find positive and statistically significant coefficients for intra-annual volatility of barley and wheat (in two out of five cases) and for inter-annual volatility of wheat (in two out of five cases) (tables 4 and 5). We find an inverse relationship between domestic consumption and intra-annual volatility of corn (in specification (E)), inter-annual volatility of barley and wheat (respectively in specification (C) and (E)), global volatility of all commodities (in 11 out of 15 cases) (table 6). A decrease in domestic consumption causes an upsurge of price instability, according to Cafiero et al. (2011) and Thompson et al. (2012).

Following shocks of demand, grain price volatility decreases because of the rigidity of the demand with respect to the supply (Cafiero et al., 2011; Thompson et al., 2012). For this reason, shocks of demand are more impacting than shocks of supply on grain price volatility. When we consider shocks of demand and supply in absolute value, we find that the magnitude of the estimated coefficients for production (deriving from the sum[16] of coefficients for harvested area and yield) is greater than the magnitude of coefficients for domestic consumption. In fact, when a supply shock occurs, domestic consumptions firstly absorb surplus of production, while the remaining part is devoted to exports or to storage, depending on the economic advantage. In every occasion shocks of supply are, in absolute value, more impacting than shocks of

[16] It is not necessary that supply shocks occur simultaneously. We would be able to consider separately shocks in harvested area and yield. For this reason, instead of multiply, we sum them.

demand: this is particularly evident in results of global volatility (specification (E)). The most remarkable effects occur for barley, for which global volatility suffers an upward change of 0.12% when production increases of a 1% and of 0.03% following a 1% decrease in domestic consumption. Also the magnitude of the estimated coefficients for corn is comparable: global volatility grows of 0.13% when production rises of 1% and of 0.08% following a reduction in domestic consumption of 1%. A lower difference occurs for wheat, for which global volatility upsurges of 0.08% both in case of uptrend shocks of production and with downward shocks of consumption (table 6).

[TABLE 6 ABOUT HERE]

Controlling for the influence of external drivers is essential to outline a clearer framework on the effects that market based drivers may have on price volatility in grain market.

In agreement with several empirical studies that seek to quantify the relationship between grain and energy markets (e.g. Serra and Gil, 2012; Ott, 2014; Tadesse et al., 2014; Baffes and Haniotis, 2016; Brümmer et al., 2016), we found a deeply positive correlation between oil instability over time and price fluctuations in grain market. In particular, a 1% growth in volatility of oil prices causes an increase in volatility of grain that fluctuates from 0.07 to 0.35%, depending on commodity and type of volatility under investigation. This finding may depend on the crucial role that energy has for for input and output sides of agricultural sector: the reference is to the usage of energy for activities related to crops cultivation (e.g. tillage and rotation practices, fertilizers and pesticides application, transportation of materials, etc.) for the input side, and to the current relevance of bioenergy for the output side, for which the linkage is remarkable in the case of corn.

Controlling for the influence of exchange rates, we found that an increase in their instability leads to a negative impact on grain price volatility, as in Ott (2014), Baffes and Haniotis (2016), and Brümmer et al. (2016).

Controlling for a measure that captures the overall influence of policy intervention (i.e. TRI) is a way to better understand the relationship that occurs between trade and volatility. The correlation between trade flows and trade barriers is negative because trade restrictions occur exactly when trade is excessively active (Trefler, 1993). We find a negative and significant correlation between variables of policy intervention and price volatility of grain.

Positive, although negligible, correlation appears within price volatility of grain and natural disasters, as also reported in Brümmer et al. (2016). Natural disasters may be considered as completely exogenous drivers, because they can indiscriminately damage any parts of the world, reducing the capacity of a producer to obtain adequate yields. The negligibility of the coefficients' magnitude may be due to the offsetting effect played by other producers located in different parts of the world, and to the storability features of grain.

5. CONCLUDING REMARKS

Price volatility, a typical feature of prices of grain commodity, is driven by several factors. Understanding how the drivers of volatility act is a way to define actions able to limit negative consequences of price instability. Among determinants of price volatility of grain, market based drivers deserve particular attention: we classified them in spatial and temporal arbitrage, and in demand and supply side drivers. We investigated the dynamics of price volatility of the three most important grains (i.e. wheat, corn, and barley).

Our findings confirm the negative relationship that links drivers of arbitrage side to grain price volatility, already established in literature. Storage acts as an authentic buffer of volatility in grain market, thanks to the storability features of grain (Ott, 2014; Tadesse *et al*, 2014; Guerra et al., 2015; Clech and Fillat-Castejón, 2017). Although results highlight a not straightforward evidence for trade flows effects on price volatility of grain, it is clear the presence of a deep dependence between them, as shown by Ivanic and Martin (2014). If free trade is able to control price volatility of agricultural commodity is still unclear, and more work needs to be done to support this hypothesis. We also found that demand shocks diminish price volatility, whereas supply shocks exacerbate it. This result, surprisingly in contrast with Haile et al. (2015), I splausiby explained by the larger rigidity of the demand with respect to the supply (Cafiero et al., 2011; Thompson et al., 2012).

Besides market based drivers of price fluctuations, a set external factors, in various capacities related to agricultural commodities, contribute to boost or to curb price instability of grain. We have selected some of the potential external drivers of volatility (i.e. real and financial economy variables) discussed in the literature (Zhang et al., 2010; Tadesse *et al.*, 2014; Baffes and Haniotis, 2016) and added also original variables (i.e. indicators of policy intervention and exogenous events) to corroborate our model. We show that energy and financial markets, as well as unpredictable events, tend to have potentially destabilizing impacts on prices, whereas policy intervention may buffer instability in grain prices.

Our paper contributes to the existing debate is at least twofold: first, we provide commodity-specific evidence, discriminating short-and long-run dynamics; second, we explicitly assess the role of market based and of external drivers of price volatility in grain market.

Given that price formation mostly takes place on a global scale, policies aiming to prevent price volatility would have to be tailor-made to the international grain market. For storable and tradable commodities, such as grain, those policies should take into account the different role played by spatial and temporal arbitrage, domestic consumption, land and inputs use, among others.

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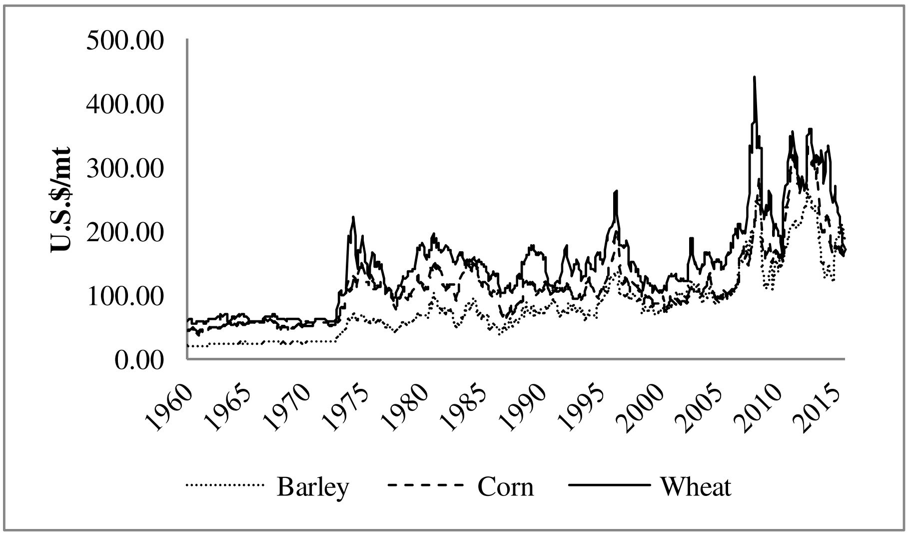
FIGURE

Figure 1. World prices of major grain from crop year 1960 to 2015.



Source: Authors' elaboration on IMF database.

TABLES

Table 1. Descriptive statistics for price level and volatility of the major grain.

	Barley		**Corn**		**Wheat**	
	Level	*Volatility*	*Level*	*Volatility*	*Level*	*Volatility*
Min	19.20	0.001	38.00	0.003	52.18	0.005
Max	265.69	0.12	333.05	0.09	439.72	0.12
Median	71.70	0.06	106.30	0.05	142.94	0.05
Mean	81.85	0.06	113.88	0.05	147.78	0.05
Std. dev.	53.89	0.03	58.08	0.02	72.99	0.02

Table 2. Sources of data.

Series		Description	Sample	Frequency	Unit	Source
Nominal price by commodity						
Grains	Barley	Barley (US) feed, No. 2, spot, 20 days To-Arrive, delivered Minneapolis from May 2012 onwards; during 1980 - 2012 April Canadian, feed, Western No. 1, Winnipeg Commodity Exchange, spot, wholesale farmers' price	1960-2015 1960-2015	Month Year	US$/Mt US$/Mt	World Bank (Pink Sheet)
	Corn	Maize (US), no. 2, yellow, f.o.b. US Gulf ports	1960-2015 1960-2015	Month Year	US$/Mt US$/Mt	World Bank (Pink Sheet)
	Wheat	Wheat (US), no. 1, hard red winter, ordinary protein, export price delivered at the US Gulf port for prompt or 30 days shipment	1960-2015 1960-2015	Month Year	US$/Mt US$/Mt	World Bank (Pink Sheet)
Energy	Crude oil	Crude oil, average spot price of Brent, Dubai and West Texas Intermediate, equally weighed	1960-2015	Month	US$/bbl	World Bank (Pink Sheet)
Market fundamentals by commodity (for barley, corn, rice and wheat)						
Grain		Annual beginning stock	1960-2015	Annual crop	1000 Mt	USDA FAS
		Annual ending stock	1960-2015	Annual crop	1000 Mt	
		Annual export	1960-2015	Annual crop	1000 Mt	
		Annual import	1960-2015	Annual crop	1000 Mt	
		Annual production	1960-2015	Annual crop	1000 Mt	
		Annual area harvested	1960-2015	Annual crop	1000 Mt	
		Annual yield	1960-2015	Annual crop	Mt/ha	
		Annual domestic consumption (food, seed, industrial, feed and waste consumption)	1960-2015	Annual crop	1000 Mt	
Common series and macro variables						
Exchange rates		China/U.S. Foreign Exchange Rate	1981-2015	Month	-	Federal Reserve Bank
		U.S./Australia Foreign Exchange Rate	1971-2015	Month	-	
TRI		Trade reduction index, commodity-specific, all covered tradable products (for barley, corn, rice and wheat)	1960-2011	Year	%	Anderson & Nelgen's dataset
Disasters		Natural disasters (world total)	1960-2015	Year	1,000 US$	EM-DAT

Table 3. Descriptive statistics for explanatory variables.

Variables		Measure units	Min	Max	Mean	Std. dev.
Barley	Ending stock	mln 1,000 Mt	106.00	374.00	238.00	65.30
	Exports	mln 1,000 Mt	52.00	278.00	145.00	50.20
	Harvested area	mln 1,000 Mt	472.00	840.00	659.00	110.00
	Yield	mln Mt/ha	0.64	1.61	1.42	0.33
	Domestic consumption	mln 1,000 Mt	764.00	1,740.00	1,400.00	251.00
Corn	Ending stock	mln 1,000 Mt	337.00	2,050.00	1,140.00	521.00
	Exports	mln 1,000 Mt	140.00	1,310.00	636.00	269.00
	Harvested area	mln 1,000 Mt	1,020.00	1,810.00	1,330.00	204.00
	Yield	mln Mt/ha	1.15	3.70	2.43	0.81
	Domestic consumption	mln 1,000 Mt	1,940.00	3,880.00	4,970.00	2,170.00
Wheat	Ending stock	mln 1,000 Mt	607.00	2,100.00	1,410.00	451.00
	Exports	mln 1,000 Mt	439.00	1,660.00	948.00	316.00
	Harvested area	mln 1,000 Mt	2,020.00	2,390.00	2,200.00	84.20
	Yield	mln Mt/ha	0.74	2.27	1.56	0.48
	Domestic consumption	mln 1,000 Mt	2,290.00	7,130.00	4,820.00	1,420.00
Oil price		U.S.$/bbl	1.21	132.83	28.18	29.85
USD/AUD[a]		-	0.50	1.49	0.88	0.23
CNY/USD[b]		-	1.55	8.73	6.12	2.22
Natural disasters		mln 1,000 U.S.$	0.48	3.44.00	48.80	65.70
TRI[c]	Barley	-	-0.28	1.09	0.18	0.26
	Corn	-	-0.06	0.21	0.05	0.07
	Rice	-	0.03	1.23	0.45	0.19
	Wheat	-	-0.24	0.53	0.10	0.15

[a] USD/AUD is the exchange rate between U.S. Dollar and Australian Dollar.

[b] CNY/USD is the exchange rate between Chinese Yuan and U.S. Dollar.

[c] TRI is the Trade Reduction Index.

Table 4. SURE results for inter annual volatility.

	Market based drivers			External drivers											
	Basic (A)			Real economy (B)			Financial economy (C)			Exogenous events (D)			Policy intervention (E)		
VARIABLES	*Barley*	*Corn*	*Wheat*	*Barley*	*Corn*	*Wheat*	*Barley*	*Corn*	*Wheat*	*Barley*	*Corn*	*Wheat*	*Barley*	*Corn*	*Wheat*
Ending stock	-0.07	-0.04	-0.13*	-0.06	-0.05	-0.13*	-0.09	-0.16	-0.22***	-0.08	-0.16	-0.22***	-0.08	-0.08	-0.16*
	(0.06)	(0.04)	(0.07)	(0.06)	(0.04)	(0.07)	(0.10)	(0.11)	(0.08)	(0.09)	(0.11)	(0.08)	(0.10)	(0.12)	(0.09)
Exports	-0.06	0.04	-0.13	-0.06	0.03	-0.11	-0.19	0.03	-0.16	-0.22	0.03	-0.17	-0.29*	0.17	-0.21
	(0.06)	(0.08)	(0.10)	(0.06)	(0.08)	(0.10)	(0.16)	(0.20)	(0.13)	(0.15)	(0.19)	(0.13)	(0.17)	(0.23)	(0.16)
Harvested area	-0.21	-0.21	0.13	-0.22	-0.23	0.08	-0.24	0.75	1.32***	-0.13	0.62	1.31***	-0.01	0.47	1.47***
	(0.13)	(0.33)	(0.32)	(0.13)	(0.32)	(0.32)	(0.35)	(0.59)	(0.44)	(0.35)	(0.59)	(0.44)	(0.36)	(0.61)	(0.47)
Yield	0.05	0.23	0.16	0.04	0.21	0.17	-0.05	0.42	0.23*	-0.08	0.35	0.23*	-0.04	0.60	0.11
	(0.09)	(0.20)	(0.13)	(0.09)	(0.20)	(0.13)	(0.15)	(0.34)	(0.12)	(0.15)	(0.34)	(0.12)	(0.16)	(0.41)	(0.16)
Domestic consumption	0.29*	-0.09	0.14	0.30*	-0.06	0.10	0.40	-0.60	0.48*	0.33	-0.62	0.37	0.25	-0.81*	0.60*
	(0.15)	(0.25)	(0.17)	(0.16)	(0.25)	(0.17)	(0.65)	(0.44)	(0.25)	(0.64)	(0.43)	(0.26)	(0.63)	(0.46)	(0.34)
Oil	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
USD/AUD[a]	NO	NO	NO	NO	NO	NO	YES	NO	NO	YES	NO	NO	YES	NO	NO
CNY/USD[b]	NO	NO	NO	NO	NO	NO	NO	YES	YES	NO	YES	YES	NO	YES	YES
Natural disasters	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES
Barley TRI_{t-12}[c]	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO
Corn TRI_{t-12}[c]	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO
Wheat TRI_{t-12}[c]	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES
Constant	-0.16	3.28	-2.65	-0.15	3.57	-1.31	2.57	-5.72	-34.53***	2.68	-1.50	-31.53***	2.36	-2.32	-38.75***
	(1.66)	(4.36)	(6.92)	(1.67)	(4.32)	(6.86)	(6.00)	(6.70)	(11.26)	(5.87)	(7.07)	(11.40)	(6.36)	(7.94)	(12.92)
Observations	52	52	52	52	52	52	31	31	31	31	31	31	30	30	30
R-squared	0.14	0.03	0.06	0.15	0.08	0.11	0.19	0.22	0.49	0.23	0.27	0.51	0.27	0.27	0.52

Standard errors are in parentheses. ***, **, and * indicate statistical significance at 1%, 5%, and 10%.

[a] USD/AUD is the exchange rate between U.S. Dollar and Australian Dollar.

[b] CNY/USD is the exchange rate between Chinese Yuan and U.S. Dollar.

[c] TRI is the Trade Reduction Index.

Table 5. SURE results for intra annual volatility.

	Market based drivers			**External drivers**											
	Basic (A)			Real economy (B)			Financial economy (C)			Exogenous events (D)			Policy intervention (E)		
VARIABLES	*Barley*	*Corn*	*Wheat*	*Barley*	*Corn*	*Wheat*	*Barley*	*Corn*	*Wheat*	*Barley*	*Corn*	*Wheat*	*Barley*	*Corn*	*Wheat*
Ending stock	-0.01	0.00	-0.04***	-0.01	0.00	-0.04***	-0.02***	0.00	-0.03***	-0.02***	0.00	-0.03***	-0.02***	0.00	-0.04***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Exports	0.04***	0.03***	-0.01	0.04***	0.02***	0.02*	0.03***	0.02***	0.02**	0.03***	0.02***	0.00	0.03***	0.02***	0.03***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Harvested area	0.06***	-0.01	0.01	0.07***	0.00	-0.02	0.09***	0.00	0.00	0.08***	0.00	0.06**	0.07***	0.04*	-0.02
	(0.01)	(0.02)	(0.03)	(0.01)	(0.02)	(0.03)	(0.01)	(0.02)	(0.02)	(0.01)	(0.02)	(0.02)	(0.01)	(0.02)	(0.02)
Yield	0.02**	0.02	0.01	0.02**	0.01	0.01	0.03***	0.01	0.03***	0.04***	0.00	0.03***	0.03***	-0.01	0.08***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Domestic consumption	0.02	-0.02	0.07***	0.00	-0.02	0.03*	-0.02*	-0.01	0.01	-0.02	-0.01	0.00	-0.01	0.00	-0.06***
	(0.01)	(0.02)	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)	(0.02)	(0.01)
Oil	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
USD/AUD[a]	NO	NO	NO	NO	NO	NO	YES	NO	NO	YES	NO	NO	YES	NO	NO
CNY/USD[b]	NO	NO	NO	NO	NO	NO	NO	YES	YES	NO	YES	YES	NO	YES	YES
Natural disasters	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES
Barley TRI$_{t-12}$[c]	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO
Corn TRI$_{t-12}$[c]	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO
Wheat TRI$_{t-12}$[c]	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES
Constant	-2.46***	-0.15	-0.75	-2.27***	-0.27	0.17	-1.89***	-0.24	-0.22	-1.72***	-0.08	-1.01**	-1.74***	-0.97***	0.70
	(0.15)	(0.27)	(0.58)	(0.15)	(0.27)	(0.54)	(0.14)	(0.28)	(0.52)	(0.14)	(0.30)	(0.51)	(0.16)	(0.35)	(0.50)
Observations	661	661	661	661	661	661	661	661	661	661	661	661	624	624	624
R-squared	0.38	0.20	0.17	0.43	0.32	0.39	0.55	0.31	0.40	0.55	0.32	0.46	0.57	0.35	0.54

Standard errors are in parentheses. ***, **, and * indicate statistical significance at 1%, 5%, and 10%.

[a] USD/AUD is the exchange rate between U.S. Dollar and Australian Dollar.

[b] CNY/USD is the exchange rate between Chinese Yuan and U.S. Dollar.

[c] TRI is the Trade Reduction Index.

Table 6. SURE results for global volatility.

	Market based drivers			**External drivers**											
	Basic (A)			Real economy (B)			Financial economy (C)			Exogenous events (D)			Policy intervention (E)		
VARIABLES	*Barley*	*Corn*	*Wheat*	*Barley*	*Corn*	*Wheat*	*Barley*	*Corn*	*Wheat*	*Barley*	*Corn*	*Wheat*	*Barley*	*Corn*	*Wheat*
Ending stock	0.00	0.00	-0.03***	-0.01	0.00	-0.01***	-0.01***	0.01***	-0.01***	-0.01***	0.01***	-0.01***	-0.02***	0.00	-0.02***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Exports	0.02***	0.04***	-0.01	0.02***	0.03***	0.02***	0.02***	0.04***	0.02**	0.02***	0.04***	0.00	0.02***	0.03***	0.02***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Harvested area	0.08***	0.02**	0.03	0.08***	0.02*	-0.03	0.12***	0.03**	0.01	0.12***	0.02	0.07***	0.09***	0.08***	-0.01
	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.02)
Yield	0.05***	0.06***	0.01	0.04***	0.04***	-0.01	0.05***	0.06***	0.04***	0.05***	0.05***	0.03***	0.03***	0.05***	0.08***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Domestic consumption	0.01	-0.07***	0.05***	0.00	-0.05***	0.01	-0.07***	-0.08***	-0.02**	-0.06***	-0.08***	-0.03***	-0.03***	-0.08***	-0.08***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Oil	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
USD/AUD[a]	NO	NO	NO	NO	NO	NO	YES	NO	NO	YES	NO	NO	YES	NO	NO
CNY/USD[b]	NO	NO	NO	NO	NO	NO	NO	YES	YES	NO	YES	YES	NO	YES	YES
Natural disasters	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES
Barley TRI_{t-12}[c]	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO
Corn TRI_{t-12}[c]	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO
Wheat TRI_{t-12}[c]	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES
Constant	-2.72***	-0.45***	-0.98**	-2.38***	-0.35**	0.45	-1.68***	-0.43***	-0.22	-1.78***	-0.20	-1.06***	-1.69***	-1.27***	0.79**
	(0.12)	(0.159)	(0.49)	(0.11)	(0.14)	(0.41)	(0.10)	(0.16)	(0.40)	(0.103)	(0.16)	(0.36)	(0.11)	(0.18)	(0.31)
Observations	637	637	637	637	637	637	637	637	637	637	637	637	601	601	601
R-squared	0.44	0.36	0.13	0.54	0.50	0.51	0.74	0.50	0.52	0.74	0.53	0.61	0.74	0.61	0.77

Standard errors are in parentheses. ***, **, and * indicate statistical significance at 1%, 5%, and 10%.

[a] USD/AUD is the exchange rate between U.S. Dollar and Australian Dollar.

[b] CNY/USD is the exchange rate between Chinese Yuan and U.S. Dollar.

[c] TRI is the Trade Reduction Index.