Grain price and volatility transmission from international to domestic markets in developing countries

Francisco Ceballos
IFPRI
f.ceballos@cgiar.org

Manuel A. Hernandez*
IFPRI
m.a.hernandez@cgiar.org

Nicholas Minot
IFPRI
n.minot@cgiar.org

Miguel Robles
IFPRI
m.robles@cgiar.org

*Corresponding author: 2033 K Street NW, Washington, DC, 20006, Tel: +1.202.862.5645

Selected Paper prepared for presentation at the 2015 Agricultural & Applied Economics Association and Western Agricultural Economics Association Annual Meeting, San Francisco, CA, July 26-28

Abstract

Understanding the sources of domestic food price volatility in developing countries and the extent to which it is transmitted from international to domestic markets is critical to help design better global, regional, and domestic policies to cope with excessive food price volatility and to protect the most vulnerable groups. This paper examines price and volatility transmission from major grain commodities to 41 domestic food products across 27 countries in Africa, Latin America, and South Asia. We follow a multivariate GARCH approach to model the dynamics of monthly price volatility in international and domestic markets. The period of analysis is 2000 through 2013. In terms of price transmission in levels, we only observe lead-lag relationships from international to domestic markets in few cases. To calculate volatility spillovers, we simulate a shock equivalent to a 1% increase in the conditional volatility of prices in the international market and evaluate its effect on the conditional volatility of prices in the domestic market. The transmission of price volatility is statistically significant in just one-quarter of the maize markets tested, almost half of rice markets tested, and all wheat markets tested. Volatility transmission seems to be more common when trade (imports or exports) are large relatively to domestic requirements.

Keywords: Volatility transmission, price transmission, grain commodity prices, domestic markets, MGARCH

JEL code: Q11, C32

1. Introduction

The global food crisis of 2007-2008 was characterized by a sharp spike in grain and other commodity prices. These price increases have been attributed to supply shortages, increased bio-fuel production, reduced stock-to-use ratios, export bans by major grain exporters, and panic buying by some major importers (Gilbert, 2010). Commodity prices rose rapidly again in 2010 and 2011. Overall, since 2007 global grain markets have seen an increase in price volatility, defined as the standard deviation of monthly price returns. For example, comparing the 27-year period before the crisis (1980-2006) with the four-year period during and after the crisis (2007-2010), the unconditional volatility of international prices rose 52 percent for maize, 87 percent for rice, and 102 percent for wheat (Minot, 2014).

To the extent that this price volatility is transmitted to markets in developing countries, it may have serious implications for farmers and low-income consumers. First, low-income consumers spend a large share of their income on food in general and on staple foods in particular, making them more vulnerable to food price volatility. For instance in some countries, such as Tanzania, Sri Lanka, and Vietnam, low-income households allocate more than 60 percent of their budgets to food (Seale, Regmi, and Bernstein, 2003). Second, food price volatility affects poor, small-scale farmers who rely on food sales for a significant part of their income and possess limited capacity for timing their sales. Third, price volatility is likely to inhibit agricultural investment and reduce agricultural productivity growth, especially in the absence of efficient risk-sharing mechanisms, with long-run implications for poor consumers and farmers.

A key question, however, is whether food price volatility in world grain markets is indeed transmitted to local markets in developing countries. If so, efforts to reduce excessive price volatility should perhaps be focused on concerted regional and international actions through the

World Trade Organization or other multilateral bodies. Alternatively, if food price volatility in developing countries is mostly attributed to domestic factors, then the most effective policy remedies would likely include domestic investment to reduce storage and transport costs and strengthen safety nets.

One approach to answering this question has been to examine the transmission of prices (in levels) from world markets to local markets.[1] Although it seems reasonable to assume that markets with high transmission of prices would also be characterized by high transmission of volatility, this may not necessarily be the case. For example, prices from highly-volatile world markets may only be transmitted to local markets with a one-to-six month lag, thus insulating local markets from international turmoil and resulting in local prices that exhibit much less volatility. Alternatively, even if there were no direct price transmission, it is possible for local market volatility to be determined by the degree of uncertainty among local traders, which could be influenced by a sudden increase in the volatility of world markets.

The objective of this paper is to both estimate grain price and volatility transmission from world markets to local markets in developing countries. In particular, we focus on the effect of the world price of maize, rice, wheat, and sorghum on 41 domestic prices of grain products in 27 countries in Latin America, Africa, and Asia. The price data are monthly, and most cover the period from January 2000 to December 2013, though there is some variation in starting and ending points. The analysis is based on a multivariate generalized auto-regressive conditional

[1] Section 2 discusses the relatively large body of research examining price transmission.

heteroskedasticity (MGARCH) model using the BEKK specification proposed by Engle and Kroner (1995).[2]

The main contribution of this paper is that it is one of the first to estimate the transmission of food price volatility from international markets to local markets across several developing countries and regions. As discussed below, while most other studies have examined the transmission of (mean) price levels from global markets to developing countries, the ones that have analyzed the transmission of price volatility have mainly focused on examining volatility dynamics across different commodities and international markets. Focusing on market interactions in terms of the conditional second moment and allowing for volatility spillovers provides better insight into the dynamic price relationship of international and domestic markets.

The remainder of the paper is organized as follows. Section 2 provides a review of recent research on transmission of prices and volatility. Section 3 details the methodology used in the study. Section 4 describes the data. Section 5 presents and discusses the estimation results while Section 6 summarizes the findings and draws some conclusions for future research.

2. Previous research on transmission of prices and volatility

There is a large body of research on the transmission of prices between markets within developing countries (see Baulch, 1997; Abdulai, 2000; Rashid, 2004; Lutz, Kuiper, and van Tilburg, 2006; Negassa and Myers 2007; Van Campenhout, 2007; Myers, 2008; Moser, Barrett, and Minten, 2009). Most of these studies use cointegration analysis in the form of error-correction

[2] The BEKK acronym comes from the synthetized work on multivariate GARCH models by Baba, Engle, Kraft, and Kroner (1990).

models, though some of the more recent ones apply threshold cointegration models and assymetric response to positive and negative price shocks (e.g., Meyer and von Cramon-Taubadel, 2004).

Fewer studies have examined the transmission of prices from world markets to local markets. Mundlak and Larson (1992) estimate the transmission of world food prices to domestic prices in 58 countries using annual price data. They find very high rates of price transmission, but the analysis is carried out in levels rather than first differences, so the results probably reflect spurious correlation due to nonstationarity. Quiroz and Soto (1995) repeat the analysis of Mundlak and Larson (1992) using cointegration analysis and an error correction model. They find no relationship between domestic and international prices for 30 of the 78 countries examined. Conforti (2004) examines price transmission in 16 countries, including 3 in Sub-Saharan Africa, using an error correction model. In general, he finds that the degree of price transmission in Sub-Saharan African countries is less than in Asian and Latin-American countries. Robles and Torero (2010) find empirical evidence of price tranmsission from international markets to domestic prices of several food products across four countries in Latin America. Minot (2010) analyzes the transmission of prices from world grain markets to 60 markets in sub-Saharan Africa, finding a statistically significant long-term relationship in only 13 of the 62 prices examined. He also finds that rice prices are more closely linked to world markets than are maize prices, presumably because most African countries are close to self-sufficient in maize but import a large share of their rice requirements.

Another set of studies has focused on the co-movement of world commodity prices. In their seminal paper, Pindyck and Rotemberg (1990) find “excessive co-movement” of seven commodity prices, which they attribute to herd behavior among traders in financial markets. The hypothesis of excess co-movement, however, was challenged by Deb, Trivedi, and Varangis

(1996) and Ai, Chatrath, and Song (2006). These studies argue that the Pindyck and Rotemberg results suffer from model misspecification and that fundamental supply and demand factors are sufficient to explain the co-movement.[3] In the case of international agricultural commodity prices, Gilbert (2010) indicates that price shocks for individual commodities are often supply related whereas joint price movement can be explained by macro-economic and monetary conditions.

Fewer studies have examined the co-movement of conditional price volatility. As noted by Gallagher and Twomey (1998), dynamic models of conditional volatility like MGARCH models, widely used in empirical finance, can provide a better understanding of the dynamic price relationship between markets by evaluating volatility spillovers. Volatility transmission between commodity markets may occur through substitution effects or as a result of common underlying factors, such as uncertainty in financial markets.

Some of the recent studies that study market interactions between agricultural commodities using MGARCH models include Le Pen and Sevi (2010), Zhao and Goodwin (2011), Hernandez, Ibarra, and Trupkin (2014), Beckmann and Czudaj (2014) and Gardebroek, Hernandez, and Robles (2014), with mixed results. Le Pen and Sevi (2010) use different multivariate models, including a factor model and a Dynamic Conditional Correlation (DCC) model, to examine the interrelationship between eight agricultural and non-agricultural commodities and find moderate co-movement in prices and volatility. Zhao and Goodwin (2011) find important volatility spillovers between corn and soybean futures prices based on a BEKK model. Using both a BEKK and a DCC model, Hernandez, Ibarra, and Trupkin (2014) show significant volatility spillovers within corn, wheat, and soybean futures exchanges in the United States, Europe, and Asia as well

[3] See Saadi (2010) for an extensive review of commodity price co-movement in international markets.

as an increase in their interdependence in recent years. Beckmann and Czudaj (2014) also show evidence supporting short-run volatility transmission between futures prices of corn, wheat, and cotton, based on bivariate GARCH-in-mean VAR models. Lastly, Gardebroek, Hernandez, and Robles (2014) implement different MGARCH models and find little evidence of price transmission in levels between corn, wheat, and soybean spot markets, but significant transmission in price volatility, particularly at weekly and monthly frequencies.

3. Methodology

We follow a multivariate GARCH (MGARCH) approach to evaluate the dynamics of volatility in monthly price returns from major agricultural international commodities to key domestic products in Africa, South Asia, and Latin America.[4] In particular, we estimate a bivariate T-BEKK model, proposed by Engle and Kroner (1995), which allows us to measure volatility transmission from international to domestic markets and is flexible enough to account for both volatility spillovers and persistence across markets.[5]

The T-BEKK approach involves modeling both a conditional mean equation and a conditional variance equation for each price return series considered in the analysis. In our case, we define price returns as $r_{mt} = \ln(p_{mt} / p_{mt-1})$, where p_{mt} is the price of a certain product (commodity) in market *m* at month *t*, and *m*=1 refers to the domestic market while *m*=2 to the international market. The logarithmic transformation is a standard measure for net returns in a

[4] See Bauwens et al. (2006) and Silvennoinen and Teräsvirta (2009) for an extensive overview of different MGARCH models.

[5] The T acronym refers to the Student's t density used in the model estimation in order to better control for the leptokurtic distribution of the price returns series.

market and is generally applied in empirical finance to obtain a convenient support for the distribution of the error term in the estimated model.

We first test for the presence of cointegration between domestic and international price returns using the Johansen trace test, with the number of lags (k) selected based on the Schwarz Bayesian information criterion (SBIC). For those cases where the pair of price returns are not found to be cointegrated, the conditional mean equation is simply modeled as a vector autoregressive (VAR) process such that

$$r_t = \alpha_0 + \sum_{s=1}^{k} \alpha_s r_{t-s} + \varepsilon_t , \quad \varepsilon_t \mid I_{t-1} \sim (0, H_t) , \qquad \text{(1a)}$$

where r_t is a 2x1 vector of price returns for the corresponding product (commodity) in the domestic and international market at month *t*, i.e. $r_t = \begin{pmatrix} r_{1t} \\ r_{2t} \end{pmatrix}$; α_0 is a 2x1 vector of constants; α_s, *s*=1,..,*k*, are 2x2 matrices of parameters capturing own and cross lead-lag relationships between markets at the mean level; and ε_t is a 2x1 vector of innovations with zero mean, conditional on past information I_{t-1}, and conditional variance-covariance matrix H_t .

For those cases where the pair of price returns are found to be cointegrated, the conditional mean equation is modeled as a vector-error correction (VEC) model such that

$$r_t = \alpha_0 + \sum_{j=1}^{k} \alpha_j r_{t-j} - \lambda ECT_{t-1} + \varepsilon_t , \quad \varepsilon_t \mid I_{t-1} \sim (0, H_t), \qquad \text{(1b)}$$

where ECT_{t-1} is the lagged error correction term resulting from the cointegration relationship, i.e. $ECT_{t-1} = \ln p_{1t-1} - \beta_0 - \beta_1 \ln p_{2t-1}$; and λ is a 2x1 vector of parameters that measure the adjustment of each (log) price series to deviations from the long-run equilibrium.

The conditional variance-covariance matrix H_t at time t (with one time lag) is, in turn, given by

$$H_t = C'C + A'\varepsilon_{t-1}\varepsilon_{t-1}^{'}A + G'H_{t-1}G, \qquad (2)$$

where C is a 2x2 upper triangular matrix of constants c_{ij}; A is a 2x2 matrix whose elements a_{ij} capture the direct effect of an innovation in market i on the current price return volatility in market j; and G is a 2x2 matrix whose elements g_{ij} measure the direct influence of past volatility in market i on the current volatility in market j (persistence). If we expand equation (2), the resulting conditional variance equation for the domestic market is defined as

$$\begin{aligned} h_{11,t} &= c_{11}^2 + a_{11}^2\varepsilon_{1,t-1}^2 + 2a_{11}a_{21}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + a_{21}^2\varepsilon_{2,t-1}^2 \\ &\quad + g_{11}^2 h_{11,t-1} + 2g_{11}g_{21}h_{12,t-1} + g_{21}^2 h_{22,t-1} \end{aligned}. \qquad (3)$$

This variance-covariance specification allows us to characterize the magnitude and persistence of volatility transmission from international to domestic markets. Moreover, similar to Gardebroek and Hernandez (2013) and Hernandez, Ibarra, and Trupkin (2014), we can derive an impulse-response function for the estimated conditional volatility to assess how a shock or innovation in the international market transmits to the domestic market and obtain the elasticity of domestic price volatility with respect to international price volatility.

4. Data

We compile a large dataset of monthly prices for maize, rice, wheat, and sorghum —and domestic products directly derived from these— for 41 markets in 27 countries. We obtain domestic price data from two sources. Our main source is the Famine Early Warning Systems Network (FEWSNET), a project funded by the United States Agency for International Development (USAID), which tracks the nominal prices of a number of food commodities across several key domestic markets on a monthly basis. This service is provided as part of their Price Bulletin product and is only available for countries in which the network has a presence—mostly African and Central American economies. Our second source is the Global Information and Early Warning System (GIEWS) of the Food and Agriculture Organization (FAO), which relies on price information from a number of local primary sources across FAO's 190 member countries. We rely on this source to obtain domestic prices for Asian, South American, and some additional Central American countries.

Out of all the price series available from these sources, we work with the domestic prices of the most important food staples in each country, identified as those with the largest contribution to caloric intake according the FAO (2014). Moreover, for each product we use the price from the main local market—generally the capital city. For a few countries, we include prices observed in more than one market (for example, in India we include prices from both the Mumbai and the New Delhi markets). As prices are denominated in local currency, each series is converted into U.S. dollars using monthly exchange rates from the IMF's International Financial Statistics (IFS) database. We exclude price series with less than 100 observations or with more than 10% of missing values. Missing values in the remaining series are replaced by linear interpolation between the two closest available data points. Table A.1 in the Appendix shows the details for each of the price series used, including its source (FEWSNET or GIEWS), the corresponding local market, whether it is a retail or a wholesale price, and its unit of measurement.

International monthly price series are compiled by the FAO International Commodity Prices database (FAOSTAT). All prices are expressed in U.S. dollars per tonne. The maize price is for No.2 Yellow Maize, U.S. Gulf; the rice price is for A1 Super, White rice broken, Bangkok, f.o.b.; the sorghum price is for No.2 Yellow Sorghum, U.S. Gulf; and the wheat price is for No.2 Hard Red Winter Wheat (Ordinary Protein), U.S. Gulf, f.o.b. Table A.2 in the Appendix shows the details of each of the international price series used.

Figure 1 shows the evolution of international monthly prices for maize, rice, sorghum, and wheat over the 2000-2014 period. In general, prices seem to have been rising in a relatively stable way until the spikes experienced during the food crisis of 2007-2008 and the subsequent spikes observed between 2010 and 2011. Interestingly, the figure shows a large degree of comovement between the prices for these four commodities during the past years, with a striking similarity between the prices of sorghum and maize.

[Insert Figure 1]

International prices for different food commodities also seem to comove in terms of unconditional volatility. Figure 2 shows the evolution of price volatility (the standard deviation of monthly price returns) for these four commodities over a 2-year moving window from 2000 to

2014.[6] The price volatility of these commodities seems to have followed a similar pattern during most of the period of analysis, with a considerable increase during and following the 2007-2008 food crisis, followed by a subsequent decrease—though to higher volatility than that prior to the crisis. This is more clearly observed in Figure 3, which compares price volatility before the crisis (2000-2006) and after the crisis (2009-2014). Although volatility in the price of sorghum shows only a moderate increase, volatility in the prices of the other three commodities increased by more than 30% after the crisis.

[Insert Figure 2]

[Insert Figure 3]

As discussed above, the main purpose of this study is to analyze volatility transmission from international to domestic markets. As a first step, it is useful to analyze the dynamics of the volatility of domestic prices vis-à-vis that of the international reference prices. Figure 4 plots the evolution of price volatility (the standard deviation of international and domestic price returns) by commodity over a 2-year moving window, in a similar fashion to Figure 2. The results are mixed. In the case of rice and wheat, there seems to be a substantial comovement in the volatility of domestic and international prices, particularly in the case of rice. The volatility of the international price for sorghum also shows some evidence of comovement with domestic volatilities. The pattern of price volatility in domestic maize markets, in contrast, do not generally resemble the pattern of volatility exhibited by the international price of maize. Note also that while for maize and sorghum the international price volatility is generally lower than in domestic markets, for rice

[6] For instance, the number for January 2000 reflects the standard deviation of the monthly realized price returns from February 1998 until January 2000.

and wheat the opposite is true. We examine volatility dynamics between domestic and international price returns more formally in the next section.

[Insert Figure 4]

Table 1 provides some descriptive statistics for the domestic and international price returns used in the analysis. First, the Jarque-Bera test indicates that the returns for almost every domestic price and all international prices do not follow a normal distribution. The kurtosis in all of the analyzed markets is greater than 3, further pointing to a leptokurtic distribution of returns. These results reveal the need to use a Student's t density for the estimation of the BEKK models below.

[Insert Table 1]

Second, both the Ljung-Box (LB) statistics for up to 5 and 10 lags and the Portmanteau (Q) statistics for the first- and second-order autocorrelation coefficients generally reject the null hypothesis of no autocorrelation for the squared returns. This autocorrelation suggests the existence of nonlinear dependencies in several of the price returns, which motivates the use of MGARCH models to better capture own-and cross-market interdependencies between domestic and international markets.

Third, the Augmented Dickey-Fuller (ADF) tests suggest that several of the domestic and international prices (in natural logarithms) are non-stationary. As explained in the methodology section, for all these cases a cointegration test is first conducted to determine the need to account for a potential long-run relationship between the corresponding domestic and international price through a vector error-correction model. Finally, the ADF test confirms the stationarity of all the domestic and international prices when expressed as returns (first differences in logarithms).

5. Results

5.1 Transmission in levels

This section describes the degree of transmission of prices in levels (lead-lag relationships) based on the estimation of the conditional mean equations discussed in Section 3. The first panel of Table 2 presents the relevant VAR and VEC coefficients describing the conditional mean equation for the domestic price return. Figure 5 shows the elasticity of price transmission for maize prices (Panel A), rice prices (Panel B), and sorghum and wheat prices (Panel C). We define the elasticity as the coefficient $\alpha_{1,12}$ of the conditional mean equation. By comparing this coefficient and its standard error in Table 2 it is clear that many of the elasticities are not significantly different than zero at the 5% level of confidence. More specifically, of the 16 maize price transmission elasticities, only one is statistically significant: the Honduran retail price of maize in market 1 in the capital, Tegucigalpa. Over the period covered by the study (2000-2013), Honduras imported about 37% of its maize requirements, which helps explain why its prices move with international prices (see Table 3). The importance of maize imports in domestic supply was less than 10% in all nine African countries listed and no more than one-quarter in Mexico and Nicaragua. However, the import share is over 50% in Colombia so clearly other factors are at work.

[Insert Table 2]

[Insert Figure 5]

[Insert Table 3]

Panel B of Table 2 gives the results for 15 rice prices in Africa, Asia, and Latin America. The standard errors indicate that just three of the 15 coefficients are statistically significant: Nepal, Philippines (regular milled), and Brazil. The linkage with the world market is somewhat surprising in all three countries because price imports account for a small (3-12%) share of domestic supply. The result for Nepal is particularly difficult to understand because the sign is negative, suggesting that domestic prices fall when international prices rise. One hypothesis is that Nepal prices are influenced by Indian rice markets, which are heavily managed by government programs to purchase, stock, and sell rice and wheat.

Panel C of Table 2 shows the price transmission for three sorghum markets and seven wheat markets. None of the three sorghum markets (Burundi, Chad, and Nigeria) have statistically significant links to world sorghum markets. This is expected since international trade in sorghum is negligible in all three countries (see Table 3). In the case of wheat, two of the seven markets show a statistically significant link with world wheat markets: Mumbai, India and Lima, Peru. It is not surprising that wheat prices in Lima are linked to world markets given the countries heavy reliance on imported wheat. On the other hand, it is somewhat surprising to find a link between Mumbai prices and world prices, given that India is (on average) self-sufficient in wheat. It should be noted, however, that the Mumbai is a wheat deficit region at some distance from the wheat surplus zone in the Punjab. In contrast, New Delhi is quite close to the Punjabi wheat zone. Brazil and Bolivia are depend heavily on wheat imports, but Argentina is the main source of wheat and Argentinian prices are imperfectly integrated with US wheat prices, used as the benchmark for world prices in this study. The lack of linkage between Ethiopian wheat prices and world wheat prices is probably due to the large (but variable) share of wheat imports that are in the form of food aid, thus less driven by market forces.

5.2 Volatility transmission

In this section, we describe our price volatility transmission estimates from international commodity markets to domestic food markets across countries and commodities. Due to space limitations, we only report in the second panel of Table 2 the estimated coefficients of the BEKK model describing the conditional variance equation of domestic markets (specified in equation (3)).[7] The lower panel of Table 3 also reports different residual diagnostic tests, which generally support the adequacy of BEKK model specification. In particular, the Ljung-Box, Lagrange Multiplier (LM), and Hosking Multivariate Portmanteau test statistics for up to 6 and 12 lags show no or weak evidence of autocorrelation, ARCH effects, and cross-correlation in the standardized squared residuals of the estimated models.

First, we assess the reliability of our estimations by comparing model predictions to sample price volatility statistics (sample standard deviation of domestic price returns) for each domestic price.[8] For model predictions of price returns volatilities we use i) the average of predicted conditional standard deviations of price returns and ii) the estimated steady-state (or unconditional) price return volatility.[9]

Figure A.1 in the Appendix compares the sample and model estimates of domestic price volatilities. Sample data indicates that maize volatility is on average larger than rice and wheat volatility. Average sample maize volatility is 10.4% while for rice and wheat are 4.7% and 4.8%, respectively. Across regions African countries have the highest sample volatilities (average of

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[7] Wald joint tests indicate that in several cases there are immediate innovation and persistence effects from international to domestic markets. We discuss in more detail below volatility transmission from international to domestic markets.

[8] The sample volatility is equal to $\left(h_{11}^{sample}\right)^{0.5} = \sqrt{\frac{\sum_{t=1}^{n}(r_t-\bar{r})^2}{n}}$.

[9] The average of predicted conditional volatilities is equal to $\overline{\widehat{h_{11}}} = \frac{\sum_{t=1}^{n}\hat{h}_{11.t}^{0.5}}{n}$ while the steady–state volatility $(h_{11}^{SS})^{0.5}$ satisfies $H^{SS} = C'C + G'H^{SS}G$.

11.3%) while in Asia and Latin America the averages are less than half of the African average. Our estimated steady-state and predicted volatilities yield similar conclusions when comparing commodities and regions. When we compare steady-state volatility with sample volatility, the former is consistently lower than the latter. In particular, steady-state volatility estimates are on average 60% of the sample estimates. This is expected as steady-state estimates reflect the standard deviations to be reached over time in the absence of shocks. This finding is also consistent with results reported by Gardebroek, Hernandez, and Robles (2014).

When we compare average predicted volatility with sample volatility, we also observe that our estimated models perform reasonably well. The ratio of the average predicted volatility to the sample volatility is on average 0.99 for the full set of countries and commodities. and our average predicted volatilities further reaffirm that on average maize price volatility is much more volatile (more than two times larger) than rice and wheat price volatility.

To obtain estimates for the degree of volatility transmission from international markets to domestic markets we carry out the following two steps for each estimated model (one per country/commodity):

1. We estimate the size of a shock in the international market ($\bar{\varepsilon}_2$) such that the steady-state standard deviation of the international price return increases in one percent after one period:

$$\frac{\sqrt{H_{1,22}(\bar{\varepsilon}_2)} - \sqrt{H_{0,22}}}{\sqrt{H_{0,22}}} = 0.01$$

2. We introduce shock $\bar{\varepsilon}_2$ in expression (2) and estimate the percentage change in the standard deviation of the domestic price return (with respect to its steady-state value) and compute our volatility transmission VT indicator according to:

$$VT = \frac{\sqrt{H_{1,11}} - \sqrt{H_{0,11}}}{\sqrt{H_{0,11}}} \div 0.01$$

In other words, our volatility transmission indicator shows the reaction (after one period and assuming the system is on steady-state) of the domestic volatility (standard deviation of price return) to a shock in the international market. If our volatility transmission indicator is equal to one it means that the domestic volatility increases in one period in the same proportion as the international price volatility, after introducing a shock in the international market.

We present our volatility transmission estimates for each country and commodity in Figure 6 and aggregated median and frequencies across commodities and regions in Table A.3 in the Appendix. Overall most of our estimates are within reasonable values.[10]

[Insert Figure 6]

An approximate measure of the statistical significance of the relationship between international price volatility and domestic volatility is given by the Wald test for the joint significance of α_{21} and g_{21} in the conditional variance equation (see Table 2). α_{21} represents the short-term effect of an international price shock on domestic volatility, while g_{21} represents the short-term effect of changes in international price volatility on domestic volatility.

In the case of maize, 4 of the 16 Wald tests reject the null hypothesis that both coefficients are zero: Benin, Ethiopia, Nigeria, and Colombia. The linkage between international and domestic volatility is easy to understand in the case of Colombia, which imports 64% of its maize requirements over the period under study. The linkage for the other three countries is unexpected, given that all three rely on imports for less than 2% of domestic requirements (see Table 3).

[10] Only in 6 out of 41 cases our estimates show extreme values larger than 10.

In the case of rice, 7 of the 15 markets show evidence of a statistically significant spillover from international volatility to domestic volatility (see Table 2). This is expected in the case of Senegal, which imported 82% of its domestic requirements, and the two prices in Thailand, which exported more than 40% of its production (see Table 3). Similarly, the lack of linkage in India, Nepal, Brazil, and Ecuador is explained by small contribution of rice imports in these countries. More surprising is the volatility spillover in Colombia and Peru, where rice imports meet less than 7% of local demand.

In the case of sorghum, one of the three prices shows signs of a statistically significant spillover in volatility from international markets: Burundi (see Table 2). This is surprising given that Burundi is landlocked and has virtually no sorghum imports from world markets. The lack of spillover for Chad and Nigeria are, however, expected given the negligible volumes of traded sorghum.

Wheat markets in developing countries appear to be relatively sensitive to volatility in international wheat markets. All seven of the markets tests showed evidence of a statistically significant link between international and domestic price volatility (see Table 2). This is expected in the case of Peru, Bolivia, and Brazil, given their reliance on imported wheat for more than half of local consumption, and understandable in the case of Ethiopia, which imports 32% of its requirements (see Table 3). On the other hand, India is largely self-sufficient in wheat in most years, so the volatility linkage with world wheat markets is harder to explain.

5.3 Conditional correlations

Lastly, we are interested in examining whether the dynamic price relationship between domestic and international markets has changed in recent years, particularly after the global food price crisis of 2007-2008. From the BEKK model, we can recover time-varying conditional correlations between the price returns of each domestic market and the international market. This correlation is given by $\hat{\rho}_{12,t} = \frac{\hat{h}_{12,t}}{\sqrt{\hat{h}_{11,t}\hat{h}_{22,t}}}$, where $\hat{h}_{11,t}$ and $\hat{h}_{22,t}$ are the estimated conditional variance equations and $\hat{h}_{12,t}$ is the covariance equation. We then run separate regressions of these recovered conditional correlations on a trend term, trend squared and a dummy shifter for the period July 2007 onwards, as mid-2007 was the period where the crisis was felt most (food prices peaked).

Table 4 reports the number of cases where we find a statistically significant change after June 2007 in the degree of co-movement between domestic and international price returns by commodity and region (at the 95% confidence level). Overall, we do not observe major changes in the dynamic interrelationship between domestic and international price returns after the food price crisis. Only in nine cases (out of 41) there is a positive shift in the domestic-international conditional correlation and in two cases there is a negative shift. The two negative cases are in Africa (maize in Mozambique and wheat in Ethiopia), while the nine positive cases are distributed four in Asia (rice in Philippines (well milled) and Thailand (25% broken) and wheat in Mumbai and New Delhi), four in Latin America (rice in Ecuador and Peru (milled, standard), maize in Honduras and wheat in Peru), and one in Africa (maize in Ethiopia). Figure A.2 in the Appendix further reports the median change in the domestic-international correlations by commodity and region, confirming that the shifts were generally small, except for rice with a median shift of 10 percentage points.

[Insert Table 4]

6. Conclusions

Food price volatility in developing countries is economically and politically important. In these economies a large share of household budgets is spent on food, so food price levels and volatility have a direct and large impact on welfare. Food price volatility particularly affects poor, small-scale farmers who rely on crop sales for a significant part of their income. It is also likely to inhibit agricultural investment and reduce the growth in agricultural productivity, with long-run implications for poor consumers and farmers. Hence, it is important to better understand the sources of food price volatility and whether it is mostly transmitted from international agricultural commodity markets or largely determined by domestic factors. This in turn can help design better global, regional, and domestic policies to cope with excessive food price volatility and to protect the most vulnerable groups.

The objective of this paper is to estimate the extent of both grain price and volatility transmission from world markets to local markets in developing countries, in a context where volatility interactions has not been largely analyzed in the literature. In particular, we focus on the effect of the world price of maize, rice, wheat, and sorghum on 41 prices of grain products in 27 countries in Latin America, Africa, and Asia. The price data are monthly, and most cover the period from January 2000 to December 2013. The analysis is based on a MGARCH approach using a BEKK model.

In terms of price transmission in levels, we only observe lead-lag relationships from international to domestic markets in few cases. Only 6 international-domestic price elasticities (out of 41) are statistically significant. In terms of volatility transmission, however, we observe more interactions across markets. We propose as a volatility transmission estimator (or elasticity) one that shows the reaction (after one period and assuming the system is on steady-state) of the domestic price volatility (the standard deviation of price returns) given a one-percent shock in international price volatility of the commodity. We find that most of our elasticity estimates are within reasonable values.

Maize markets in developing countries are the least susceptible to volatility in international markets, with just one-quarter of them (4 of 16) showing evidence of a statistically significant effect. Rice markets appear to be more sensitive to volatility in international markets, with almost half the markets tested (7 of 15) having statistically significant spillover. And wheat markets were the most sensitive to international price volatility, with a significant linkage in all seven markets tested. In general terms, this pattern reflects the fact that most of the countries in our sample are relatively self-sufficient in maize: on average, net trade represents 16% of domestic use. In contrast, these countries are more dependent on rice trade (average 38%) and most reliant on international trade in wheat (average 78%).

These patterns extend to individual markets. Colombia is heavily dependent on maize imports and is one of just four markets with significant volatility linkages. Senegal and Thailand are both deeply involved in rice trade, as importer and exporter respectively, and both show volatility spillover from world markets. Similarly, Brazil, Bolivia, Peru, and Ethiopia rely heavily on wheat imports and show transmission of volatility from world markets.

At the same time, there are a number of exceptions to these patterns. Some countries with little trade in a commodity have domestic price volatility that appears linked to international volatility. Examples include maize in Ethiopia, rice in Peru, sorghum in Burundi, and wheat in India. One hypothesis is that the behavior of local traders or government trading enterprises monitor international markets and are prompted by international volatility to respond in ways that contribute to local volatility even in the absence of direct trade effects. Another possibility is that price volatility is actually being transmitted through closely related staple grain markets for which there is trade. Testing these hypotheses would be a fruitful direction for future research.

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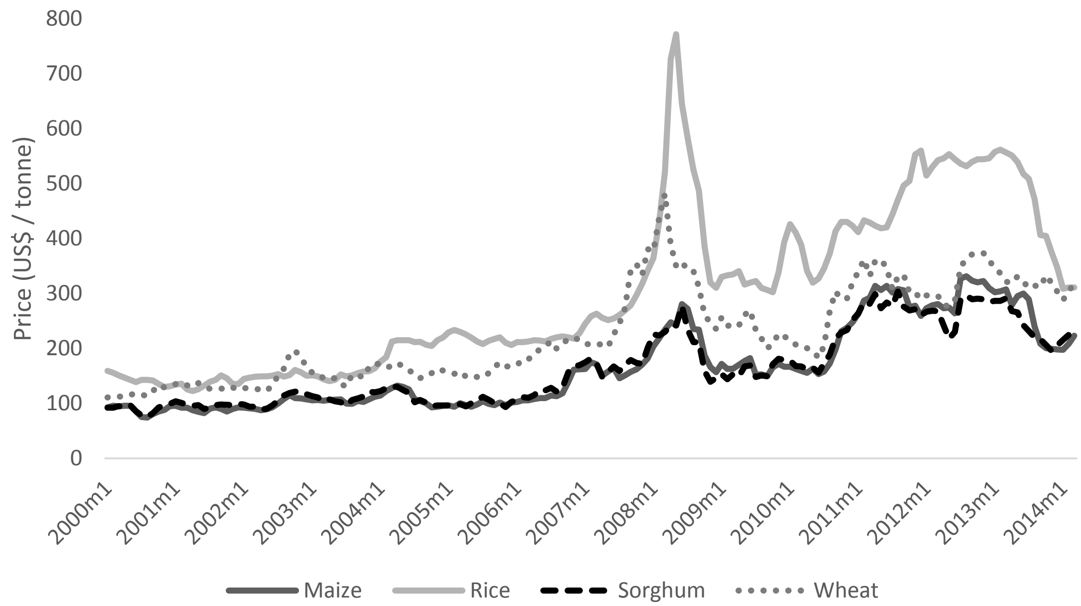
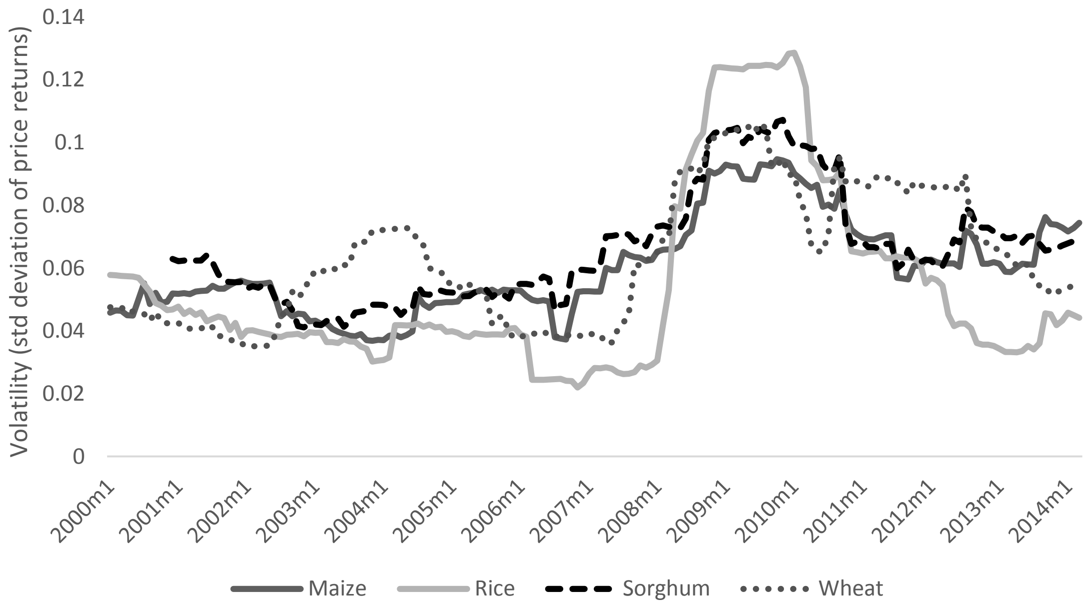
Figure 1. International Commodity Prices - 2000-2014



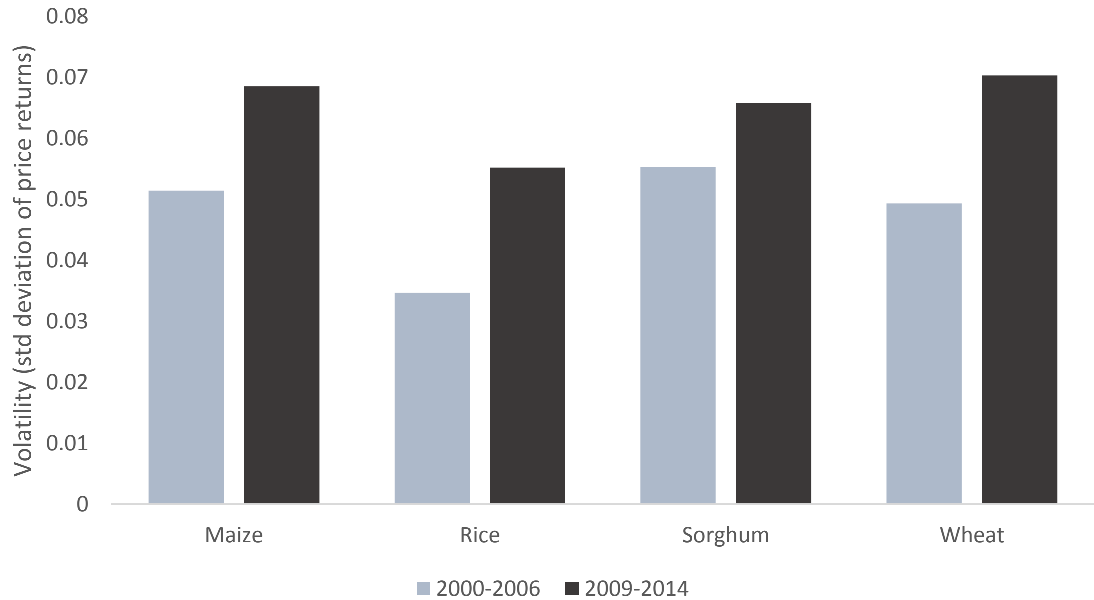
Note: This figure shows the evolution of the monthly international prices of maize, rice, sorghum, and wheat during the 2000-2014 period. Prices are expressed in US$ per tonne.

Figure 2. Volatility of International Grain Prices (2-year moving window) - 2000-2014



Note: This figure shows the evolution of the volatility of monthly international prices of maize, rice, sorghum, and wheat during the 2000-2014 period. The volatility for every month is calculated as the standard deviation of the monthly price returns observed during that and the previous 23 months.

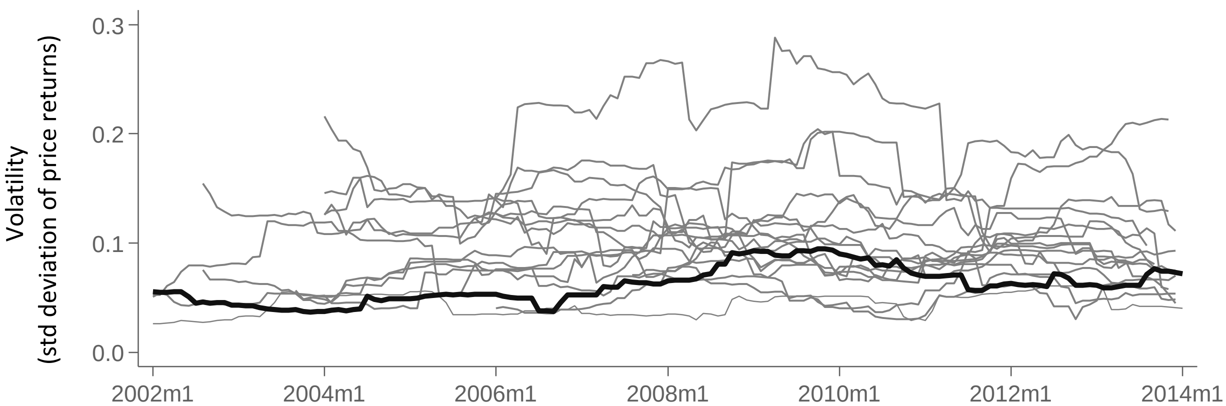
Figure 3. Volatility of International Grain Prices before and after the 2007-2008 Crisis



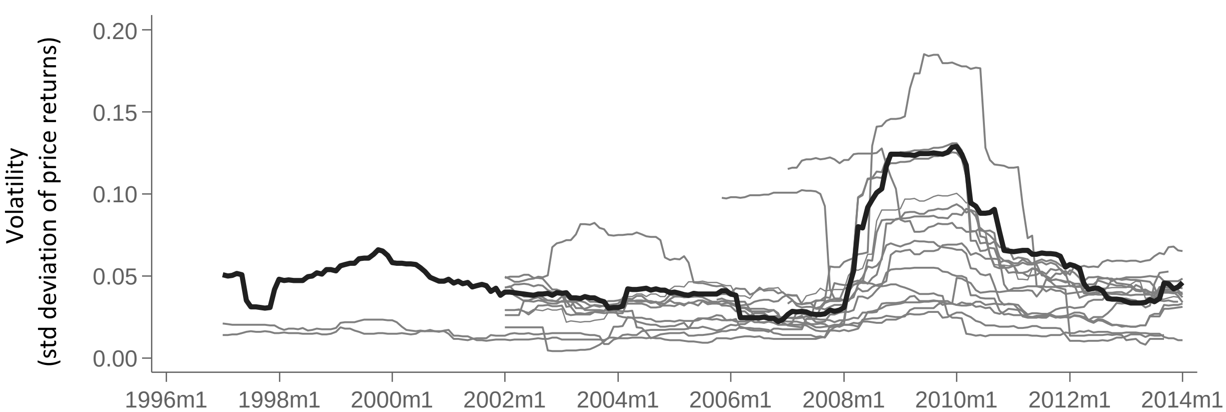
Note: This figure shows the volatility of monthly international prices of maize, rice, sorghum, and wheat before and after the 2007-2008 food crisis. The "before" period spans 2000-2006 while the "after" period spans 2009-2014. The volatility for each period is calculated as the standard deviation of the observed monthly price returns for each commodity.

Figure 4. Volatility (2-year moving window) of Domestic and International Prices

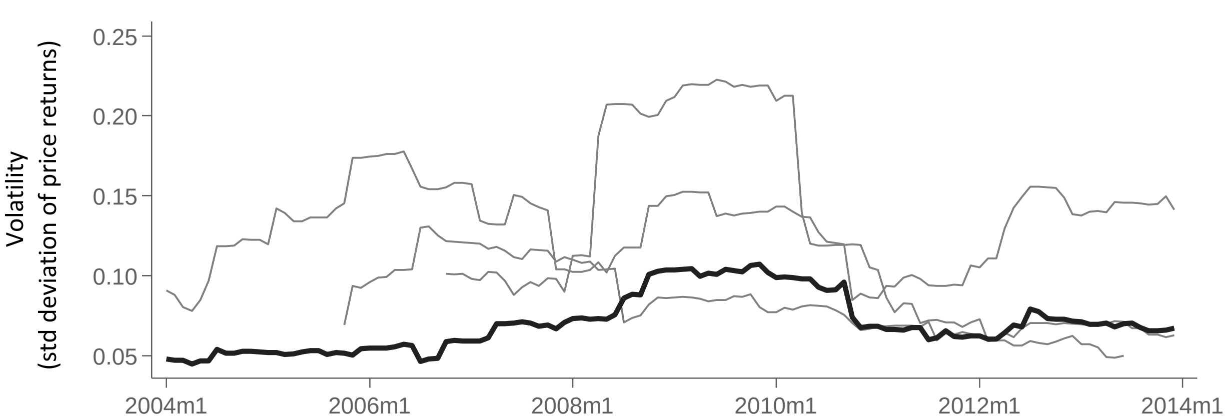
Panel A. Maize



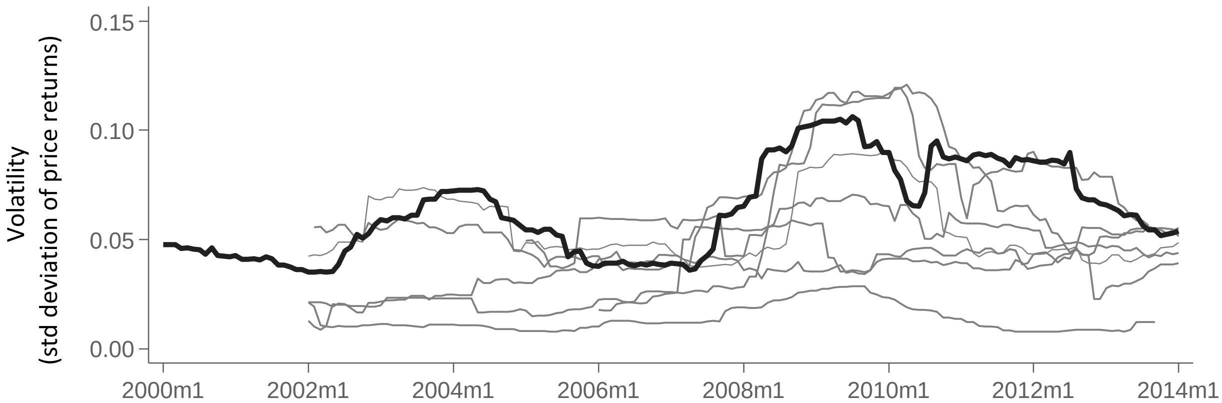
Panel B. Rice



Panel C. Sorghum



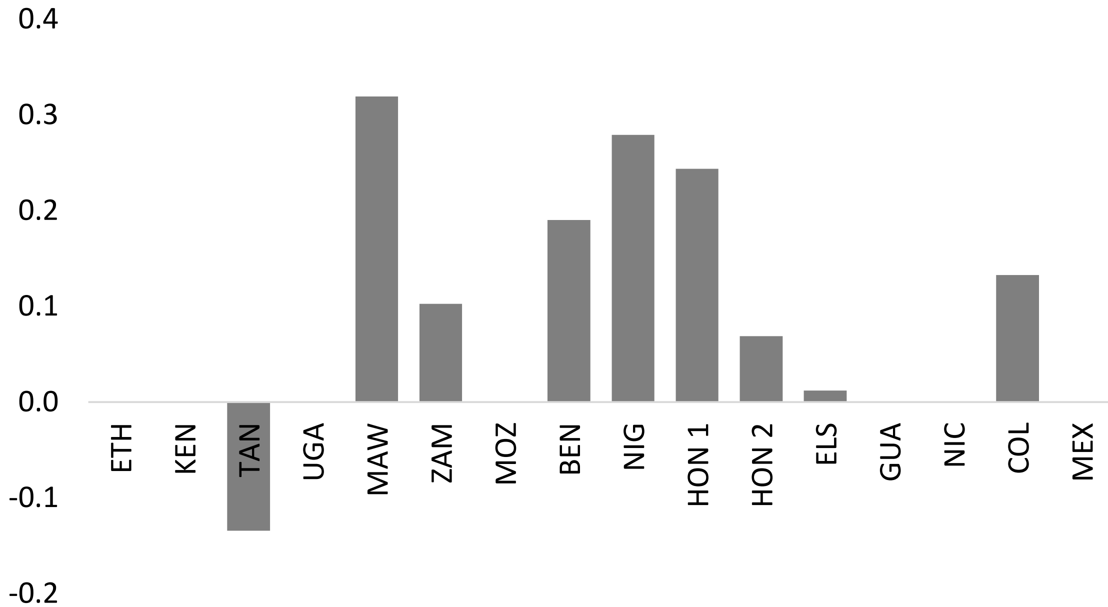
Panel D. Wheat



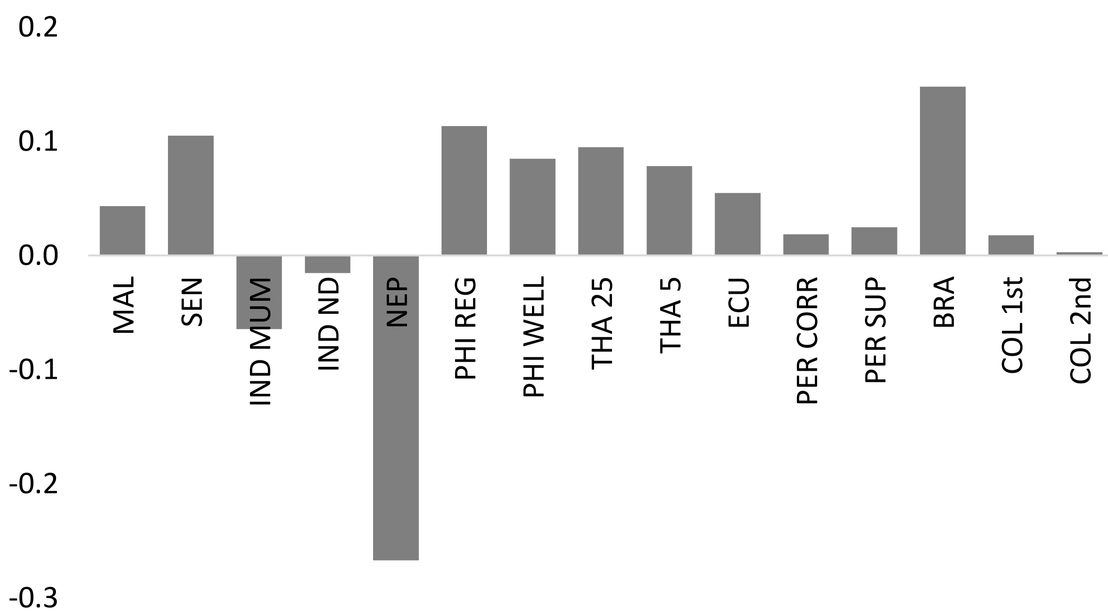
Note: This figure shows the evolution of the volatility of monthly domestic and international prices of maize, rice, sorghum, and wheat during the 2000-2014 period. The volatility for every month is calculated as the standard deviation of the monthly price returns observed during that and the previous 23 months. The line in bold represents the volatility of each international price series.

Figure 5. Price Return Transmission Estimates (in Levels)

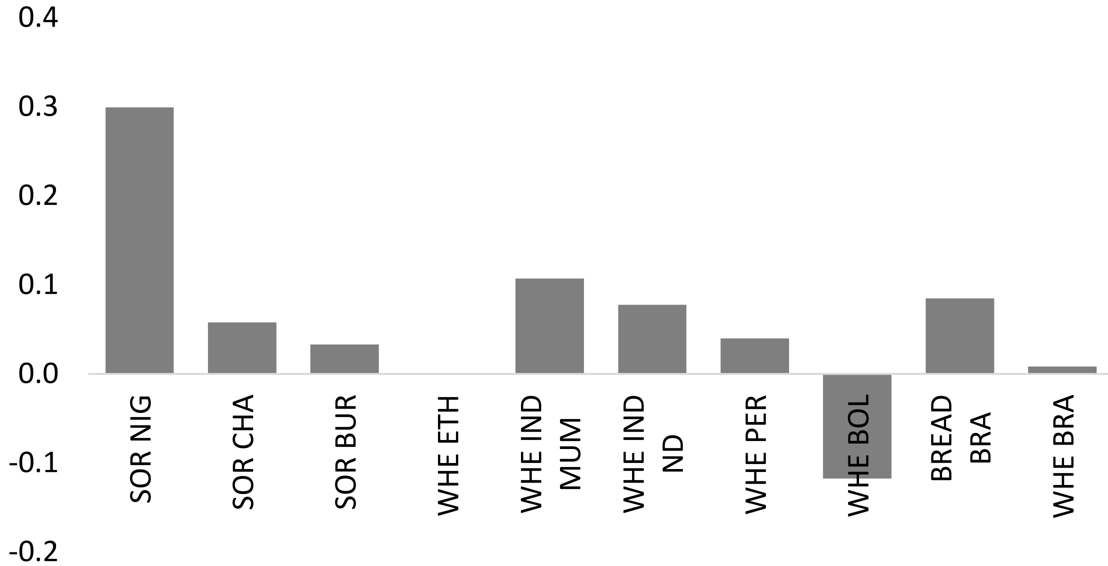
Panel A. Maize



Panel B. Rice



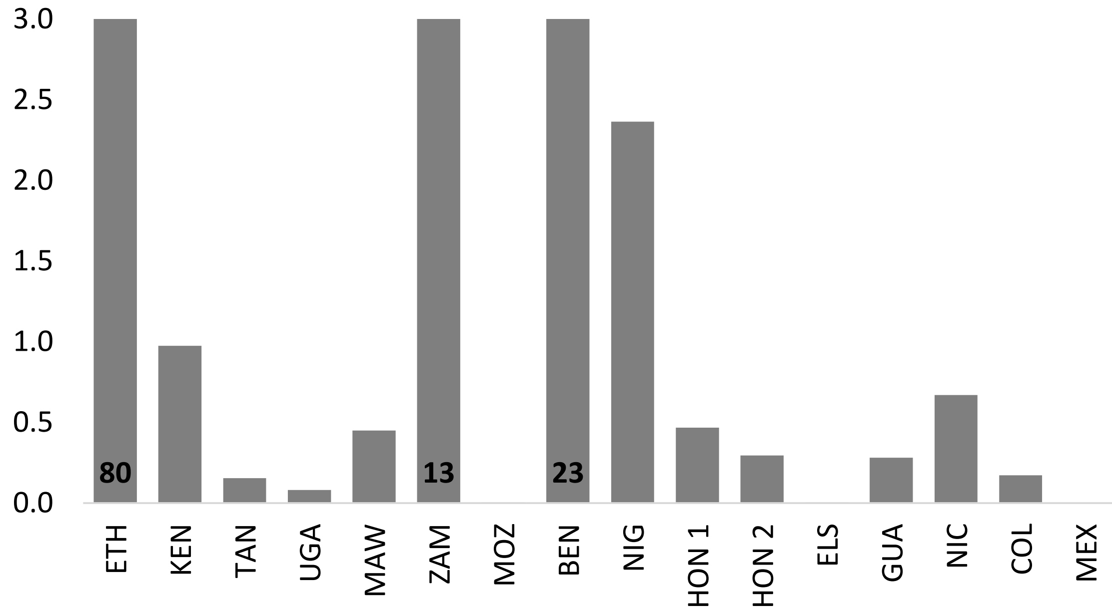
Panel C. Sorghum / Wheat



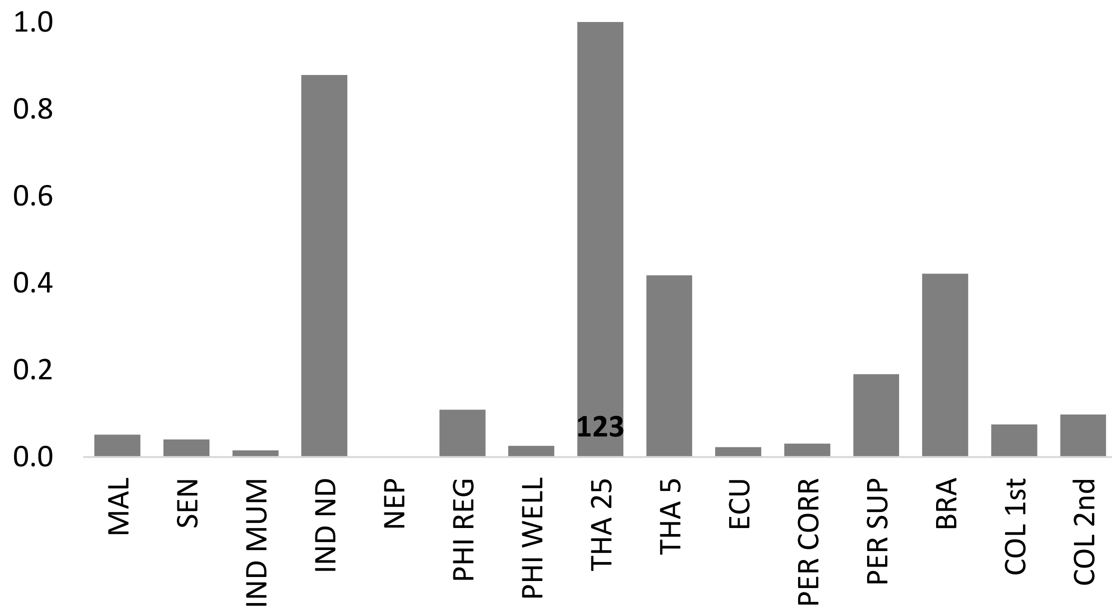
Note: This figure shows estimates for the elasticity of price transmission from international markets to domestic markets for each available country and commodity. Panel A focuses on transmission of the international maize price, panel B on transmission of the international price of rice, and panel C on transmission of the international prices of sorghum (first three country-commodities) and wheat. The elasticity of price transmission is defined as the coefficient $\alpha_{1,12}$ of the conditional mean equation (see Section 3 of the main text for details).

Figure 6. Price Return Volatility Transmission Estimates

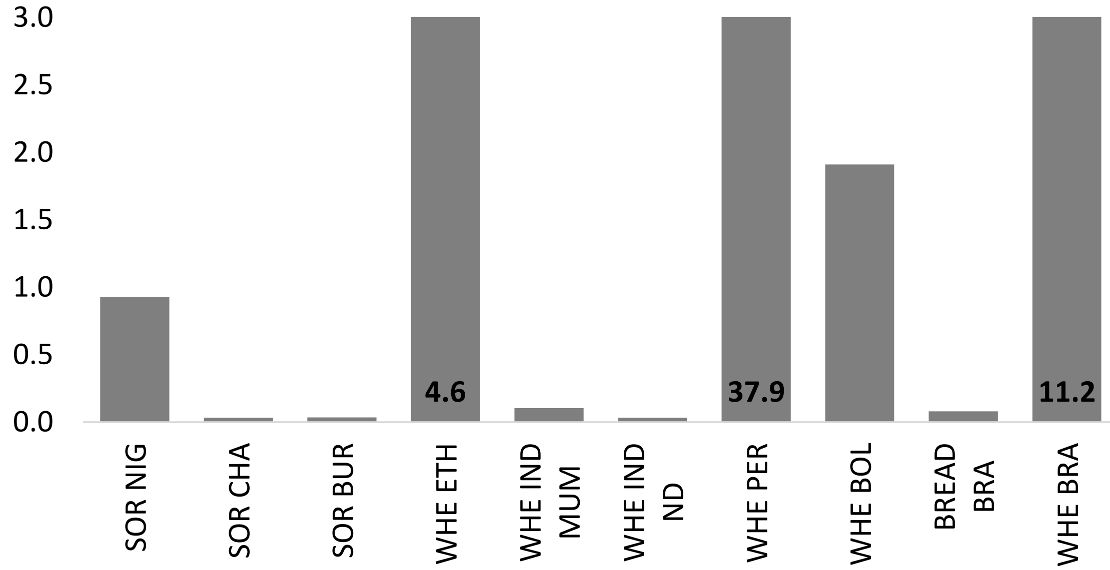
Panel A. Maize



Panel B. Rice



Panel C. Sorghum / Wheat



Note: This figure shows estimates for the elasticity of price volatility transmission from international markets to domestic markets for each available country and commodity. Panel A focuses on volatility transmission of the international maize price, panel B on volatility transmission of the international price of rice, and panel C on volatility transmission of the international prices of sorghum (first three country-commodities) and wheat. The elasticity of price volatility is defined as the percentage change in the standard deviation of the domestic price return (with respect to its steady-state value), relative to that of the international price return standard deviation (see Section 5.2 of the main text for details). The figure is truncated to preserve scale, outlier values are indicated in bold.

Table 1. Summary Statistics and Selected Normality, Autocorrelation, and Stationarity Tests

Panel A. Domestic price series

	Maize	Rice	Sorghum	Wheat	Total
Number of domestic price series	16	15	3	7	41
Mean price returns	0.42%	0.33%	0.47%	0.46%	0.40%
% of series with kurtosis > 3	100.0%	100.0%	100.0%	100.0%	100.0%
% of series rejecting Jarque-Bera test's H_0	93.8%	100.0%	100.0%	100.0%	97.6%
% of series rejecting Ljung-box test's H_0 on squared returns (5 lags)	31.3%	66.7%	0.0%	71.4%	48.8%
% of series rejecting Ljung-box test's H_0 on squared returns (10 lags)	31.3%	73.3%	33.3%	71.4%	53.7%
% of series rejecting AC Q test's H_0 on squared returns (first lag)	37.5%	73.3%	33.3%	71.4%	56.1%
% of series rejecting AC Q test's H_0 on squared returns (second lag)	43.8%	80.0%	33.3%	85.7%	63.4%
% of series rejecting ADF test's H_0 on logarithm of price in levels (5 lags)	56.3%	13.3%	0.0%	57.1%	36.6%
% of series rejecting ADF test's H_0 on price returns (5 lags)	100.0%	100.0%	100.0%	100.0%	100.0%

Panel B. International price series

	Maize	Rice	Sorghum	Wheat
Mean price returns	0.52%	0.39%	0.54%	0.62%
Standard deviation of price returns	6.44%	6.18%	6.74%	6.65%
Jarque-Bera statistic	28.68*	273.10*	39.46*	39.37*
Kurtosis	4.84	9.15	5.27	5.11
Ljung-box statistic on squared returns (5 lags)	1.58	53.74*	4.42	7.25
Ljung-box statistic on squared returns (10 lags)	11.86	80.14*	8.71	11.86
AC Q statistic on squared returns (First lag)	0.09	0.35*	0.08	0.17*
AC Q statistic on squared returns (Second lag)	0.03	0.34	0.01	0.09*
ADF statistic - Logarithm of price in levels (5 lags)	-1.40	-1.58	-1.47	-1.78
ADF statistic - Price returns (5 lags)	-5.88*	-5.74*	-5.74*	-4.68*

Note: This table presents summary statistics and selected normality, autocorrelation, and stationarity tests for domestic (panel A) and international (panel B) price return series for maize, rice, sorghum, and wheat.

Table 2. Selected Model Results and Residual Tests

	MAIZE															
	BEN	ETH	KEN	MAW	MOZ	NIG	TAN	UGA	ZAM	ELS	GUA	HON 1	HON 2	MEX	NIC	COL
Conditional Mean Equation																
Model	VAR	VEC	VEC	VAR	VEC	VAR	VAR	VEC	VAR	VAR	VEC	VAR	VEC	VEC	VEC	VAR
No. of lags	1	0	0	1	0	1	2	0	1	1	0	2	1	0	0	1
α_0	0.006	-0.003	-0.001	0.002	-0.001	0.010	0.003	-0.001	-0.001	0.002	-0.002	0.003	0.000	0.001	0.000	-0.001
	(0.012)	(0.009)	(0.007)	(0.019)	(0.009)	(0.012)	(0.009)	(0.013)	(0.009)	(0.005)	(0.006)	(0.006)	(0.006)	(0.003)	(0.009)	(0.006)
$\alpha_{1,11}$	0.019			0.179		-0.015	0.221		-0.019	0.172		0.206	0.464			0.230
	(0.093)			(0.091)		(0.094)	(0.084)		(0.084)	(0.077)		(0.083)	(0.071)			(0.078)
$\alpha_{1,12}$	0.190			0.319		0.279	-0.134		0.103	0.012		0.244	0.069			0.133
	(0.179)			(0.267)		(0.174)	(0.145)		(0.135)	(0.081)		(0.100)	(0.092)			(0.092)
Conditional Variance Equation																
c_{11}	11.813	-0.029	3.694	19.345	1.676	4.373	8.508	-6.674	0.211	0.613	0.629	5.493	6.199	2.267	-5.438	2.336
	(1.661)	(0.095)	(2.901)	(2.291)	(2.074)	(2.006)	(2.345)	(3.068)	(0.260)	(1.365)	(1.579)	(1.617)	(0.662)	(1.216)	(7.301)	(2.101)
a_{11}	0.346	0.530	-0.250	0.336	0.622	-0.105	0.475	0.683	-0.707	0.408	0.798	-0.938	0.409	0.675	0.789	0.279
	(0.105)	(0.145)	(0.574)	(0.165)	(0.328)	(0.196)	(0.141)	(0.168)	(0.399)	(0.706)	(0.224)	(0.342)	(0.129)	(0.181)	(0.222)	(0.196)
a_{21}	-0.807	-0.198	-0.409	0.539	-0.028	0.738	-0.260	0.102	-0.146	-0.012	0.084	0.111	0.162	-0.005	-0.290	0.138
	(0.381)	(0.114)	(0.418)	(0.257)	(0.112)	(0.278)	(0.177)	(0.275)	(0.112)	(0.065)	(0.075)	(0.195)	(0.092)	(0.108)	(0.173)	(0.135)
g_{11}	0.002	0.897	-0.785	0.001	-0.837	0.855	-0.408	0.565	0.807	-0.765	0.656	-0.059	0.000	-0.001	-0.384	0.831
	(0.016)	(0.053)	(0.376)	(0.012)	(0.095)	(0.134)	(0.196)	(0.241)	(0.101)	(0.112)	(0.189)	(0.237)	(0.015)	(0.204)	(0.202)	(0.193)
g_{21}	0.000	-0.102	-0.434	0.000	-0.430	0.067	-0.446	-0.918	-0.388	0.606	-0.300	-0.077	0.000	0.358	0.688	-0.459
	(0.011)	(0.102)	(1.015)	(0.033)	(0.296)	(0.553)	(0.433)	(0.495)	(0.353)	(0.383)	(0.194)	(0.366)	(0.009)	(0.200)	(1.225)	(0.070)
v	4.314	3.717	4.231	4.728	2.813	3.667	3.722	7.037	3.665	4.600	6.029	3.730	6.207	4.051	4.413	3.744
	(1.287)	(0.924)	(1.835)	(1.209)	(0.782)	(0.919)	(0.821)	(2.587)	(1.746)	(1.570)	(2.768)	(1.238)	(1.702)	(0.897)	(0.972)	(0.851)
Wald test for presence of innovation and persistence effects from international to domestic market (H_0: $a_{21} = g_{21} = 0$)																
Chi-squared	9.083	7.399	3.384	4.429	3.507	12.159	5.663	5.408	2.520	2.506	2.469	0.423	3.287	5.307	4.131	43.095
p-Value	0.011	0.025	0.184	0.109	0.173	0.002	0.059	0.067	0.284	0.286	0.291	0.809	0.193	0.070	0.127	0.000
Ljung-Box test for autocorrelation (H_0: no autocorrelation in squared residuals)																
LB(6)	2.522	16.574	8.201	6.945	10.494	10.843	3.668	3.973	7.967	2.477	3.981	9.137	2.020	4.971	6.578	14.003
p-Value	0.866	0.011	0.224	0.326	0.105	0.093	0.722	0.680	0.241	0.871	0.679	0.166	0.918	0.547	0.362	0.030
LB(12)	10.152	32.112	15.799	22.446	22.996	20.540	8.285	8.196	13.254	12.784	31.099	30.716	12.912	14.728	21.938	20.610
p-Value	0.603	0.001	0.201	0.033	0.028	0.058	0.763	0.770	0.351	0.385	0.002	0.002	0.375	0.257	0.038	0.056
Lagrange multiplier (LM) test for ARCH residuals (H_0: no ARCH effects)																
LM(6)	1.002	2.442	4.045	1.104	0.654	2.200	2.807	1.833	8.384	3.022	6.344	3.488	2.904	4.138	3.508	0.549
p-Value	0.986	0.875	0.671	0.981	0.995	0.900	0.833	0.934	0.211	0.806	0.386	0.746	0.821	0.658	0.743	0.997
LM(12)	6.154	5.542	6.436	4.294	2.008	4.113	9.094	4.804	8.461	7.299	13.614	4.758	5.117	6.745	6.885	2.162
p-Value	0.908	0.937	0.893	0.978	0.999	0.981	0.695	0.964	0.748	0.837	0.326	0.966	0.954	0.874	0.865	0.999
Hosking Multivariate Portmanteau test for cross-correlation (H_0: no cross-correlation in squared residuals)																
M(6)	12.367	11.711	18.921	46.859	5.756	9.724	9.894	9.141	30.430	17.910	15.418	10.739	14.110	15.136	9.683	4.389
p-Value	0.975	0.983	0.756	0.003	1.000	0.996	0.995	0.997	0.171	0.807	0.908	0.991	0.944	0.917	0.996	1.000
M(12)	51.848	30.398	31.940	73.003	24.924	34.904	44.511	34.225	55.156	43.978	47.272	34.011	34.071	41.570	44.185	38.139
p-Value	0.326	0.978	0.964	0.011	0.998	0.921	0.617	0.933	0.222	0.638	0.503	0.937	0.936	0.732	0.630	0.845
Log Likelihood	-861.8	-770.0	-1117.1	-892.6	-968.9	-804.3	-975.0	-1034.8	-977.9	-1017.8	-637.3	-915.4	-926.0	-989.5	-1097.6	-969.2
No. of Obs.	123	120	168	120	144	123	144	144	144	161	101	148	148	171	161	154

Table 2. Selected Model Results and Residual Tests (cont.)

	RICE														
	MAL	SEN	IND MUM	IND ND	NEP	PHI REG	PHI WELL	THA 25	THA 5	BRA	COL 1st	COL 2nd	ECU	PER CORR	PER SUP
Conditional Mean Equation															
Model	VEC	VAR	VAR	VEC	VAR	VEC	VEC	VAR	VAR	VEC	VAR	VAR	VEC	VAR	VAR
No. of lags	1	4	2	1	3	1	1	2	2	1	3	3	1	2	2
α_0	0.002	-0.001	0.003	0.002	0.001	0.002	0.002	0.002	0.003	0.002	0.002	0.002	0.005	0.001	0.001
	(0.005)	(0.007)	(0.002)	(0.002)	(0.007)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.001)	(0.001)
$\alpha_{1,11}$	0.069	-0.498	0.227	0.193	0.484	0.135	0.219	0.421	0.416	0.203	0.347	0.316	-0.153	0.280	0.335
	(0.093)	(0.095)	(0.077)	(0.078)	(0.099)	(0.078)	(0.079)	(0.132)	(0.110)	(0.076)	(0.078)	(0.078)	(0.097)	(0.067)	(0.066)
$\alpha_{1,12}$	0.043	0.105	-0.064	-0.015	-0.267	0.113	0.085	0.095	0.078	0.148	0.018	0.003	0.055	0.019	0.025
	(0.082)	(0.141)	(0.045)	(0.034)	(0.122)	(0.054)	(0.046)	(0.143)	(0.120)	(0.071)	(0.063)	(0.070)	(0.041)	(0.029)	(0.019)
Conditional Variance Equation															
c_{11}	4.243	1.638	0.008	0.017	2.357	2.006	0.743	1.444	1.818	3.029	1.167	1.852	0.615	1.065	0.767
	(0.908)	(1.203)	(0.025)	(0.023)	(2.070)	(0.966)	(0.257)	(0.369)	(0.582)	(1.392)	(0.705)	(0.651)	(0.229)	(0.369)	(0.157)
a_{11}	0.440	0.364	0.091	0.629	0.343	0.254	-0.278	0.487	0.813	0.312	-0.039	0.061	0.660	0.520	0.474
	(0.459)	(0.105)	(0.096)	(0.122)	(0.111)	(0.135)	(0.084)	(0.134)	(0.161)	(0.262)	(0.084)	(0.078)	(0.193)	(0.134)	(0.124)
a_{21}	0.252	0.232	0.044	-0.070	0.011	0.204	0.115	0.118	-0.303	-0.292	-0.218	0.179	0.018	-0.047	-0.064
	(0.323)	(0.128)	(0.038)	(0.057)	(0.177)	(0.076)	(0.083)	(0.087)	(0.120)	(0.186)	(0.071)	(0.094)	(0.039)	(0.036)	(0.018)
g_{11}	-0.123	0.907	0.997	0.854	0.896	0.742	0.943	0.952	0.854	0.585	0.890	0.804	0.762	0.676	-0.678
	(0.561)	(0.067)	(0.011)	(0.046)	(0.116)	(0.266)	(0.026)	(0.102)	(0.139)	(0.459)	(0.102)	(0.070)	(0.106)	(0.152)	(0.087)
g_{21}	0.109	-0.473	-0.031	0.037	-0.012	-0.353	-0.015	-0.267	-0.630	0.530	0.151	-0.370	-0.007	-0.011	-0.042
	(0.309)	(0.152)	(0.014)	(0.022)	(0.105)	(0.111)	(0.024)	(0.059)	(0.164)	(0.233)	(0.088)	(0.100)	(0.060)	(0.049)	(0.064)
ν	3.957	5.166	5.101	4.420	5.229	9.175	5.016	8.985	8.816	13.610	132.498	10.599	7.369	4.101	8.132
	(1.487)	(1.336)	(1.825)	(1.114)	(2.500)	(3.853)	(1.059)	(3.800)	(3.785)	(10.981)	(330.799)	(6.190)	(4.910)	(0.766)	(2.889)
Wald test for presence of innovation and persistence effects from international to domestic market (H_0: $a_{21} = g_{21} = 0$)															
Chi-squared	2.198	9.734	5.435	2.956	0.013	12.546	2.886	23.040	21.981	5.548	9.335	18.338	0.211	2.025	12.704
p-Value	0.333	0.008	0.066	0.228	0.994	0.002	0.236	0.000	0.000	0.062	0.009	0.000	0.900	0.363	0.002
Ljung-Box test for autocorrelation (H_0: no autocorrelation in squared residuals)															
LB(6)	6.794	13.517	8.398	0.821	8.533	2.908	3.741	4.675	4.998	3.695	6.004	5.095	7.670	1.752	5.119
p-Value	0.340	0.036	0.210	0.991	0.202	0.820	0.712	0.586	0.544	0.718	0.423	0.532	0.263	0.941	0.529
LB(12)	10.996	20.869	13.984	4.935	15.420	8.230	9.706	12.043	13.360	10.083	11.055	12.741	10.466	6.336	9.857
p-Value	0.529	0.052	0.302	0.960	0.219	0.767	0.642	0.442	0.343	0.609	0.524	0.388	0.575	0.898	0.629
Lagrange multiplier (LM) test for ARCH residuals (H_0: no ARCH effects)															
LM(6)	20.121	6.745	2.583	2.040	1.348	2.239	7.008	2.669	2.198	2.379	9.819	3.467	6.180	2.365	2.191
p-Value	0.003	0.345	0.859	0.916	0.969	0.896	0.320	0.849	0.901	0.882	0.132	0.748	0.403	0.883	0.901
LM(12)	22.214	15.907	10.044	5.465	3.407	5.564	9.824	4.293	6.550	7.305	10.994	4.501	9.726	4.690	4.816
p-Value	0.035	0.196	0.612	0.941	0.992	0.936	0.631	0.978	0.886	0.837	0.529	0.973	0.640	0.968	0.964
Hosking Multivariate Portmanteau test for cross-correlation (H_0: no cross-correlation in squared residuals)															
M(6)	31.893	16.927	14.748	43.910	11.413	14.392	32.630	21.456	15.355	17.461	40.464	16.529	34.438	41.278	40.700
p-Value	0.130	0.852	0.928	0.008	0.986	0.937	0.112	0.612	0.910	0.828	0.019	0.868	0.077	0.016	0.018
M(12)	46.515	32.029	44.182	59.293	22.062	32.705	41.889	38.219	33.908	31.333	58.757	33.401	52.108	52.395	63.919
p-Value	0.534	0.963	0.630	0.127	1.000	0.955	0.720	0.843	0.938	0.970	0.137	0.946	0.317	0.307	0.062
Log Likelihood	-690.8	-695.5	-872.1	-851.1	-641.2	-914.9	-886.4	-865.9	-890.0	-977.4	-908.6	-931.3	-546.1	-1063.7	-1018.1
No. of Obs.	122	121	171	171	110	170	170	170	170	171	171	171	111	225	225

Table 2. Selected Model Results and Residual Tests (cont.)

	SORGHUM			WHEAT						
	SOR BUR	SOR CHA	SOR NIG	WHE ETH	WHE IND MUM	WHE IND ND	WHE PER	WHE BOL	WHE BRA	BREAD BRA
Conditional Mean Equation										
Model	VAR	VAR	VAR	VEC	VAR	VAR	VAR	VEC	VEC	VAR
No. of lags	1	1	1	0	2	2	2	1	1	1
α_0	0.005	0.005	0.001	-0.001	0.003	0.002	0.002	0.003	0.003	0.008
	(0.008)	(0.011)	(0.012)	(0.006)	(0.003)	(0.003)	(0.001)	(0.005)	(0.004)	(0.005)
$\alpha_{1,11}$	0.043	-0.078	-0.126		0.134	0.314	0.367	0.063	0.201	-0.148
	(0.092)	(0.084)	(0.098)		(0.079)	(0.077)	(0.074)	(0.085)	(0.073)	(0.077)
$\alpha_{1,12}$	0.033	0.058	0.299		0.107	0.077	0.040	-0.118	0.008	0.085
	(0.103)	(0.153)	(0.163)		(0.044)	(0.044)	(0.016)	(0.067)	(0.064)	(0.077)
Conditional Variance Equation										
c_{11}	5.253	9.518	9.968	1.016	0.426	0.555	0.746	-1.361	2.302	2.174
	(1.764)	(3.785)	(2.708)	(2.573)	(0.878)	(1.251)	(0.259)	(2.123)	(1.892)	(0.816)
a_{11}	-0.140	0.347	0.445	0.599	0.294	-0.072	0.174	-0.306	-0.313	0.421
	(0.194)	(0.239)	(0.174)	(0.283)	(0.190)	(0.144)	(0.165)	(0.130)	(0.152)	(0.110)
a_{21}	0.087	-0.172	0.145	-0.428	0.031	0.033	0.131	-0.180	-0.305	0.112
	(0.174)	(0.415)	(0.506)	(0.144)	(0.054)	(0.058)	(0.031)	(0.125)	(0.099)	(0.089)
g_{11}	-0.225	0.443	-0.175	-0.563	0.962	0.980	0.042	0.878	0.545	0.734
	(0.509)	(0.344)	(0.541)	(0.188)	(0.073)	(0.052)	(0.346)	(0.190)	(0.185)	(0.080)
g_{21}	0.849	-0.617	-0.211	0.345	-0.132	0.023	0.097	-0.112	0.420	-0.328
	(0.285)	(0.699)	(0.739)	(0.279)	(0.050)	(0.036)	(0.042)	(0.092)	(0.217)	(0.074)
v	4.572	4.591	3.675	4.705	4.980	8.305	7.305	6.337	8.857	9.796
	(1.306)	(1.381)	(1.485)	(1.271)	(1.470)	(3.979)	(2.634)	(2.123)	(3.750)	(4.273)
Wald test for presence of innovation and persistence effects from international to domestic market (H_0: a										
Chi-squared	23.122	0.869	0.098	29.637	11.372	8.677	24.074	23.050	61.000	21.846
p-Value	0.000	0.648	0.952	0.000	0.003	0.013	0.000	0.000	0.000	0.000
Ljung-Box test for autocorrelation (H_0: no autocorrelation in squared residuals)										
LB(6)	1.760	2.548	2.948	5.671	4.266	6.102	3.927	3.064	2.333	3.944
p-Value	0.940	0.863	0.815	0.461	0.641	0.412	0.687	0.801	0.887	0.684
LB(12)	3.521	13.764	13.638	13.769	11.379	11.067	13.213	15.411	8.128	16.633
p-Value	0.991	0.316	0.324	0.316	0.497	0.523	0.354	0.220	0.775	0.164
Lagrange multiplier (LM) test for ARCH residuals (H_0: no ARCH effects)										
LM(6)	1.981	2.248	1.013	3.325	2.113	11.629	10.164	1.720	6.353	1.423
p-Value	0.921	0.896	0.985	0.767	0.909	0.071	0.118	0.944	0.385	0.964
LM(12)	18.856	7.192	2.727	5.745	3.635	22.112	14.158	5.829	11.153	12.860
p-Value	0.092	0.845	0.997	0.928	0.989	0.036	0.291	0.924	0.516	0.379
Hosking Multivariate Portmanteau test for cross-correlation (H_0: no cross-correlation in squared residuals)										
M(6)	16.616	5.755	26.227	27.096	15.606	22.684	16.061	10.518	21.972	25.534
p-Value	0.865	1.000	0.342	0.300	0.902	0.538	0.886	0.992	0.581	0.377
M(12)	50.349	35.123	49.785	48.966	29.998	60.651	38.569	18.919	40.587	62.906
p-Value	0.381	0.917	0.402	0.434	0.981	0.104	0.833	1.000	0.767	0.073
Log Likelihood	-815.7	-1011.5	-720.8	-703.7	-953.8	-969.4	-770.3	-809.3	-1028.6	-1052.7
No. of Obs.	123	144	111	120	171	171	165	135	171	170

Note: This table presents selected coefficients from the estimated conditional mean and conditional variance equations for each available country-commodity series, together with goodness of fit tests. See Section 3 of the main text for details on the estimations and Section 5.2 of the main text for details on the tests.

Table 3. Net imports as a share of domestic availability

	Maize	Rice	Sorghum	Wheat
Benin	0%	85%	0%	95%
Chad	8%	2%	4%	91%
Ethiopia	1%	49%	3%	32%
Kenya	9%	86%	10%	70%
Malawi	0%	3%	8%	108%
Mali	1%	16%	0%	103%
Mozambique	9%	77%	1%	95%
Nigeria	0%	37%	0%	98%
Senegal	30%	82%	1%	100%
Tanzania	0%	9%	0%	100%
Uganda	-2%	29%	7%	94%
Zambia	-7%	46%	35%	10%
India	-13%	-5%	-1%	-2%
Nepal	3%	5%	109%	1%
Philippines	4%	12%	97%	104%
Thailand	-6%	-70%	-3%	105%
Bolivia	1%	3%	-1%	72%
Brazil	-18%	3%	-1%	56%
Colombia	64%	6%	52%	98%
Ecuador	33%	-5%	44%	100%
El Salvador	38%	72%	1%	100%
Guatemala	32%	71%	0%	97%
Honduras	37%	83%	1%	97%
Mexico	25%	76%	32%	44%
Nicaragua	15%	35%	-1%	100%
Peru	50%	5%	99%	88%
Mean abs value	16%	36%	22%	72%

Note: This table shows the degree of dependence on food imports for each of the countries available in our sample. The degree of dependence on food import is calculated as (M-X)/A, where M is the volume of imports, X is the volume of exports, and A is total domestic availability, defined as production plus net imports plus change in stocks. All quantities reflect 2000-2013 averages. Data for Burundi is not available.

Table 4. Conditional Correlation between Domestic and International Price Returns, by Commodity and Region

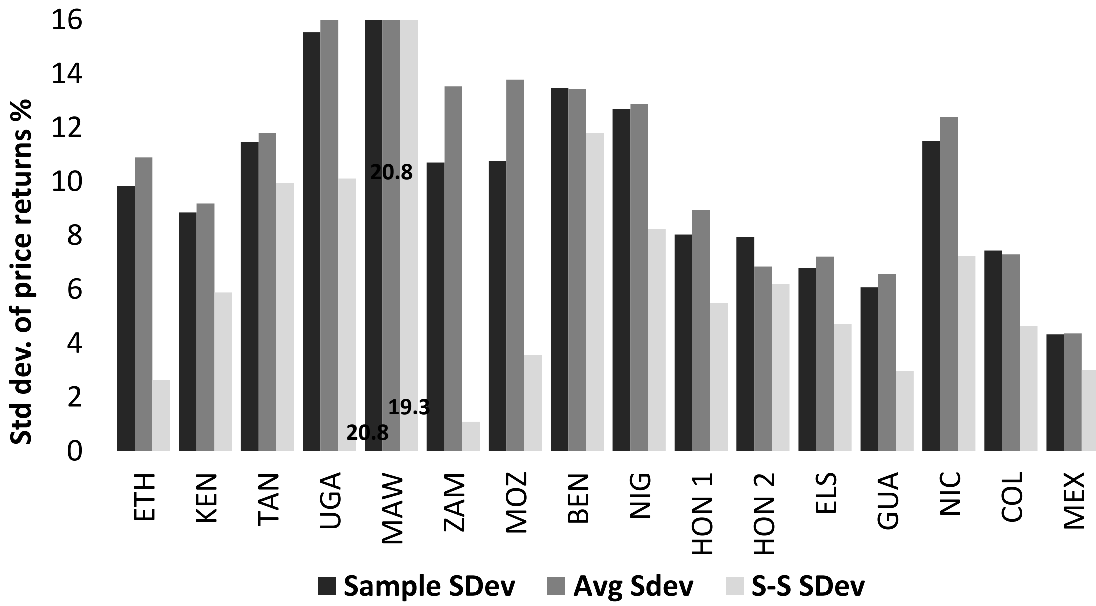
Commodity / Region	# cases positive shift mid-2007	# cases negative shift mid-2007	Total series
By commodity			
Maize	2	1	16
Rice	4	0	15
Wheat	3	1	7
Sorghum	0	0	3
By region			
Africa	1	2	15
Asia	4	0	9
Central America & Mexico	1	0	6
South America	3	0	11
Total	9	2	41

Note: This table portrays the behavior of the estimated conditional correlations between domestic and international price returns around the 2007-2008 food crisis. We run separate regressions of the estimated conditional correlations for each available month on trend and trend squared terms, plus a dummy shifter for the period July 2007 onwards. The table then reports the number of cases for which the dummy shifter is statistically significant (at the 95% confidence level), by region and commodity (see Section 5.3 of the main text for details).

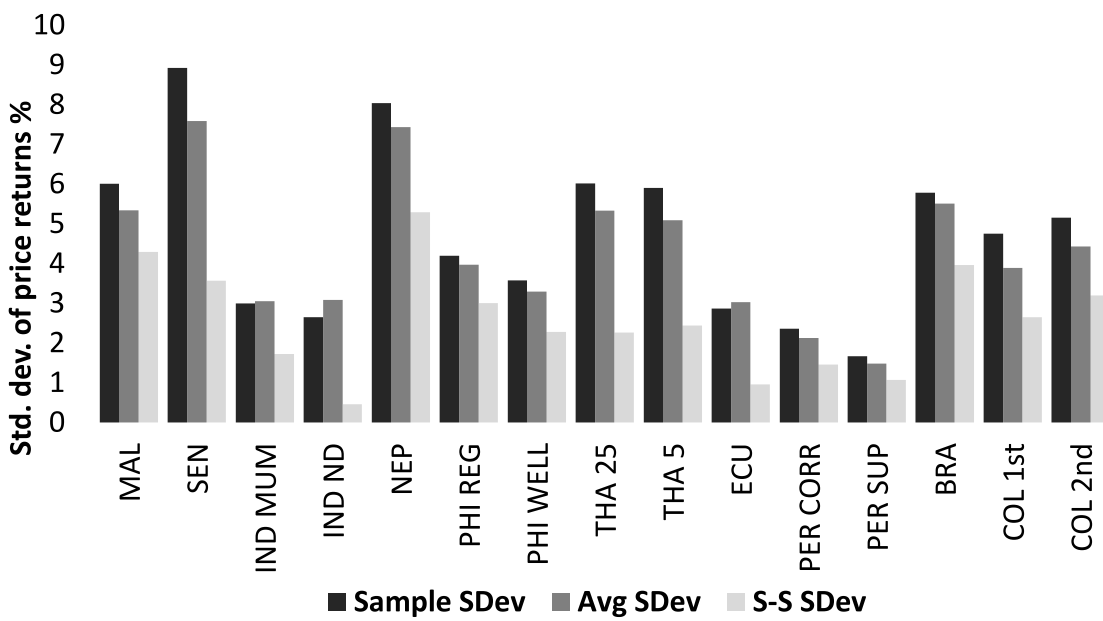
Appendix. Supplementary Figures and Tables

Figure A.1. Volatility of Monthly Prices (in %)
Sample, Average, and Steady-State

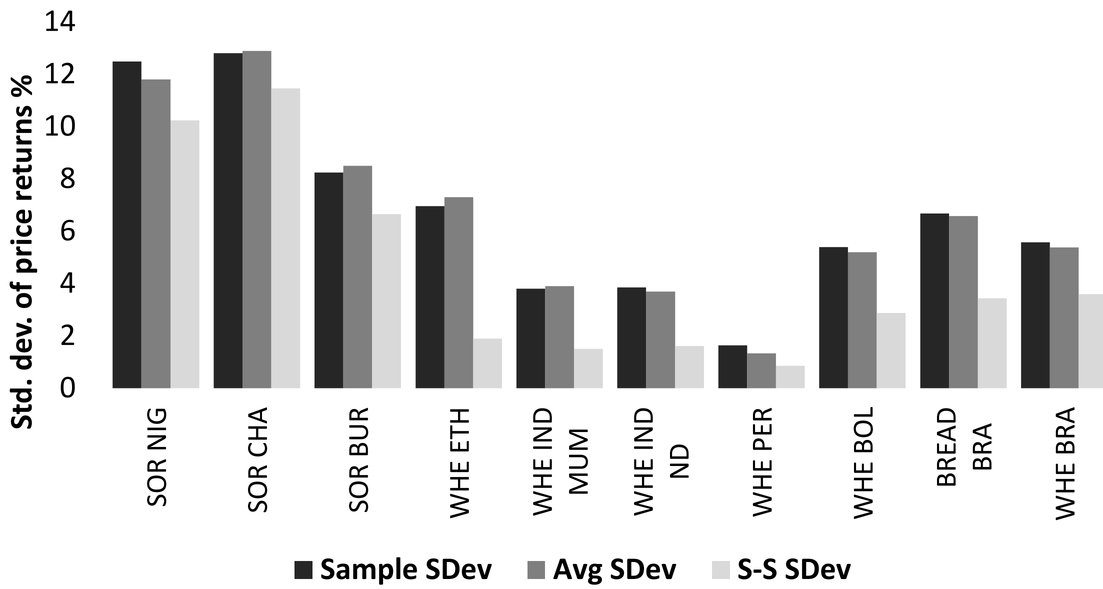
Panel A. Maize



Panel B. Rice

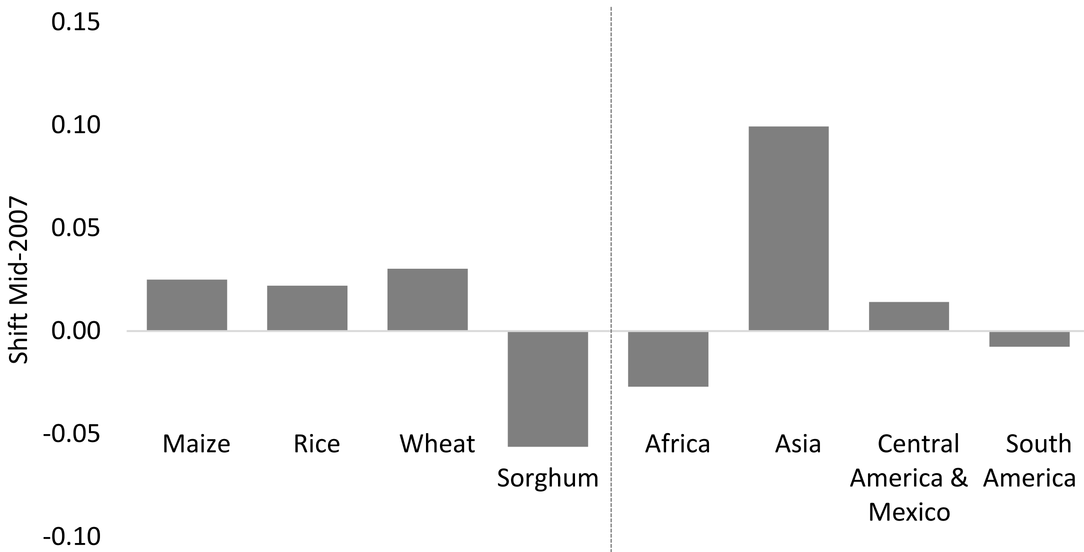


Panel C. Sorghum / Wheat



Note: This figure compares the sample, average, and steady-state volatilities of monthly price returns. Sample volatility is defined as the standard deviation of the domestic price returns. Average and steady-state volatilities come from the results of the conditional variance estimation. The average volatility is the average of the squared roots of the estimated domestic variance terms. The steady-state volatility is the squared root of the domestic variance term after the estimated system reaches a hypothetical steady-state. See Section 5.2 of the main text for details. The figure is truncated to preserve scale, outlier values are indicated in bold.

Figure A.2. Median Shift in Mid-2007 in the Conditional Correlation between Domestic and International Price Returns, by Commodity and Region



Note: This figure portrays the median behavior of the estimated conditional correlations between domestic and international price returns around the 2007-2008 food crisis, by commodity and region. We run separate regressions of the estimated conditional correlations for each available month on trend and trend squared terms, plus a dummy shifter for the period July 2007 onwards. The table the median coefficient for the dummy shifter across a region or a commodity (see Section 5.3 of the main text for details).

Table A.1. Domestic Price Series' Sources and Information

	International Commodity	Country	Local Product	Market	Abbreviation	Units	Price Type	Start Date	End Date	Num. of Obs.	Region	Source
1	Maize	Benin	Maize (White)	Cotonou	BEN	FCFA / Kg.	Retail	2003-10	2013-12	123	Africa	FEWSNET
2	Maize	Ethiopia	Maize (White)	Addis Ababa	ETH	ETB / 100 Kg.	Wholesale	2004-01	2013-12	120	Africa	FEWSNET
3	Maize	Kenya	Maize (White)	Nairobi	KEN	KES / 90 Kg.	Wholesale	2000-01	2013-12	168	Africa	FEWSNET
4	Maize	Malawi	Maize (White)	Lunzu	MAW	MWK / Kg.	Retail	2004-01	2013-12	120	Africa	FEWSNET
5	Maize	Mozambique	Maize (White)	Maputo	MOZ	MZN / Kg.	Retail	2002-01	2013-12	144	Africa	FEWSNET
6	Maize	Nigeria	Maize (White)	Ibadan	NIG	NGN / Kg.	Retail	2003-10	2013-12	123	Africa	FEWSNET
7	Maize	Tanzania	Maize (White)	Dar es Salaam	TAN	TZS / 100 Kg.	Wholesale	2002-01	2013-12	144	Africa	FEWSNET
8	Maize	Uganda	Maize (White)	Kampala	UGA	UGX / Kg.	Wholesale	2002-01	2013-12	144	Africa	FEWSNET
9	Maize	Zambia	Maize (White)	Lusaka	ZAM	ZMW / Kg.	Retail	2002-01	2013-12	144	Africa	FEWSNET
10	Maize	El Salvador	Maize (White)	San Salvador	ELS	USD / Pound	Retail	2000-08	2013-12	161	Central America & Mexico	FEWSNET
11	Maize	Guatemala	Maize (White)	Guatemala City	GUA	GTQ / Pound	Retail	2005-08	2013-12	101	Central America & Mexico	FEWSNET
12	Maize	Honduras	Maize (White, Mkt 1)	Tegucigalpa	HON 1	HNL / 5 Pounds	Retail	2001-09	2013-12	148	Central America & Mexico	FEWSNET
13	Maize	Honduras	Maize (White, Mkt 2)	Tegucigalpa	HON 2	HNL / 5 Pounds	Retail	2001-09	2013-12	148	Central America & Mexico	FEWSNET
14	Maize	Mexico	Maize (White)	Mexico City	MEX	Peso / Kg.	Wholesale	2000-01	2014-03	171	Central America & Mexico	GIEWS
15	Maize	Nicaragua	Maize(White)	Managua	NIC	NIO / Pound	Retail	2000-08	2013-12	161	Central America & Mexico	FEWSNET
16	Maize	Colombia	Maize (White)	Bogotá	COL	Peso / Kg.	Wholesale	2000-01	2012-10	154	South America	GIEWS
17	Rice	Mali	Rice (Local)	Bamako	MAL	FCFA / Kg.	Retail	2003-11	2013-12	122	Africa	FEWSNET
18	Rice	Senegal	Rice (Imported)	Dakar	SEN	FCFA / Kg.	Retail	2003-10	2013-10	121	Africa	FEWSNET
19	Rice	India	Rice (Mumbai)	Mumbai	IND MUM	Rupee / Kg.	Retail	2000-01	2014-03	171	Asia	GIEWS
20	Rice	India	Rice (New Delhi)	New Delhi	IND ND	Rupee / Kg.	Retail	2000-01	2014-03	171	Asia	GIEWS
21	Rice	Nepal	Rice (Coarse)	Kathmandu	NEP	USD / Kg.	Retail	2005-01	2014-02	110	Asia	GIEWS
22	Rice	Philippines	Rice (Regular Milled)	MetroManila	PHI REG	USD / Kg.	Retail	2000-01	2014-02	170	Asia	GIEWS
23	Rice	Philippines	Rice (Well Milled)	MetroManila	PHI WELL	USD / Kg.	Retail	2000-01	2014-02	170	Asia	GIEWS
24	Rice	Thailand	Rice (25% Broken)	Bangkok	THA 25	Baht / Tonne	Wholesale	2000-01	2014-02	170	Asia	GIEWS
25	Rice	Thailand	Rice (5% Broken)	Bangkok	THA 5	Baht / Tonne	Wholesale	2000-01	2014-02	170	Asia	GIEWS
26	Rice	Brazil	Rice	São Paulo	BRA	Real / Kg.	Retail	2000-01	2014-03	171	South America	GIEWS
27	Rice	Colombia	Rice (First Quality)	Bogotá	COL 1st	Peso / Kg.	Wholesale	2000-01	2014-03	171	South America	GIEWS
28	Rice	Colombia	Rice (Second Quality)	Bogotá	COL 2nd	Peso / Kg.	Wholesale	2000-01	2014-03	171	South America	GIEWS
29	Rice	Ecuador	Rice (Long Grain)	Quito	ECU	Usd / Kg.	Wholesale	2005-01	2014-03	111	South America	GIEWS
30	Rice	Peru	Rice (Milled, Corriente)	Lima	PER CORR	Nuevo Sol / Kg.	Retail	1995-01	2013-09	225	South America	GIEWS
31	Rice	Peru	Rice (Milled, Superior)	Lima	PER SUP	Nuevo Sol / Kg.	Retail	1995-01	2013-09	225	South America	GIEWS
32	Sorghum	Burkina Faso	Sorghum (White)	Ouagadougou	SOR BUR	FCFA / Per Kg.	Retail	2003-10	2013-12	123	Africa	FEWSNET
33	Sorghum	Chad	Sorghum (Red)	N'Djamena	SOR CHA	FCFA / Per Kg.	Retail	2002-01	2013-12	144	Africa	FEWSNET
34	Sorghum	Nigeria	Sorghum (Mixed)	Ibadan	SOR NIG	NGN / Kg.	Retail	2004-10	2013-12	111	Africa	FEWSNET
35	Wheat	Ethiopia	Wheat	Addis Ababa	WHE ETH	ETB / 100 Kg.	Wholesale	2004-01	2013-12	120	Africa	FEWSNET
36	Wheat	India	Wheat (Mumbai)	Mumbai	WHE IND MUM	Rupee / Kg.	Retail	2000-01	2014-03	171	Asia	GIEWS
37	Wheat	India	Wheat (New Delhi)	New Delhi	WHE IND ND	Rupee / Kg.	Retail	2000-01	2014-03	171	Asia	GIEWS
38	Wheat	Bolivia	Wheat (Pealed)	La Paz	WHE BOL	Boliviano / Kg.	Wholesale	2003-01	2014-03	135	South America	GIEWS
39	Wheat	Brazil	Bread (French)	São Paulo	BREAD BRA	Real / Kg.	Retail	2000-02	2014-03	170	South America	GIEWS
40	Wheat	Brazil	Wheat (Flour)	São Paulo	WHE BRA	Real / Kg.	Retail	2000-01	2014-03	171	South America	GIEWS
41	Wheat	Peru	Wheat (Flour)	Lima	WHE PER	Nuevo Sol / Kg.	Retail	2000-01	2013-09	165	South America	GIEWS

Table A.2. International Price Series' Sources and Information

International Commodity	Description	Country	Market	Units	Source
Maize	No. 2 Yellow	United States	U.S. Gulf	US$ / Tonne	FAOSTAT (Primary source: USDA)
Rice	A1 Super, White Broken	Thailand	Bangkok	US$ / Tonne	FAOSTAT (Primary source: Jackson Son & Co. (London) Ltd.)
Sorghum	No. 2 Yellow	United States	U.S. Gulf	US$ / Tonne	FAOSTAT (Primary source: USDA)
Wheat	No. 2 Hard Red Winter	United States	U.S. Gulf	US$ / Tonne	FAOSTAT (Primary source: International Grains Council)

Table A.3. Price Return Volatility Transmission, by Commodity and Region

	Median	Volatility Transmission (elasticity)				Total
		Lower than 0.1	Between 0.1 and 1	Between 1 and 2	Higher than 2	
Total	0.173	17	3	1	8	41
By Commodity						
Maize	0.373	4	8	0	4	16
Rice	0.075	9	5	0	1	15
Sorghum	0.036	2	1	0	0	3
Wheat	1.910	2	1	1	3	7
By Region						
Africa	0.451	6	4	0	5	15
Asia	0.103	4	4	0	1	9
Central America & Mexico	0.289	2	4	0	0	6
South America	0.173	5	3	1	2	11

Note: This table shows estimates for the elasticity of price volatility transmission from international markets to domestic markets by commodity and region. The first column presents the median elasticity, while columns 2 through 5 show the number of cases for which the estimated elasticity falls between certain values. The elasticity of price volatility is defined as the percentage change in the standard deviation of the domestic price return (with respect to its steady-state value), relative to that of the international price return standard deviation (see Section 5.2 of the main text for details).