# Transport Costs and Food Price Volatility in Africa

**Article** *in* Journal of African Economies · December 2017

DOI: 10.1093/jae/ejx015



Tristan Le Cotty
Cirad - La recherche agronomique pour le développement


Elodie Maitre d'hotel
Cirad - La recherche agronomique pour le développement

*Journal of African Economies*, 2017, 1–30
doi: 10.1093/jae/ejx015
Article

OXFORD

# Transport Costs and Food Price Volatility in Africa

**T. Le Cotty[a,*], E. Maitre d'Hotel[a], and M. Ndiaye[b]**

[a]Department of ES (Environment and Societies), CIRAD, Ouagadougou, Burkina Faso, and [b]Department of SESG (Economics, Management and Social Sciences), SUPAGRO, Montpellier, France

*Corresponding author: T. Le Cotty, CIRAD, Ouagadougou, Burkina Faso. E-mail: lecotty@cirad.fr

## Abstract

We analyze the role of market remoteness on maize price volatility in a developing country, Burkina Faso. A trade model between a rural area and an urban area is used to show that transport costs increase volatility in rural markets when this volatility is due to local supply or demand shocks in the rural area. We provide empirical support to this proposition by exploring a dataset of monthly maize price series across 28 markets over the 2004–2014 period in Burkina Faso. Travel time, kilometric distance and road pavement are used as proxies for transport costs. We estimate an autoregressive conditional heteroskedasticity model to investigate the statistical effect of these proxies on maize price volatility. We find a robust and positive effect of transport costs on maize price volatility. Our findings suggest that enhancing road infrastructure in landlocked countries would strengthen the link between rural and urban markets, thereby smoothing grain price volatility.

**Key words:** maize, price volatility, market remoteness, transport costs, Africa

**JEL classification:** Q11, R32, R41

## 1. Introduction

High transport costs in Sub-Saharan Africa directly stem from distance and lack of quality infrastructure which reduce rural smallholders market access (Brenton, 2012, Limao and Venables, 2001), while traders from urban areas may be discouraged from purchasing food items directly from remoted farmers. It is well known that this decreases average price in supply areas but one may also want to know whether it influences price volatility. The purpose of this research is to understand how transport cost modifies price volatility in rural areas. An important factor of price volatility in Sub-Saharan Africa is the volatility transmitted from international markets (Jacks *et al*., 2011, Minot, 2010, Rapsomanikis and Mugera, 2011). However, in countries that hardly depend on grain imports to satisfy domestic consumption, like Burkina Faso, domestic factors are more likely to explain volatility.

Trade costs include a large range of costs whose effects on international trade have been thoroughly documented (see review by Anderson and Van Wincoop, 2004). Among these costs, the relative role of transport cost in monetary terms has been decreasing, because of an increase in shipment volumes and because of the rise of new other costs like technical barriers to trade. But contrary to common wisdom and some authors' prediction (the Death of Distance, Cairncross, 1999), recent empirical evidences find a 'puzzling persistence of distance' as a major explanation of bilateral trade (Anderson and Van Wincoop, 2004, Disdier and Head, 2008, Carrere and Schiff, 2005). One reason of this persistence of the distance effect is that shipment volumes reduce monetary costs of transport but not time of transport. Time of transport makes the trade more risky because it makes transactions more uncertain (Hummels and Schaur, 2010). Furthermore, the predicted 'death of distance' is based on high-quality infrastructure, which is not the case in Africa (Limao and Venables, 2001). In Africa, the transaction risk due to transportation average time adds to a transport risk due to hazardous road quality (risk of breakdown, risk of being stuck in the mud, etc.). More than a distance effect *per se*, in this paper, we target the remoteness effect, which combines distance and infrastructures quality (see Shepherd and Wilson, 2007).

By contrast, the role of trade costs on domestic trade has not received so much attention, and the effect of domestic remoteness in particular on price behaviour has not been fully established. Several studies show the effect of trade costs on domestic trade and price, including road quality (Minten and Kyle, 1999) or traders' margins (Fafchamps, 1992, Minten and Kyle, 1999). But they do not analyse the impact of these variables on price volatility.[1] Some empirical studies explain the role of geographical domestic factors on price volatility. In particular, Kilima *et al.* (2008) establish that maize prices in Tanzania are less volatile in more developed regions, in deficit regions and in regions bordering other countries. Minot (2014) uses a sample of eleven African countries and six staple foods to show that food prices are less volatile in capital cities. This tends to indicate that prices are more volatile in remote and rural areas, but is this volatility related to transport cost ? This is the issue we address in this paper.

The intuition of what we show in this paper is related to Abdulai (2000) and Badiane and Shively (1998), who suggest that transport cost modifies price transmission between two markets. In Badiane and Shively (1998), maize price volatility occurring in local markets, in Ghana, is transmitted from central markets, and this transmission depends on transport cost. If a local market is close to the central market, price level and volatility are highly correlated with price history in the central market, and if the local market is far from the central market, price level and volatility are more correlated to price history in the local market. Their data being based on two local markets (one is integrated and close to the central market and one is less integrated and farther located), they cannot test the above assumption that differences in correlation are due to differences in transport cost. Furthermore, their purpose is to understand how a price shock in market A affects a market B, while our purpose is to understand how a shock on quantities in market A affects prices

1 In this paper as in many recent papers, we differentiate 'price variability' and 'price volatility': price variability gives an overall measure of price variation i.e. the deviation from an average or from a trend, while price volatility is defined in the literature as the unpredictable part of price variations (Engle, 1982, Bollerslev, 1986, Gilbert and Morgan, 2010). For instance, seasonality may increase price variations in surplus areas, but this is not volatility because it is a regular and predictable pattern of price variations.

in this market A, depending on transport cost between this market and a central market. Our contribution is to show that transport cost increases price volatility in rural areas when this volatility arises from local supply or demand shocks.

The paper is organised as follows. In Section 2, we introduce a simple model to explain the role of transport cost in high price volatility observed in remote rural markets. In Section 3, we present the data and some empirical features of maize production and marketing in Burkina Faso. In Section 4, we present our empirical strategy to analyze the effect of market remoteness on price volatility, based on the estimation of an autoregressive conditional heteroskedasticity model. In Section 5, we deliver our empirical results by exploring a database of maize prices in Burkina Faso on twenty-eight markets over 2004–14. We find robust evidence that maize price volatility increases with transport cost between rural and urban markets.

## 2. A model of transport cost and price volatility

### 2.1 Transport cost

The most common model of transport cost was introduced by Samuelson (1952), where price differences between two markets equal the cost of transporting the good from the low-price market (e.g. the exporting country) to the high-price market (e.g. the importing country), provided effective trade between the two regions exists. This implies that the transport cost between the importing region is not greater than the difference between the autarky price in the importing region and the autarky price in the exporting region. We apply this framework at the intra-domestic scale, where the rural area is similar to the exporting country and the urban centre is similar to the importing country. Let $P^u$ and $P^r$ stand for the market price in the urban and the rural markets, respectively, $E$ is the quantity exchanged from the rural market to the urban market and $T$ the transport cost between the two markets. We have (Samuelson, 1952)

$$\begin{aligned} P^u &= P^r + T \quad if \qquad E > 0 \\ P^u &< P^r + T \quad if \qquad E = 0 \end{aligned} \tag{1}$$

To add realism to our model and to fit the case of maize trade in Burkina Faso, we extend this general framework. The difference between farmgate price and the urban market price includes the transport cost per se $T$, and different types of costs that can be interpreted as transaction costs in a broad meaning. Transaction costs include the cost of searching information, the cost of bargaining and the cost of ensuring that the trade between markets is effectively made (Dahlman, 1979, Williamson, 1979). Whereas transport costs directly increase with remoteness, defined as the combination of distance and poor road quality, and measured either by distance or by travel time between markets, it is not obvious whether transaction costs increase with remoteness. For the purpose of our empirical analysis, we distinguish variable transaction costs (increasing with transport cost) and fixed transaction costs.

Some transaction costs may indeed increase with remoteness, like costs linked to the collection of information on stocks and prices in villages, or to the bargaining on specific transactions and to the enforcement of such sales. Collecting information on prices and stocks require more time in remote villages than in peri-urban villages, where more traders have access to reliable information on prices and stocks. As a consequence, bargaining may take more time and energy in remote villages. Because of an oligopolistic transportation supply and warehousing supply, transaction costs may also include traders' rent. This rent is probably greater for traders who exchange with remote villages, where fewer traders compete. The market power of a more limited number of traders trading with most remote villages is obviously greater and these villages are more captive. In peri-urban villages providing grain, every consumer in the city is a potential buyer, and the oligopoly vanishes. And finally, transaction costs related to trade enforcement may be greater in remote markets also because of higher risk of breakdown and uncertainty (Francois and Manchin, 2013, Anderson and Marcouiller, 2002). This uncertainty can be formalised as acting as a hidden tax on trade, which increases with remoteness. In these examples, transaction costs increase with remoteness.

Other transaction costs do not depend on remoteness and are the same for all markets, like administration burden, for instance when trucks are submitted to domestic trade policies and controls. These costs have proven to be large in international trade (Buys *et al.*, 2010, Pomfret and Sourdin, 2010, Shepherd and Wilson, 2007), and they are probably significant at the national scale. The administrative cost is most likely identical for all markets because the controls occur on main roads around Ouagadougou, not on remote roads that make the difference in transport costs.

The trade conditions become the following, where $T$ is transport cost per se, $V(T)$ is the sum of variable transaction costs, with $V' > 0$ and $F$ is the sum of fixed transaction costs. Imposing a linear structure on trade costs, we have

$$\begin{array}{lll} P^u = P^r + T + V(T) + F & if & E > 0 \\ P^u < P^r + T + V(T) + F & if & E = 0 \end{array} \tag{2}$$

Although it is theoretically possible that the urban market supplies grain to the rural market, this hardly occurs in Burkina Faso, except in particular conditions of heavy food insecurity episodes where public food aid is provided to rural areas. To keep the model as simple as possible, we thus only consider the empirically most generally observed case where a rural market sells grain to an urban market.

## 2.2 Price shocks and price volatility

While price variability gives an overall measure of price variation, price volatility is the unpredictable part of price variation. The most appropriate indicator of volatility is probably the variance of a series of unexpected price shifts (Engle, 1982). The empirical counterpart of what price shifts are expected and what price shifts are unexpected differ among authors, but the idea that volatility is about the unpredictable price shifts is now widely accepted (Prakash, 2011, Shively, 1996, Barrett, 1997).

Nevertheless, this synthetic measure is not very convenient to understand how volatility is generated. To contribute to this understanding, Badiane and Shively (1998) concentrate on one shock and extrapolate to a succession of price shocks that produce volatility. We adopt the same approach here. We analyse the role of transport cost on the properties of one unexpected price shift occurring in a rural area (resulting from an unexpected supply shock), and we will extrapolate the outcome to the relation between transport cost and a succession of unexpected price shocks that produce volatility.

### 2.3 Market equilibrium

Whereas Badiane and Shively (1998) model the transmission of a price shock from one market to another, we model the conversion of a shock on quantity into a price shock as a function of market remoteness. Indeed, remoteness impacts transmission of price shocks between two markets (Roehner, 1996), and transmission of price shocks impacts the magnitude of this shock in both markets. The intuition is simple: high transport cost between market A and market B 'protects' market B from price volatility generated in market A, and amplifies price volatility in market A.

Like in the international trade model by Samuelson (1952), we call excess supply the difference between local supply and local demand in the rural market (3), and excess demand the difference between urban demand and all other sources of supply addressed to the urban market. These other sources of supply include in particular domestic rural markets apart from the one we are analyzing. Excess supply is modelled as a monthly excess supply $x_t$, where subscript $t$ is a monthly index. This excess supply is a function of local price $P_t^r$ prevailing in the rural market at month $t$, the stock volume $S_t$ available in the rural area at month $t$, the time of the year $t$ because sale decisions depend on the time to go until next harvest, and a monthly shock on grain availability $\theta_t$ due to unexpected events affecting local supply (rodents, fires, etc.) or local demand (disease, social events, etc.):

$$x_t(P_t^r, S_t, t, \theta_t) \tag{3}$$

Assuming no carryover, stock volume is equal to the latest yearly harvest $H$ minus the sum of what has been sold since the latest harvest, indexed as $t = 0$:

$$S_t = H - \sum_{i=0}^{t} x_i \tag{4}$$

We introduce (3) in (4) and iteratively replace $S_i$ in the resulting expression. Noting that $S_0 = H$ in case of no carry-over, we get an expression of $S_t(H, P_0^r, \ldots, P_t^r, t, \theta_0, \ldots, \theta_t)$. The excess supply then writes

$$x_t(H, P_0^r, P_1^r, \ldots, P_t^r, t, \theta_0, \theta_1, \ldots, \theta_t) \tag{5}$$

The monthly 'excess demand' from the urban market can be written simply $m_t(P_t^u)$ if all determinants other than price are given. The urban income is assumed to have no seasonality, and the monthly urban demand is constant during the year. It is decreasing and convex in price, $m_t' < 0$, $m_t'' > 0$.

As in Samuelson (1952), there are two market clearing conditions, depending on whether the two areas actually trade or not. The market equilibria are

$$T = P_t^u - P_t^r - V(T) - F; \quad x_t(H, P_0^r, P_1^r, \ldots, P_t^r, t, \theta_0, \theta_1, \ldots, \theta_t) = m_t(P_t^r + T + V(T) + F) \tag{6}$$

$$T > P_t^u - P_t^r - V(T) - F; \quad x_t = 0 \tag{7}$$

If $T > P_t^u - P_t^r - V(T) - F$, both prices are independent, and the trade cost has no impact on volatility in the rural market. If $T = P_t^u - P_t^r - V(T) - F$, the equilibrium defines a market price in rural areas that depends on all exogenous variables, $P_t^{r*}(H, P_0^r, P_1^r, \ldots, P_{t-1}^r, t, \theta_0, \theta_1, \ldots, \theta_t, T, F)$. We then have two price regimes:

$$T = P_t^u - P_t^r - V(T) - F; \quad P_t^r = P_t^{r*}(H, P_0^r, P_1^r, \ldots, P_{t-1}^r, t, \theta_0, \theta_1, \ldots, \theta_t, T, F) \tag{8}$$

$$T > P_t^u - P_t^r - V(T) - F; \quad P_t^r = P_t^r(H, P_0^r, P_1^r, \ldots, P_{t-1}^r, t, \theta_0, \theta_1, \ldots, \theta_t) \tag{9}$$

## 2.4 Comparative statics in a connected market

Totally differentiating equation (6) leads to

$$\begin{aligned} dP_t^r = & -\frac{\frac{\partial x_t}{\partial H}}{\frac{\partial x_t}{\partial P_t} - m_t'} dH - \frac{\frac{\partial x_t}{\partial \theta_t}}{\frac{\partial x_t}{\partial P_t} - m_t'} d\theta_t + \frac{m_t'(1 + V')}{\frac{\partial x_t}{\partial P_t} - m_t'} dT + \frac{m_t'}{\frac{\partial x_t}{\partial P_t} - m_t'} dF - \frac{\frac{\partial x_t}{\partial t}}{\frac{\partial x_t}{\partial P_t} - m_t'} dt \\ & - \sum_{i=0}^{t-1} \frac{\frac{\partial x_t}{\partial P_i^r}}{\frac{\partial x_t}{\partial P_t} - m_t'} dP_i^r - \sum_{i=0}^{t-1} \frac{\frac{\partial x_t}{\partial \theta_i^r}}{\frac{\partial x_t}{\partial P_t} - m_t'} d\theta_i^r \end{aligned} \tag{10}$$

The first term in equation (10) is positive since $m_t'$ is negative and tells that market price at any time of the year is lower when harvest is important.

The second term tells that a positive shock on excess supply $\frac{\partial x_t}{\partial \theta_t}$ produces an unexpected decrease in price. This decrease is all the larger as the excess supply and the excess demand are inelastic, i.e. $\frac{\partial x_t}{\partial P_t} \to 0$ and $m_t' \to 0$. Since this shock is by definition unexpected, the price shift is itself unexpected. Thus, successive unexpected shocks on excess supply produce a series of unexpected price shifts, which fuel rural price volatility.

The third term is negative and confirms that the price in the rural area decreases with transport cost. Naturally, this price drop is all the sharper as variable transaction costs increase with remoteness, i.e. $V'$ is large.

The fourth term accounts for the price drop as fixed transaction costs increase. The fifth term accounts for seasonality. For any type of time preferences with positive discount rate, farmers with no liquidity and no carry-over sell more grain in the first month after harvest, a bit less in the second month, etc. This is why we generally observe that sales decrease with time $\frac{\partial x_t}{\partial t} < 0$, which produces a increasing trend in price from the harvest to the lean season. Price seasonality is often described as a succession of two main seasons: (i) the harvest season, characterised by the abundance of products on markets, high excess supply and low prices and (ii) the lean season, featuring product scarcity, low monthly excess supply and high grain prices. The continuous counterpart of it is the progressive stock decrease described above.

The sixth term is positive since $\frac{\partial x_t}{\partial P_i^r} < 0; \; i < t$: if past prices have been high, farmers have sold more and sell less now, so that present price is all the greater as it has been high in the recent past. It is a main reason for rural prices being positively autocorrelated.

And finally, the last term indicates that positive past supply shocks have a negative effect on the current price, due to a lower current supply.

## 2.5 Comparative statics in a disconnected market

If there is no trade between the two markets, equation (7) is derived and produces

$$\mathrm{d}P_t^r = -\frac{\frac{\partial x_t}{\partial H}}{\frac{\partial x_t}{\partial P_t}}\mathrm{d}H - \frac{\frac{\partial x_t}{\partial \theta_t}}{\frac{\partial x_t}{\partial P_t}}\mathrm{d}\theta_t - \frac{\frac{\partial x_t}{\partial t}}{\frac{\partial x_t}{\partial P_t}}\mathrm{d}t - \sum_{i=0}^{t-1}\frac{\frac{\partial x_t}{\partial P_t^r}}{\frac{\partial x_t}{\partial P_t}}\mathrm{d}P_t^r - \sum_{i=0}^{t-1}\frac{\frac{\partial x_t}{\partial \theta_t^r}}{\frac{\partial x_t}{\partial P_t}}\mathrm{d}\theta_t^r \tag{11}$$

Comparing second terms of equations (10) and (11) directly shows that supply shocks have a greater impact on local prices in the disconnected market (smaller denominator of the second term).

Supply and demand shocks in a rural disconnected area produce price shocks in this area that are greater than in a rural area connected to an urban market for equivalent local or demand shocks. Since the variance of these shocks increases with their magnitude (for a same frequency), it is greater in a disconnected area. Since these shocks are unexpected (the variance of unexpected price shocks being the volatility), price volatility is greater in disconnected areas.

### 2.6 Volatility in the case of many interconnected and disconnected markets

In reality, many interconnected and disconnected markets operate simultaneously, and at each period, a price drop in a disconnected market can reconnect this market to the urban market and conversely a single price rise in a connected market can disconnect it. All connected markets have parallel price patterns by equation (1) while they are connected, and disconnected markets have their own price pattern, while they are disconnected. While they are connected, price volatility is the same in all markets, and while they are disconnected, volatility is different. Subsequently, changes in price regime (connection–disconnection) produce changes in volatility.

Comparison between equations (10) and (11) also makes it clear that unexpected prices shocks in rural markets $\theta_t^r$ have a greater impact on rural price in disconnected market $\left|\frac{\partial P_t^r}{\partial \theta_t}\right| = \left|\frac{\frac{\partial x_t}{\partial \theta_t}}{\frac{\partial x_t}{\partial P_t}}\right|$ than in connected market, $\left|\frac{\partial P_t^r}{\partial \theta_t}\right| = \left|\frac{\frac{\partial x_t}{\partial \theta_t}}{\frac{\partial x_t}{\partial P_t} - m_t'}\right|$. Since $\text{prob}(x_t = 0) = \text{prob}(T > P_t^u - P_t^r - V(T) - F)$, and since this probability increases with $T$, $\text{prob}\left(\left|\frac{\partial P_t^r}{\partial \theta_t}\right| = \left|\frac{\frac{\partial x_t}{\partial \theta_t}}{\frac{\partial x_t}{\partial P_t}}\right|\right)$ increases with $T$. This proves that the magnitude of unexpected price shocks is greater when $T$ is greater.

Proposition *When rural market volatility is due to local supply or local demand shocks, the magnitude of unexpected price shocks in this market increases with transport cost between this market and related consumption markets.*

## 3. Maize in Burkina Faso: data and trends

### 3.1 Maize production in Burkina Faso

In Burkina Faso, agriculture employs around 85% of the population and contributes to 34% of gross domestic product. Maize is the second cereal produced in Burkina Faso with around 1,500,000 metric tonnes produced, after sorghum. Maize production has significantly increased in the last decade, rising at a faster pace than sorghum, millet and rice (see Figure 6 in the Appendix).

While most of millet and sorghum production tends to be consumed by farmers, maize is mostly sold on markets. Thus, maize is one of the main sources of agricultural income in

Burkina Faso, ranking second after cotton. Maize production is mostly located in the western and southern parts of the country, where pedo-climatic conditions are more favourable. Maize is mainly traded within the country, flowing from maize-surplus to maize-deficit regions. Depending on the level of national production, small amounts of maize exports can be recorded towards Niger and Mali[2]), and even smaller imports can be imported from Côte d'Ivoire, Ghana and Togo.[3] We can consider Burkina Faso as a self-sufficient country for maize (this is not the case for rice, most of the rice consumed being imported).

### 3.2 Maize prices in Burkina Faso

Our analysis relies on historical price data collected by the public institution SONAGESS (Société Nationale de Gestion du Stock Alimentaire). SONAGESS manages its own market information system since 1992. Prices of main agricultural commodities are collected weekly on 48 markets, and price averages are computed monthly. One different agent is responsible for each market and collects price observed on the market once a week. This may be any day of the week, depending on the village or the city market day. The fact that SONAGESS provides monthly average means that our data do not account for the high-frequency volatility. We measure only inter-month fluctuations. Furthermore, averaging weekly prices tends to smoothen the monthly price as compared with monthly prices collected once a month (Brunt and Cannon, 2014).

We analyze twenty-eight markets with monthly data over the July 2004–November 2013 period. We set aside markets for which price series present discontinuities. For each market, monthly maize price series are expressed in local currency per kilogram (FCFA/kg) and then deflated by the Consumer Price Index of Burkina Faso (2008 base 100) published monthly by the INSD (National Institute of Statistics and Demography).

In Burkina Faso, maize prices are relatively disconnected from international prices because of very low quantities of maize traded with partner countries. A cointegration test between international and average national maize price series in Burkina Faso indicates that there is no long run equilibrium relation tying international and national maize prices together and thus confirms this disconnection (see Table 6 in the Appendix).

Markets are located either in surplus areas, i.e. where maize production exceeds consumption or in deficit areas, i.e. where maize production is not enough to cover maize consumption. We used production, consumption and demographic data to evaluate the difference between production and consumption at the regional levels (thirteen regions). Regional production data were obtained from the Burkina Faso CountryStat database, regional demographic data were obtained from the INSD and maize per capita average annual consumption was approximated of 108 kg/capita/ year.[4]

Figure 1 displays the evolution of maize real prices in a remote market situated in a deficit area (Dori), in a remote market situated in a surplus area (Solenzo) and in a market of the capital city (Sankaryare, Ouagadougou).

2 25,000 metric tons of maize were exported from Burkina Faso in 2013, representing less than 2% of the domestic production, FAOSTAT data downloaded on 26 August 2015.

3 5000 metric tons of maize were imported in Burkina Faso in 2013, FAOSTAT data downloaded on August 2015.

4 This proxy was obtained by the partners of the Farm Risk Management in Africa project (www.farmaf.org) who conducted 1500 rural households surveys in Burkina Faso in 2013.

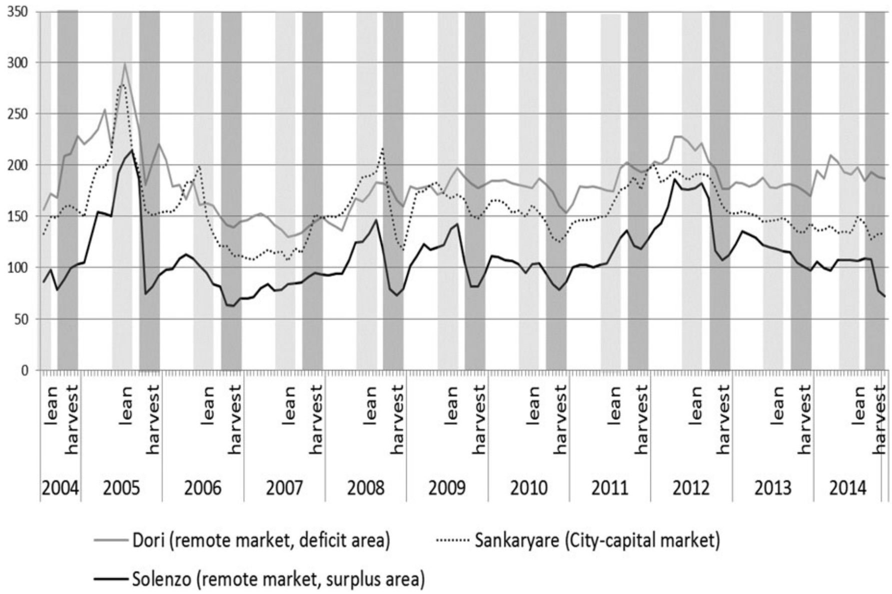


**Figure 1:** Maize real prices evolution in Dori, Solenzo and Sankaryare markets (FCFA/kg).

In these three markets (and more generally in the twenty-eight markets studied), the price patterns present similarities. First, prices are strongly affected by seasonal patterns: they are lower in the harvest season that begins in September/October and higher in the lean period that happens from June to August. Second, interannual variations also have common features. For instance, the price spike in 2005 due to grasshopper invasion during 2004 campaign is observed everywhere in the country, so is the 2008 spike due to drought during 2007 campaign and international crisis.

Nevertheless, clear differences in price patterns can be seen. Price patterns in Sankaryare and Solenzo are quite parallel most of the time, and the constant difference between the two prices could be the transport cost between the two areas.[5] Nevertheless, in two occasions of grain shortage, 2005 and 2012, the price increased more sharply in Solenzo and almost reached the same price as in Sankaryare. These facts are compatible with the above theory in case of price disconnection episodes. The price spike in Solenzo is such that the price in Solenzo plus transport cost exceeds the price in Sankaryare when Sankaryare stops purchasing maize from Solenzo and purchases more maize from other areas. This smoothens the price spike in Sankaryare and increases spike in Solenzo.

The price pattern in Dori is quite different. Since Dori is a deficit rural area, it is not surprising that price is often higher in Dori than in Sankaryare. It is easy to see that the difference between the two prices varies constantly. The reason is simply that prices are not

5 An average transport cost of 40 FCFA/kg between Solenzo and Sankaryare is expensive, but not unlikely. It means a unit cost of 274 FCFA/km per tonne, whereas in Niger reported net unit transport costs per tonne per km are 60 FCFA. Since gross transport cost includes the monetary and the opportunity cost of fixing truck, which is often higher than the net cost of transportation, we find the unit cost of 274 FCFA per tonne per km plausible.

connected in the sense of the above theory. The price in the rural area is almost all the time higher than the price in urban area minus transport cost, and the two areas do not trade grain. The reason why prices patterns are somehow similar (high at the same periods and low at the same periods) is because both areas are connected to rural areas that face similar supply shocks (drought affects more or less all suppliers).

## 4. Empirical strategy

We test the effect of transport costs on price volatility. To do so, we use a monthly panel regression of twenty-eight markets to estimate the average effect of transport costs on average maize price volatility. Price volatility is defined as the unpredictable component of price fluctuations (Prakash, 2011). Appropriate models to measure volatility are ARCH family models (for AutoRegressive Conditional Heteroskedasticity), in which the variance of residuals is allowed to depend on the most recent residuals and other variables. This variance is generally considered as a good measure of volatility.

### 4.1 ARCH models

ARCH models were introduced by Engle (1982) and generalised by Bollerslev (1986). They have extensively been used to study price volatility of agricultural products (Beck, 1993, Shively, 1996, Barrett, 1997, Kilima *et al.*, 2008, Maître d'Hôtel *et al.*, 2013). A reason is that they can be interpreted as a measure of what is predictable in price variation (the mean equation) and a measure of what is unpredictable in price variations (the variance equation). Furthermore, in the ARCH model, the conditional variance depends on the lagged squared residuals of the mean equation. Therefore, the measure of volatility varies with time, which can be used to understand changes in volatility. And by including additional regressors in the variance equation, the model can be used to identify potential determinants of price volatility.

The structure of ARCH models is made of two simultaneous equations: the first equation is the price forecast one and the second is the conditional variance one. In the second equation, the conditional variance of the residuals of the first equation typically measures the unpredictable price shifts and is thus used as an indicator of price volatility.

The typical ARCH(p) structure to describe price formation in a particular market place is given by the following equations:

$$P_t = a_0 + \sum_{i=1}^{j} a_i P_{t-i} + bX_t + \varepsilon_t, \qquad \varepsilon_t \sim \mathcal{N}(0, h_t) \tag{12}$$

$$h_t = c_0 + \sum_{i=1}^{p} c_i \varepsilon_{t-i}^2 + \sum_{i=1}^{j} d_i P_{t-i} + eZ_t + \nu_t, \qquad \nu_t \sim \mathcal{N}(0, \sigma) \tag{13}$$

where $t$ is a monthly time index, $P_t$ is the price at month $t$, $P_{t-i}$ for $i \in [1, \ldots, p]$ are lagged prices, index $j$ is for the last significant autoregressive period; $\varepsilon_t$ is the error term, $h_t$ is the time-dependent variance of the error and $X$ and $Z$ are two column vectors of exogenous variables like international prices or seasonal dummies.

### 4.2 Model specification

We use a panel of twenty-eight time series corresponding to twenty-eight market places and 125 cross sections corresponding to 10 years of monthly observations. The effect of transport costs on price level is interpreted from the first equation of the ARCH model, and the effect on volatility is interpreted from the second equation.

#### 4.2.1 First set of estimations: a common price dynamics

In a first set of estimations, the following two ARCH equations are estimated jointly:

$$\begin{aligned} P_{it} = {} & \gamma_0 + \gamma_1 P_{it-1} + \gamma_2 IP_t + \gamma_3 ER_t + \gamma_4 HARVEST_t + \gamma_5 LEAN_t + \gamma_6 BORDER_i \\ & + \gamma_7 TRANSPORT_i + \gamma_8 TREND_t + \gamma_9 RAINFALL_i + \sum_1^3 \eta_k REGION_k \\ & + \sum_1^9 \sigma_k ETHNY_k + \sum_{j=1}^{27} \Delta_j M_j + \varepsilon_{it}, \qquad \varepsilon_{it} \sim N(0, h_{it}) \end{aligned} \tag{14}$$

$$\begin{aligned} h_{it} = {} & \varphi_0 + \varphi_1 \varepsilon_{it-1}^2 + \varphi_2 P_{it-1} + \varphi_3 IP_t + \varphi_4 ER_t + \varphi_5 HARVEST_t + \varphi_6 LEAN_t + \varphi_7 BORDER_i \\ & + \varphi_8 TRANSPORT_i + \varphi_9 TREND_t + \varphi_{10} RAINFALL_t + \sum_1^3 \chi_k REGION_k \\ & + \sum_1^9 \phi_k ETHNY_k + \sum_{j=1}^{27} \rho_j M_j + \nu_{it}, \qquad \nu_{it} \sim N(0, \sigma) \end{aligned} \tag{15}$$

where $P_{it}$ is the real maize price in market $i$ at month $t$, $IP_t$ is the real international maize price at month $t$, $ER_t$ is the nominal exchange rate at month $t$, $HARVEST_t$ is a seasonal dummy that indicates the harvest season (October–December), $LEAN_t$ is a dummy that indicates the lean season (June–August), $BORDER_i$ is the travel time between the market $i$ and the nearest cross-border maize point with Ghana, Côte d'Ivoire, or Togo, $TRANSPORT_i$ is the transport cost between the market $i$ and Ouagadougou (and as robustness tests, between the market $i$ and the nearest city and between the market $i$ and the remaining markets), $TREND_t$ is a monthly trend, $RAINFAL_i$ is the annual average rainfall in the area where market $i$ is located, $REGION_k$ is a regional dummy for each of the four climatic zones (Sahelian, South Sahelian, Soudanian and South Soudanien), $ETHNY_k$ is a dummy for the market located in one of the ten dominant ethnic groups (see map below), $M_i$ denotes maize market dummy variables and $\varepsilon_{it}$ is the heteroscedastic error term (Figures 2 and 3). The market-specific variables and the regional variables are to reflect heterogeneity in markets price dynamics that is not due to remoteness. The localisation of the four climatic zones and the ten ethnic groups is depicted in Figures 2 and 3 in the Appendix.

Coefficients $\gamma_7$ and $\varphi_8$, which we are particularly interested in, include the direct effect of transport cost on rural price, and the indirect effects of transport cost through the effect of variable transaction costs on rural price. As we have seen, both effects have the same negative sign. The size of the coefficient should then be interpreted cautiously, but the expected sign is not ambiguous. The effect of fixed transaction costs on price is included in the constant terms $\gamma_0$ and $\varphi_0$, since fixed costs are supposedly the same for every market. If it is not the case, for instance because these unobserved fixed transaction costs are market specific, they could potentially produce a bias of omitted variables. Nevertheless, the panel structure allows us to estimate fixed effects to capture some unobserved heterogeneity, including latter costs. Fixed


**Figure 2:** Climatic zones in Burkina Faso.
*Source*: http://ornithologieetbetta.free.fr/ornitho/ornitho_burkina_pays.php.

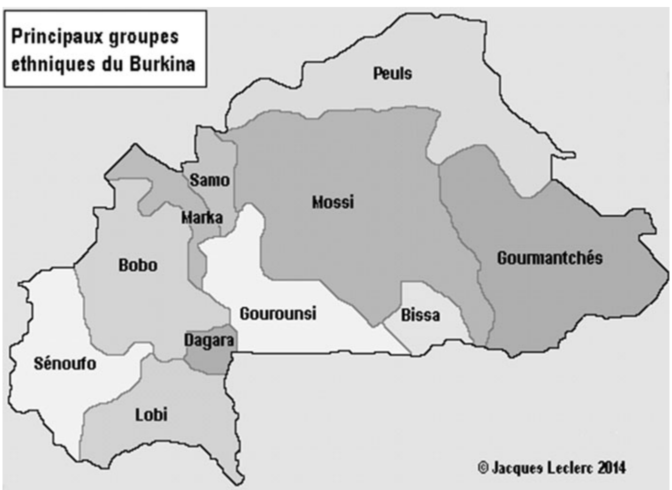


**Figure 3:** Ethnic groups in Burkina Faso.
*Source*: http://www.axl.cefan.ulaval.ca/afrique/burkina.htm.

effects are not compatible with the introduction of explicit fixed geographical variables since fixed effects include all geographical fixed effects, so that we show results of both strategies.

Monthly nominal maize prices obtained from SONAGESS were deflated with the monthly Burkinabe Consumer Price Index obtained from INSD. Monthly nominal exchange rates were obtained from the International Monetary Fund database. Nominal international price (US Gulf No. 2, yellow), obtained from the International Monetary Fund database, has been converted into FCFA and deflated using the monthly Burkinabe Consumer Price Index obtained from INSD.

The variable $TRANSPORT_i$ synthesises the sum of costs of transporting grain from the rural market $i$ to the main urban centre that actually or potentially purchases this grain. The travel time and the kilometric distance to a main urban centre or a major market are the most commonly used measures (Barrett, 1996, Minten and Kyle, 1999, Stifel and Minten, 2008, Minot, 2014). The quality of road infrastructure can be alternatively used to have a more accurate measure of travel costs, especially in countries with poor road infrastructure (Minten and Randrianarison, 2003). In our first set of estimations, we took Ouagadougou, the capital city of Burkina Faso, with a population of around 2 million inhabitants, as the urban centre for all markets. Three proxies are used to measure the transport cost: (i) the TRAVEL TIME needed from the rural market to reach Ouagadougou, (ii) the kilometric DISTANCE between the market and Ouagadougou and (iii) a dummy variable indicating if the market is accessible with an UNPAVED ROAD or not (see Figure 4). To compute information on travel time and kilometric distance, we extracted information from the route planning application of Google Maps desktop service. To compute information on road pavement, we use the road map of Burkina Faso published in 2009 map by the Geographical Institute of Burkina Faso where paved road and unpaved roads are identified.

It could be that the most relevant urban centre for each market may differ from Ouagadougou, because of its closest location and its relative activity size. It could be also, especially if we consider that trade is a network, that remoteness should not be defined as a distance to a single reference location. For these two reasons, we led two additional estimations based on two different measures of remoteness (the results are presented in the Robustness tests section). First, we chose three main cities, namely Ouagadougou, Bobo-Dioulasso and Koudougou as relevant urban centre to define remoteness and constructed a *TIME_TO_CLOSEST_CITY* variable. Bobo-Dioulasso is the second major city, with an estimated population of 500,000 inhabitants, and Koudougou is the third city with a population around 100,000 inhabitants. Ouagadougou and Bobo-Dioulasso are growing fast, with population growth rate estimated at, respectively, 7.6% and 7.2%. Second, we constructed the variable *CUMULATIVE_TIME* to compute, for each market, the sum of its time travel time to all other twenty-seven markets.

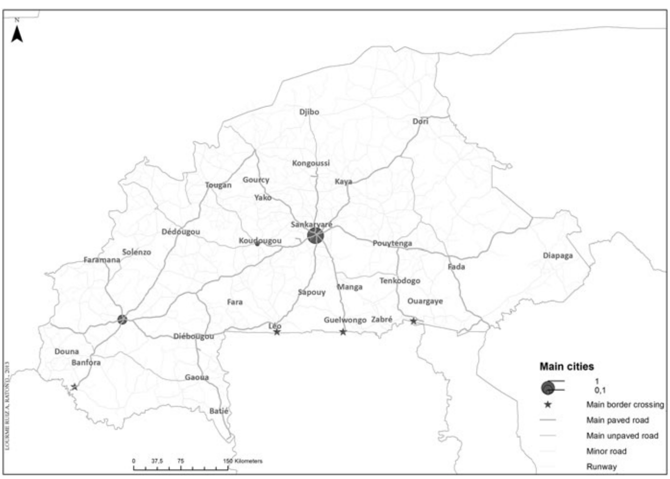


**Figure 4:** Maize markets localisation in Burkina Faso.

For the definition of the *BORDER* variable, we have considered the four main border points in terms of maize trade volumes, and consequently estimated the travel time from the twenty-eight markets to the nearest border point. Relying on relatively scarce data we had from the CountryStat database on the volume of maize traded, we identified four major maize border-crossing points among eighteen: Bittou (Togo), Dakola (Ghana), Leo (Ghana) and Niangoloko (Côte d'Ivoire). The reported trade amounts are very low (respectively, 9 tonnes, 8 tonnes, 1 tonne and 5 tonnes for 2002), suggesting that maize may be traded informally between Burkina Faso and its southern neighbours. Descriptive statistics of all the variables used in our study are presented in Table 8 in the Appendix.

The *ETHNY* variable is introduced to check whether belonging to an ethnic group may rend the negotiation tougher for instance (Aker *et al*., 2014). The *REGION* variable may also influence price, and also the transport cost itself during the rainy season. The *RAINFALL* variable tests the same idea more directly, since it is a continuous variable.

The order of the ARCH model is determined through an assessment of the statistical significance generated from the Lagrange multiplier test. Results suggest that the price process is correctly described by an autoregressive order of one, $ARCH(1)$.

The system of equations (14) and (15) is estimated with maximum likelihood estimation. Before starting the estimations, maize price series, the dependent variable, was tested for stationarity. The Augmented Dickey Fuller (ADF) test for panel was applied to test the null hypothesis of the presence of unit roots, following Im *et al.* (2003). The panel unit root test leads to reject the null hypothesis of non-stationarity at the 5% level.

Existing tests for cross-sectional dependences (Pesaran, 2007, Pesaran *et al*., 2013, Kapetanios *et al*., 2014, Driscoll and Kraay, 1998) require an unconditional variance of the error term. Because of the existence of possible bias due to cross-sectional dependences, we develop a second set of estimation below, where cross-sectional dependence can be tested and corrected for through Driscoll and Kraay standard error correction.

#### 4.2.2 Second set of estimations: market-specific price dynamics

In above estimation, we make the assumption that price dynamics are similar in all markets and can be correctly described by a single ARCH(1) model: we estimate average coefficients. Indeed, coefficients $\gamma_0$, $\gamma_1$, etc. are the same for all markets. However, price dynamics may differ from one market to one another and we may find it more appropriate to estimate coefficients that are specific to each market. Thus, we develop a set of estimations where in a first step we estimate separately the price dynamics with twenty-eight time series and we extract the corresponding twenty-eight series of volatility and in a second step we regress those volatility series with independent variables in a panel setting. Before starting the estimations, the twenty-eight maize price series were tested for stationarity with the classic ADF test: twenty-seven markets presented stationary price patterns at the 10% level, while prices in the remaining market could be considered stationary at the 15% level. The estimation of twenty-eight ARCH models revealed that in twenty-six of the markets, prices dynamics were correctly described with an autoregressive order of one, while the model failed to converge in two of the markets that were excluded from the panel regression.

The estimation procedure has two steps. We first estimate separately ARCH model below for each market, equations (16) and (17), where the $\gamma$'s and the $\varphi$'s are now market specific (indexed by $i$). We store the series of variances $h_{it}$ and use them as the endogenous variable of a panel model (equation (18)), which yields average coefficients as in the previous procedure. In this procedure, heterogeneity in volatility between markets come both from different variable values ($P_{it-1}$, $BORDER_i$, $TRANSPORT_i$) and different coefficients, accounting for market specific effects of these variables.

For $i = 1$–28, we estimate

$$P_{it} = \gamma_{0,i} + \gamma_{1,i}P_{it-1} + \gamma_{2,i}IP_t + \gamma_{3,i}ER_t + \gamma_{4,i}HARVEST_t + \gamma_{5,i}LEAN_t + \gamma_{8,i}TREND_t + \varepsilon_{it}, \qquad \varepsilon_{it} \sim N(0, h_{it}) \tag{16}$$

$$h_{it} = \varphi_{0,i} + \varphi_{1,i}\varepsilon^2_{it-1} + \nu_{it}, \qquad \nu_{it} \sim N(0, \sigma_i) \tag{17}$$

and then we build the panel

$$h_{it} = \beta_0 + \beta_1\varepsilon^2_{it-1} + \beta_2P_{it-1} + \beta_3IP_t + \beta_4ER_t + \beta_5HARVEST_t + \beta_6LEAN_t + \beta_7BORDER_i + \beta_8TRANSPORT_i + \beta_9TREND_t + \beta_{10}RAINFALL_t + \sum_1^3 \alpha_kREGION_k + \sum_1^9 \psi_kETHNY_k + \sum_{j=1}^{27} \delta_jM_j + \nu_{it}, \qquad \nu_{it} \sim N(0, \sigma) \tag{18}$$

Both Driscoll and Kraay's and Pesaran's test show cross-sectional correlation. Driscoll and Kraay (1998) propose a non-parametric covariance matrix estimator that produces heteroskedasticity- and autocorrelation-consistent standard errors that are robust to general forms of cross-sectional and temporal dependence. It is in particular compatible with fixed effects panel estimation. We provide below panel estimates with this Driscoll and Kraay standard errors correction. It comes out that the cross-sectional dependence does not alter the sign and significance of the effects of variables at the core of the paper.

Our analysis, like virtually all existing GARCH and ARCH empirical models in the literature, is subject to the caveat that we have to assume weak cross-sectional dependence across the panel: we have employed Driscoll and Kraay standard errors to address weak dependence, but our strategy fails if cross-sectional dependence is of the strong type such as that arising from a common factor model. To the best of our knowledge, there is at present no convenient remedy available in the literature.

### 4.3 Predicted effects

The effect of transport cost between rural market and urban market on average price in the rural market is summarised by the coefficient $\gamma_7$ in equation (14). In accordance with equation (10), we expect maize prices to be lower in remote markets than in markets located close to the urban centre, i.e. $\gamma_7 < 0$. The effect of transport cost on volatility in the rural market is summarised by $\varphi_8$ in equation (15) and $\beta_8$ in equation (18). According to our proposition, we expect remote markets to exhibit greater maize price volatility than markets located close to the urban centre, i.e. $\varphi_8 > 0$ and $\beta_8 > 0$.

## 5. Empirical results

Results from a common ARCH model are found in Table 1 for the three different proxies of transport cost. In each one of the three specifications, the first column lists estimates of the mean equation and the second column lists estimates of the variance equation. Thus,

**Table 1:** Effect of Transport Costs on Maize Price Volatility: Common Price Dynamics

| | [1] | | [2] | | [3] | | [4] | | [5] | | [6] | | [7] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Variance | Mean | Variance | Mean | Variance | Mean | Variance | Mean | Variance | Mean | Variance | Mean | Variance |
| Constant | 33.88*** | 12.09 | 30.80* | −81.49*** | 35.67*** | −84.34* | 34.19*** | 174.17*** | 45.55*** | 209.19*** | 33.41*** | −100.95** | 33.22*** | 49.16 |
| | (0.000) | (0.783) | (0.000) | (0.075) | (0.000) | (0.060) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.011) | (0.000) | (0.213) |
| Arch term | | 0.15*** | | 0.15*** | | 0.16*** | | 0.21*** | | 0.24*** | | 0.16*** | | 0.14*** |
| | | (0.000) | | (0.000) | | (0.000) | | (0.000) | | (0.000) | | (0.000) | | (0.000) |
| Lagged price | 0.88*** | 1.15*** | 0.87*** | 0.51*** | 0.87*** | 0.57*** | 0.85*** | 0.47*** | 0.83*** | 0.29*** | 0.92*** | 1.54*** | 0.91*** | 1.54*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.006) | (0.000) | (0.000) | (0.000) | (0.000) |
| International price | 0.05*** | −0.75*** | 0.06*** | −0.55*** | 0.06*** | −0.58*** | 0.06*** | −0.31*** | 0.05** | −0.19** | 0.04*** | −0.61 | 0.04*** | −0.61*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.004) | (0.000) | (0.144) | (0.000) | (0.000) |
| Exchange rate | −0.03*** | 0.15* | −0.03*** | 0.50*** | −0.04*** | 0.51*** | −0.03*** | −0.07 | −0.03*** | −0.04 | −0.03*** | 0.11*** | −0.03*** | −0.02 |
| | (0.000) | (0.087) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.352) | (0.000) | (0.423) | (0.000) | (0.000) | (0.000) | (0.739) |
| Harvest dummy | −6.37*** | 132.71*** | −6.76*** | 140.99*** | −6.75*** | 142.60*** | −6.51*** | 113.72*** | −6.59*** | 76.46*** | −5.95*** | 126.20*** | −6.09*** | 118.25*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Lean dummy | 1.92*** | 0.03* | 1.90*** | −2.59 | 1.97*** | −2.38 | 1.40*** | −2.90 | 1.57*** | −4.39* | 1.18*** | −1.50 | 1.00*** | −0.56 |
| | (0.000) | (0.992) | (0.000) | (0.439) | (0.000) | (0.517 | (0.000) | (0.129) | (0.000) | (0.076) | (0.004) | (0.586) | (0.009) | (0.827) |
| Time to the border | 0.01*** | −0.16*** | 0.04*** | −0.00 | 0.01** | 0.04** | 0.01*** | 0.12*** | 0.04*** | 0.03 | 0.01* | −0.17*** | 0.01 | −0.42*** |
| | (0.005) | (0.000) | (0.000) | (0.910) | (0.000) | (0.013) | (0.004) | (0.002) | (0.000) | (0.656) | (0.054) | (0.000) | (0.314) | (0.000) |
| Time to Ouaga | −0.01*** | 0.21*** | | | | | −0.01*** | 0.09*** | −0.01*** | 0.11*** | −0.01*** | 0.25*** | −0.01** | 0.38*** |
| | (0.000) | (0.000) | | | | | (0.000) | (0.000) | (0.001) | (0.001) | (0.003) | (0.000) | (0.029) | (0.000) |
| Distance to Ouaga | | | −0.03*** | 0.18*** | | | | | | | | | | |
| | | | (0.000) | (0.000) | | | | | | | | | ) | |
| Unpaved road | | | | | −6.35*** | 16.86*** | | | | | | | | |
| | | | | | (0.000) | (0.000) | | | | | | | | |
| Trend | −0.06*** | −1.05*** | −0.06*** | −1.33*** | −0.06*** | −1.29*** | −0.05*** | −1.45*** | −0.05*** | −1.54*** | −0.05*** | −1.04*** | −0.05*** | −1.07*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Market dummies | YES | NO | YES | NO | YES | NO | YES | YES | YES | YES | NO | NO | NO | NO |
| Annual rainfall | | | | | | | | | −0.01*** | −0.01 | | | | |
| | | | | | | | | | (0.005) | (0.575) | | | | |
| South Sahelian climate | | | | | | | | | | | −2.16** | 43.18*** | | |
| | | | | | | | | | | | (0.013) | (0.000) | | |
| North Soudanian climate | | | | | | | | | | | −2.88*** | 73.41*** | | |
| | | | | | | | | | | | (0.001) | (0.000) | | |

| | [1] | | [2] | | [3] | | [4] | | [5] | | [6] | | [7] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| South Soudanian climate | | | | | | | | | | | −2.50** | 28.19** | | |
| | | | | | | | | | | | (0.015) | (0.005) | | |
| Peulh ethny | | | | | | | | | | | | | 2.90** | −33.19*** |
| | | | | | | | | | | | | | (0.011) | (0.003) |
| Gourmantche ethny | | | | | | | | | | | | | 0.65 | 60.05*** |
| | | | | | | | | | | | | | (0.656) | (0.000) |
| Bissa ethny | | | | | | | | | | | | | −0.55 | −33.20*** |
| | | | | | | | | | | | | | (0.686) | (0.008) |
| Lobi ethny | | | | | | | | | | | | | 2.94* | −22.74 |
| | | | | | | | | | | | | | (0.066) | (0.140) |
| Senoufo ethny | | | | | | | | | | | | | −0.83 | −86.91*** |
| | | | | | | | | | | | | | (0.650) | (0.000) |
| Dagara ethny | | | | | | | | | | | | | −1.63 | −31.50*** |
| | | | | | | | | | | | | | (0.130) | (0.001) |
| Bobo ethny | | | | | | | | | | | | | −1.14 | −6.78 |
| | | | | | | | | | | | | | (0.358) | (0.480) |
| Gourounsi ethny | | | | | | | | | | | | | −1.03 | 0.94 |
| | | | | | | | | | | | | | (0.415) | (0.932) |
| Mossi ethny | | | | | | | | | | | | | −0.27 | 11.27 |
| | | | | | | | | | | | | | (0.803) | (0.254) |
| *N* | 3472 | | 3472 | | 3472 | | 3472 | | 3472 | | 3472 | | 3472 | |
| *R* squared | 0.8362 | | 0.8370 | | 0.8371 | | 0.8370 | | 0.8377 | | 0.8311 | | 0.8327 | |

*p*-values in brackets.
*Significant at 10%; **significant at 5%; ***significant at 1%.
[1] Travel time to Ouagadougou.
Kilometric distance to Ouagadougou.
[3] Road pavement.
[4] Market dummies.
[5] Rainfall and market dummies.
[6] Climatic zone dummies.
[7] Ethnic group dummies.

for each specification, price effects of exogenous variables are in the first column, and volatility effects of exogenous variables are in second column.

Results from a panel that allows for differences in price dynamics in each market and for cross-sectional interactions are presented in Table 2.

## 5.1 Rural price drivers

In this subsection, we discuss the results presented in Tables 1 and 2. There is a strong autocorrelation in monthly price series and we can see in Tables 1 and 2 that on average, a 10 FCFA increase in maize price on a market contributes to a 9 FCFA increase in maize price the following month. The negative trend reveals that on average, the level of maize prices has decreased over the 10 years period. As expected, the seasonal dummies reveal that prices are significantly higher during the lean season and lower during the harvest season. On average, maize prices decrease by 6 or 7 FCFA in the harvest season ranging from October to December and increase by 1 or 2 FCFA in the lean season ranging from June to August.

We find a significant positive effect of maize international prices on domestic prices patterns, with a rather low coefficient however, a 10 FCFA increase in international price leading to a 0.5 FCFA increase in domestic prices. This confirms the relative disconnection between international markets and domestic markets in Burkina Faso, in line with the cointegration tests presented in the Appendix. This suggests that maize prices are mostly driven by domestic factors in Burkina Faso, a landlocked country with very low grain imports levels.

Prices are lower in remote markets, this effect being robust to the three proxies used for transport costs (Table 1) and to the inclusion of climatic and ethnic control variables (Table 2). An increase of 1 min in travel time to the capital city produces a decrease of 0.01 FCFA in prices, and an increase of 1 km of distance from the capital city produces a 0.03 FCFA decrease in prices. Prices in markets accessible by unpaved roads are on average lower by 6 FCFA/kg than those prevailing in markets accessible by paved roads. This negative effect of transport costs on the level of prices is expected in the theoretical model. Symmetrically, food price increases as one gets closer to urban areas.

When markets are more distant from the border of Côte d'Ivoire, Ghana and Togo, prices are higher. This effect is probably due to the more favourable climatic conditions in these countries that decrease production costs, and makes harvest earlier, especially in Ghana, which foster trade between neighbour countries and drives prices down in surrounding markets.

From Tables 1 and 2, we interpret that rainfall has a decreasing effect on price levels: prices are lower in rainy areas, where maize production is more important than in dry areas. The same effect is revealed by the climatic dummies: four climatic zones are identified, from the driest one to the wettest one: North Sahelian, South Sahelian, North Soudanian and South Soudanian. The North Sahelian dummy was dropped in the results indicating that the results have to be interpreted in comparison with this zone, which is the driest of Burkina Faso (the northernmost actually). Prices tend to be lower in South Sahelian, North Soudanian and South Soudanian zones than in North Sahelian zone where maize production is scarce, and where prices are higher.

The only ethnic group variable that does have a significant effect on price levels is the peulh ethnic group, primarily located at the northernmost area of Burkina Faso, and whose

**Table 2**: Effect of Transport Costs on Maize Price Volatility: Market-Specific Price Dynamics

| | [8] | [9] | [10] | [11] |
|---|---|---|---|---|
| Lagged price | 3.050*** | 3.050*** | 2.836*** | 2.784*** |
| | (0.000) | (0.000) | (0.000) | (0.000) |
| International price | −0.728 | −0.728 | −0.513 | −0.545 |
| | (0.206) | (0.206) | (0.407) | (0.374) |
| Exchange rate | 1.320*** | 1.320*** | 1.351*** | 1.386*** |
| | (0.001) | (0.001) | (0.001) | (0.001) |
| Harvest dummy | 64.49*** | 64.49*** | 64.93*** | 64.74*** |
| | (0.000) | (0.000) | (0.000) | (0.000) |
| Lean dummy | 14.17 | 14.17 | 10.52 | 14.76 |
| | (0.376) | (0.376) | (0.520) | (0.373) |
| Time to the border | −0.127 | 1.921*** | 0.0932 | −0.539*** |
| | (0.909) | (0.005) | (0.328) | (0.000) |
| Time to Ouagadougou | 1.029** | 0.991*** | 0.428*** | 0.412* |
| | (0.011) | (0.001) | (0.000) | (0.056) |
| Trend | −2.172*** | −2.172*** | −2.119*** | −2.158*** |
| | (0.000) | (0.000) | (0.000) | (0.000) |
| Market dummies | YES | YES | NO | NO |
| Annual rainfall | | −1.172*** | | |
| | | (0.000) | | |
| Sahelian climate | | | −132.8*** | |
| | | | (0.000) | |
| South Sahelian climate | | | 16.11 | |
| | | | (0.698) | |
| North Soudanian climate | | | 123.6*** | |
| | | | (0.000) | |
| Peulh ethny | | | | −141.1*** |
| | | | | (0.000) |
| Gourmantche ethny | | | | −0.735 |
| | | | | (0.979) |
| Bissa ethny | | | | −33.44 |
| | | | | (0.114) |
| Lobi ethny | | | | −24.51 |
| | | | | (0.749) |
| Senoufo ethny | | | | −157.6*** |
| | | | | (0.004) |
| Dagara ethny | | | | −2.074 |
| | | | | (0.982) |
| Samo ethny | | | | −51.73 |
| | | | | (0.243) |
| Bobo ethny | | | | 138.3*** |
| | | | | (0.008) |
| Gourounsi ethny | | | | −10.57 |
| | | | | (0.609) |

*Continued*

**Table 2:** Continued

| | [8] | [9] | [10] | [11] |
|---|---|---|---|---|
| Mossi ethny | | | | 0 |
| | | | | (.) |
| _cons | −576.9** | 0 | −813.3*** | −648.4*** |
| | (−2.24) | (.) | (−3.64) | (−2.93) |
| *N* | 3224 | 3224 | 3224 | 3224 |
| *Wald Chi*$^2$ | 640 | 843 | 486 | 505 |

*p*-values in brackets.
*Significant at 10%; **significant at 5%; ***significant at 1%.
[8] Market dummies.
[9] Rainfall and market dummies.
[10] Climatic zone dummies.
[11] Ethnic group dummies.

activity is oriented towards cattle breeding rather than maize growing. Given the dry climate and the peulh culture, it is thus rather intuitive that maize prices are higher in the northern parts of Burkina Faso.

## 5.2 Rural volatility drivers

The ARCH(1) term is positive and significant at the 1% level for the three specifications, which indicates that price volatility depends on its history: greater values of recent residuals of the mean equation produce higher present volatility.

On average, the level of maize price volatility has decreased over the last 10 years. Results also suggest that price volatility is not the same all year through. Prices are significantly more volatile during the harvest season (we did not find any significant effect of the lean season dummy on price volatility), as was also observed in other recent empirical works (Jordaan *et al.*, 2007, Kilima *et al.*, 2008, Maître d'Hôtel *et al.*, 2013). It may be related to the fact that supply and demand moves may be more unpredictable in harvest season, for example because of oligopolistic storage strategies and of food aid programs' operations.

We find that maize international prices have a small negative effect on rural markets price volatility. A possible interpretation is that when international maize prices are high, Burkina Faso stops importing grain, thus protecting its domestic markets from a volatility imported from international markets. We have said already that these imports are quite small, but they may be sufficient to create some unexpected price shifts in some markets.

Prices are more volatile in remote markets, this effect being robust to the three proxies used for transport costs and to the inclusion of climatic and ethnic control variables (Table 1). This confirms our main proposition in this article. The coefficient is greater in the market-specific dynamic estimation than in the common dynamic estimation. In the common dynamic estimation (Table 1), the coefficient varies from 0.09 in specification [4] to 0.38 in specification [7]. A coefficient of 0.38 means that one more minute of transport between the rural market and Ouagadougou (the average being 207 min) increases volatility by 0.38, the average being 235. In relative terms, this means that a 1% increase in transport time produces a 0.4% increase in volatility, on average. In the market-specific estimation, where volatility is probably better extracted from regular price dynamics, the coefficient varies from 0.41 to 1.02, meaning that one more minute of transport increases volatility by 0.41–1.02 (the average being 294). In relative terms, this means that 1% increase in transport cost produces a 0.35–0.86% increase in volatility.

Surprisingly enough, travel time to the border has no stable effect on price volatility. This may be due to the fact that exchanges with border countries may have had stabilizing effects some years and destabilizing effects some other years. Even though exchanges in general should have a stabilizing effect, it can occur that foreign countries export at exceptionally low prices or import at exceptionally high prices, which may foster domestic prices drops or spikes.

Markets located in North Sahelian zone, characterised by a very dry climate, present significantly lower maize price volatility than markets in Southern areas that are more favourable to maize growing (South Sahelian, North Soudanian and South Soudanian zones) and where maize production may exceed maize consumption. This result is consistent with Kilima *et al.* (2008) who find that price volatility tends to be higher in maize-surplus markets than in maize-deficit markets. The explanation may be that demand shocks are not as frequent or as great as supply shocks.

## 5.3 Robustness tests

To assess the robustness of our empirical results to alternative definition of transport costs and to alternative models, we run additional estimations. Our main result on the positive effect of transport costs on maize price volatility stands for all these additional specifications. First, we proxy transport costs not solely as the time travel to Ouagadougou but as the time travel, for each market, to the closest urban centre, Ouagadougou and two additional cities being included in our analysis (Table 3). Second, we proxy transport costs as the sum, for each market, of its time travel to all other twenty-seven markets (Table 4). Third, we use nominal prices to test whether inflation on prices may affect our main result (Table 5).

### 5.3.1 Time to the closest city

If we proxy remoteness by the travel time between each market and its closest city and not only to the capital city, the positive effect of remoteness on volatility holds (Table 3).

### 5.3.2 Cumulative time travel to other markets

If we consider trade as a network and thus define remoteness as the distance of one market to all the other markets, computing for each market a cumulative time travel to the other twenty-seven markets, the positive effect of remoteness on volatility holds (Table 4).

### 5.3.3 Nominal maize prices

We run the same ARCH models on series of nominal prices instead of deflated ones. Table 5 reports the estimation result when prices are expressed in nominal prices. Results are very similar and the positive and significant impact of travel time on maize price volatility holds.

**Table 3:** Effect of Transport Costs on Maize Price Volatility, Costs being Proxied by the Distance to the Closest City

| | [12] | | [13] | | [14] | | [15] | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Variance | Mean | Variance | Mean | Variance | Mean | Variance |
| Constant | 29.97*** | 208.81*** | 40.27*** | 209.92*** | 33.33*** | −151.46*** | 31.19*** | 57.57 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.123) |
| Arch Term | | 0.20*** | | 0.23*** | | 0.14*** | | 0.15*** |
| | | (0.000) | | (0.000) | | (0.000) | | (0.000) |
| Lagged price | 0.85*** | 0.39*** | 0.85*** | 0.31*** | 0.93*** | 1.04*** | 0.91*** | 1.41*** |
| | (0.000) | (0.000) | (0.000) | (0.001) | (0.000) | (0.000) | (0.000) | (0.000) |
| International price | 0.06*** | −0.31*** | 0.06*** | −0.24*** | 0.04*** | −0.54*** | 0.04*** | −0.55*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Exchange rate | −0.03*** | −0.03 | −0.04*** | −0.03 | −0.04*** | 0.23*** | −0.03*** | 0.01 |
| | (0.000) | (0.669) | (0.000) | (0.564) | (0.000) | (0.004) | (0.000) | (0.927) |
| Harvest dummy | −6.22*** | 91.52*** | −6.42*** | 92.41*** | −6.16*** | 134.39*** | −6.07*** | 115.90*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Lean dummy | 1.61*** | −3.99* | 1.41*** | −2.31** | 1.27*** | −1.52 | 1.07*** | 0.03 |
| | (0.000) | (0.061) | (0.000) | (0.036) | (0.000) | (0.625) | (0.002) | (0.987) |
| Time to border | 0.06*** | −0.02 | 0.06*** | −0.02 | 0 | 0.13*** | 0 | −0.39*** |
| | (0.000) | (0.807) | (0.000) | (0.846) | (0.719) | (0.000) | (0.328) | (0.000) |
| Time to closest city | −0.04*** | 0.21*** | −0.02*** | 0.19** | −0.01* | 0.23*** | −0.01 | 0.44*** |
| | (0.000) | (0.000) | (0.004) | (0.013) | (0.095) | (0.000) | (0.336) | (0.000) |
| Trend | −0.06*** | −1.59*** | −0.05*** | −1.56*** | −0.05*** | −1.02*** | −0.06*** | −1.07*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Market dummies | YES | YES | YES | YES | NO | NO | NO | NO |
| Annual rainfall | | | −0.009*** | −0.01 | | | | |
| | | | (0.001) | (0.790) | | | | |
| South Sahelian climate | | | | | −1.23 | 39.68*** | | |
| | | | | | (0.176) | (0.000) | | |
| North Soudanian climate | | | | | −3.28*** | 97.24*** | | |
| | | | | | (0.000) | (0.000) | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| South soudanian climate | | | | | −4.24*** | 110.58*** | | |
| | | | | | (0.000) | (0.000) | | |
| Peulh ethny | | | | | | | 3.11*** | −56.48*** |
| | | | | | | | (0.004) | (0.000) |
| Gourmatche ethny | | | | | | | 0.33 | 11.09 |
| | | | | | | | (0.823) | (0.469) |
| Bissa ethny | | | | | | | −0.46 | −62.32*** |
| | | | | | | | (0.713) | (0.000) |
| Lobi ethny | | | | | | | 1.53 | −27.89** |
| | | | | | | | (0.282) | (0.042) |
| Senoufo ethny | | | | | | | −3.07** | −1.93 |
| | | | | | | | (0.016) | (0.855) |
| Dagara ethny | | | | | | | −2.17** | −32.35*** |
| | | | | | | | (0.021) | (0.000) |
| Bobo ethny | | | | | | | −2.95*** | 60.21*** |
| | | | | | | | (0.003) | (0.000) |
| Gourounsi ethny | | | | | | | −0.8 | 0.18 |
| | | | | | | | (0.441) | (0.982) |
| Mossi ethny | | | | | | | 0.61 | −9.21 |
| | | | | | | | (0.512) | (0.255) |
| *N* | 3472 | | 3472 | | 3472 | | 3472 | |
| *R* squared | 0.8371 | | 0.837 | | 0.831 | | 0.8325 | |

*p*-values in brackets.

*Significant at 10%; **significant at 5%; ***significant at 1%.

[12] Market dummies.

[13] Rainfall and market dummies.

[14] Climatic zone dummies.

[15] Ethnic group dummies.

**Table 4:** Effect of Transport Costs on Maize Price Volatility, Costs Being Proxied by the Cumulative Distance to All Markets

| | [16] | | [17] | | [18] | | [19] | |
|---|---|---|---|---|---|---|---|---|
| | Mean equation | Variance equation | Mean equation | Variance equation | Mean equation | Variance equation | Mean equation | Variance equation |
| Constant | 48.86*** | 207.87*** | 50.46*** | 208.54*** | 34.46*** | −65.65*** | 34.50*** | 69.67* |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.054) |
| Arch term | | 0.20*** | | 0.21*** | | 0.17*** | | 0.16*** |
| | | (0.000) | | (0.000) | | (0.000) | | (0.000) |
| Lagged price | 0.84*** | 0.75*** | 0.84*** | 0.74*** | 0.92*** | 1.45*** | 0.90*** | 1.36*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| International price | 0.05*** | −0.42*** | 0.05*** | −0.42*** | 0.04*** | −0.49*** | 0.04*** | −0.58*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Exchange rate | −0.04*** | −0.18* | −0.04*** | −0.18* | −0.03*** | −0.07*** | −0.03*** | −0.20*** |
| | (0.000) | (0.080) | (0.000) | (0.082) | (0.000) | (0.006) | (0.000) | (0.002) |
| Harvest dummy | −6.20*** | 47.75*** | −6.17*** | 44.09*** | −5.97*** | 117.86*** | −6.15*** | 110.28*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Lean dummy | 1.41*** | −8.17** | 1.40*** | −8.22** | 1.02*** | 0.85 | 1.06*** | 1.71 |
| | (0.000) | (0.011) | (0.001) | (0.011) | (0.009) | (0.500) | (0.009) | (0.428) |
| Time to the border | 0.02*** | −0.07 | 0.03*** | −0.09 | 0.00 | −0.10*** | 0.01 | −0.37** |
| | (0.000) | (0.128) | (0.000) | (0.168) | (0.516) | (0.000) | (0.348) | (0.000) |
| Cumulative time | −0.00*** | 0.01*** | −0.00*** | 0.01*** | 0.00** | 0.01*** | 0.00* | 0.02*** |
| | (0.000) | (0.000) | (0.002) | (0.001) | (0.010) | (0.000) | (0.094) | (0.000) |
| Trend | −0.05*** | −1.67*** | −0.05*** | −1.66*** | −0.05*** | −1.11*** | −0.05*** | −1.20*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Market dummies | YES | YES | YES | YES | NO | NO | NO | NO |
| Annual rainfall | | | −0.01*** | 0.01 | | | | |
| | | | (0.000) | (0.818) | | | | |
| South Sahelian climate | | | | | −2.57*** | 43.11*** | | |
| | | | | | (0.004) | (0.000) | | |
| North Soudanian climate | | | | | −3.78*** | 94.39*** | | |
| | | | | | (0.000) | (0.000) | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| South Soudanian climate | | | | | −4.12** | 59.08*** | | |
| | | | | | (0.000) | (0.000) | | |
| Peulh ethny | | | | | | | 3.72*** | −55.93*** |
| | | | | | | | (0.001) | (0.000) |
| Gourmantche ethny | | | | | | | 0.85 | 9.97 |
| | | | | | | | (0.561) | (0.524) |
| Bissa ethny | | | | | | | −0.46 | −44.39*** |
| | | | | | | | (0.719) | (0.000) |
| Lobi ethny | | | | | | | 1.78 | −4.88 |
| | | | | | | | (0.165) | (0.700) |
| Senoufo ethy | | | | | | | −1.28 | −85.27*** |
| | | | | | | | (0.476) | (0.000) |
| Dagara ethny | | | | | | | −2.10** | 0.69 |
| | | | | | | | (0.018) | (0.852) |
| Bobo ethny | | | | | | | −1.80* | 7.45* |
| | | | | | | | (0.068) | (0.052) |
| Gourounsi ethny | | | | | | | −1.13 | 17.01** |
| | | | | | | | (0.311) | (0.017) |
| Mossi ethny | | | | | | | 0.25 | −2.78 |
| | | | | | | | (0.766) | (0.594) |
| *N* | 3472 | | 3472 | | 3472 | | 3472 | |
| *R* squared | 0.8732 | | 0.8373 | | 0.8311 | | 0.8331 | |

*p*-values in brackets.

*Significant at 10%; **significant at 5%; ***significant at 1%.

[16] Market dummies.

[17] Rainfall and market dummies.

[18] Climatic zone dummies.

[19] Ethnic group dummies.

**Table 5:** Effect of Transport Costs on Maize Price Volatility, Estimations led with Nominal Maize Prices

| | [20] | | [21] | | [22] | | [23] | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Variance | Mean | Variance | Mean | Variance | Mean | Variance |
| Constant | 34.79*** | 181.45*** | 43.05*** | 182.8*** | 35.27*** | −66.11 | 34.22*** | 41.96*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.103) | (0.000) | (0.000) |
| Arch Term | | 0.20*** | | 0.22*** | | 0.16*** | | 0.15*** |
| | | (0.000) | | (0.000) | | (0.000) | | (0.000) |
| Nominal lagged price | 0.87*** | 0.59*** | 0.85*** | 0.53*** | 0.94*** | 1.64*** | 0.92*** | 1.61*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Nominal International price | 0.09*** | −0.31*** | 0.08*** | −0.21*** | 0.05*** | −0.53*** | 0.05*** | −0.48*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Nominal Exchange rate | −0.04*** | −0.07 | −0.05*** | −0.06 | −0.04*** | 0 | −0.04*** | −0.07** |
| | (0.000) | (0.324) | (0.000) | (0.392) | (0.000) | (0.986) | (0.000) | (0.017) |
| Harvest dummy | −6.55*** | 117.2*** | −6.56*** | 97.55*** | −6.05*** | 120.12*** | −6.05*** | 115.05*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Lean dummy | 2.01*** | −4.06** | 1.9*** | −4.46*** | 1.54*** | −1.65 | 1.55*** | −4.2 |
| | (0.000) | (0.047) | (0.000) | (0.003) | (0.000) | (0.588) | (0.000) | (0.123) |
| Time to border | 0.01*** | −0.03 | 0.04*** | −0.02 | 0.004 | −0.20*** | 0.003 | −0.45*** |
| | (0.006) | (0.642) | (0.000) | (0.839) | (0.181) | (0.000) | (0.523) | (0.000) |
| Time to Ouaga | −0.02*** | 0.09** | −0.03** | 0.12*** | −0.01** | 0.28*** | −0.01** | 0.43*** |
| | (0.000) | (0.045) | (0.042) | (0.007) | (0.019) | (0.000) | (0.048) | (0.000) |
| Trend | −0.05*** | −1.29*** | −0.04*** | −1.4*** | −0.05*** | −1.10*** | −0.04*** | −1.15*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Market dummies | YES | YES | YES | YES | NO | NO | NO | NO |
| Annual rainfall | | | −0.009** | −0.02 | | | | |
| | | | (0.012) | (0.696) | | | | |
| South Sahelian climate | | | | | −1.95** | 44.84*** | | |
| | | | | | (0.016) | (0.000) | | |
| North Soudanian climate | | | | | −2.52*** | 78.70*** | | |
| | | | | | (0.002) | (0.000) | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| South Soudanian climate | | | | | −2.17** | 29.99*** | | |
| | | | | | (0.031) | (0.004) | | |
| Peulh ethny | | | | | | | 2.71** | −23.21*** |
| | | | | | | | (0.001) | (0.006) |
| Gourmantche ethny | | | | | | | 0.99 | 71.89*** |
| | | | | | | | (0.438) | (0.000) |
| Bissa ethny | | | | | | | −0.41 | −25.79** |
| | | | | | | | (0.718) | (0.015) |
| Lobi ethny | | | | | | | 2.92** | −23.00* |
| | | | | | | | (0.040) | (0.065) |
| Senoufo ethny | | | | | | | −0.47 | −80.1*** |
| | | | | | | | (0.783) | (0.000) |
| Dagara ethny | | | | | | | −1.03 | −22.22*** |
| | | | | | | | (0.204) | (0.000) |
| Bobo ethny | | | | | | | −0.76 | −0.12 |
| | | | | | | | (0.445) | (0.983) |
| Gourounsi ethny | | | | | | | −0.74 | 14.35 |
| | | | | | | | (0.475) | (0.103) |
| Mossi ethny | | | | | | | −0.1 | 25.17*** |
| | | | | | | | (0.906) | (0.000) |
| *N* | 3472 | | 3472 | | 3472 | | 3472 | |
| *R* squared | 0.8601 | | 0.8604 | | 0.8547 | | 0.856 | |

*p*-values in brackets.
*Significant at 10%; **significant at 5%; ***significant at 1%.
[20] Market dummies.
[21] Rainfall and market dummies.
[22] Climatic zone dummies.
[23] Ethnic group dummies.

## 6. Conclusion

Drawing on the case of maize in Burkina Faso, we analyze the effect of market remoteness on price volatility. We develop a model of price formation to shed light on the local causes of volatility in rural markets. The empirical estimations we led on twenty-eight markets established that markets that are close to the main cities and where road is paved display less volatile price series. Results also show that markets that are close to maize border-crossing points show more volatile prices, which indicate a low level of regional integration between Burkina Faso and border countries.

These findings suggest that policies aimed at reducing maize price volatility should be targeted towards infrastructure development and promote regional integration and economic development within the ECOWAS area. For instance, authorities could support remote markets by providing rural road infrastructures, thereby contributing to linking remote markets with major consumption centres across the country as well as in neighboring countries. Other studies came to the similar policy conclusion of the importance of rural roads on rural development (Jacoby, 2000), agricultural specialisation (Qin and Zhang, 2016) and poverty reduction (Van de Walle, 2002). Without such rural roads investments, it will be difficult to improve the commercialisation of agricultural products in remote areas and reduce price volatility across markets in Burkina Faso.

## Supplementary material

Supplementary material is available at *Journal of African Economies* online.

## Acknowledgements

This paper is a product of SUPAGRO and CIRAD Economic Departments. We are grateful to Luc Christiaensen, Pierre Courtois, Brian Dillon, Christopher L. Gilbert, Jonathan Kaminski, Sophie Thoyer and two anonymous referes for their suggestions and comments that have significantly improved the paper.

## References

Abdulai A. (2000) 'Spatial Price Transmission and Asymmetry in the Ghanaian Maize Market', *Journal of Development Economics*, 63 (2): 327–49.

Aker J. C., Klein M. W., O'Connell S. A., Yang M. (2014) 'Borders, Ethnicity And Trade', *Journal of Development Economics*, 107 (1): 1–16. http://works.swarthmore.edu/fac-economics/70

Anderson J. E., Marcouiller D. (2002) 'Insecurity and the Pattern of Trade: An Empirical Investigation', *Review of Economics and Statistics*, 84 (2): 342–52.

Anderson J. E., Van Wincoop E. (2004) 'Trade Costs', *Journal of Economic Literature*, 42 (3): 691–751.

Badiane O., Shively G. E. (1998) 'Spatial Integration, Transport Costs, and the Response of Local Prices to Policy Changes in Ghana', *Journal of Development Economics*, 56 (2): 411–31.

Barrett C. (1996) 'On Price Risk and the Inverse Farm Size – Productivity Relationship', *Journal of Development Economics*, 51 (2): 193–215.

Barrett C. (1997) 'Liberalization and Food Price Distributions: ARCH-M Evidence from Madagascar', *Food Policy*, 22 (2): 155–73.

Beck S. E. (1993) 'A Rational Expectations Model of Time Varying Risk Premia in Commodities Futures Markets: Theory and Evidence', *International Economic Review*, 34 (1): 149–68.

Bollerslev T. (1986) 'Generalized Autoregressive Conditional Heteroskedasticity', *Journal of Econometrics*, 31 (3): 307–27.

Brenton P. (2012) 'Africa Can Help Feed Africa: Removing Barriers to Regional Trade in Food Staples,' Discussion Paper, The Worldbank, Washington, DC.

Brunt L., Cannon E. (2014) 'Measuring Integration in the English Wheat Market, 1770–1820: New Methods, New Answers', *Explorations in Economic History*, 52: 111–30.

Buys P., Deichmann U., Wheeler D. (2010) 'Road Network Upgrading and Overland Trade Expansion in Sub-Saharan Africa', *Journal of African Economies*, 19 (3): 399–432.

Cairncross F. (1999) 'The Death of Distance: How the Communication Revolution Will Change Our Lives', *American Quarterly-Minneapolis*, 51: 160.

Carrere C., Schiff M. (2005) 'On the Geography of Trade. Distance is Alive and Well', *Revue Economique*, 56: 1249–74.

Dahlman C. J. (1979) 'The Problem of Externality', *The Journal of Law & Economics*, 22 (1): 141–62.

Disdier A.-C., Head K. (2008) 'The Puzzling Persistence of the Distance Effect on Bilateral Trade', *The Review of Economics and statistics*, 90 (1): 37–48.

Driscoll J. C., Kraay A. C. (1998) 'Consistent Covariance Matrix Estimation with Spatially Dependent Panel Data', *Review of Economics and Statistics*, 80 (4): 549–60.

Engle R. (1982) 'Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation', *Econometrica: Journal of the Econometric Society*, 50 (4): 987–1007.

Fafchamps M. (1992) 'Cash Crop Production, Food Price Volatility and Rural Market Integration in the Third World', *American Journal of Agricultural Economics*, 74 (1): 90–9.

Francois J., Manchin M. (2013) 'Institutions, Infrastructure, and Trade', *World Development*, 46: 165–75.

Gilbert C., Morgan W. (2010) 'Food Price Volatility', *Philosophical Transactions of the Royal Society*, 365: 3023–34.

Hummels D. L., Schaur G. (2010) 'Hedging Price Volatility Using Fast Transport', *Journal of International Economics*, 82 (1): 15–25.

Im K. S., Pesaran M. H., Shin Y. (2003) 'Testing for Unit Roots in Heterogeneous Panels', *Journal of Econometrics*, 115 (1): 53–74.

Jacks D. S., O'Rourke K. H., Williamson J. G. (2011) 'Commodity Price Volatility and World Market Integration Since 1700', *Review of Economics and Statistics*, 93 (3): 800–13.

Jacoby H. G. (2000) 'Access to Markets and the Benefits of Rural Roads', *Economic journal*, 713–37.

Jordaan H., Grove B., Jooste A., Alemu Z. (2007) 'Measuring the Price Volatility of Certain Field Crops in South Africa Using the ARCH/GARCH Approach', *Agrekon*, 46 (3): 306–22.

Kapetanios G., Mitchell J., Shin Y. (2014) 'A Nonlinear Panel Data Model of Cross-Sectional Dependence', *Journal of Econometrics*, 179 (2): 134–57.

Kilima F. T. M., Chung C., Kenkel P., Mbiha E. R. (2008) 'Impacts of Market Reform on Spatial Volatility of Maize Prices in Tanzania', *Journal of Agricultural Economics*, 59 (2): 257–70.

Limao N., Venables A. J. (2001) 'Infrastructure, Geographical Disadvantage, Transport Costs and Trade', *The World Bank economic review*, 15 (3): 451–79.

Maître d'Hôtel E., Le Cotty T., Jayne T. (2013) 'Trade Policy Inconsistency and Maize Price Volatility: An ARCH Approach in Kenya', *African Development Review*, 25 (4): 607–20.

Minot N. (2010) *Transmission of World Food Price Changes to Markets in Sub-Saharan Africa*. Washington, DC: International Food Policy Research Institute.

Minot N. (2014) 'Food Price Volatility in Sub-Saharan Africa: Has It Really Increased?', *Food Policy*, 45: 45–56.

Minten B., Kyle S. (1999) 'The Effect of Distance and Road Quality on Food Collection, Marketing Margins, and Traders' Wages: Evidence from the Former Zaire', *Journal of Development Economics*, 60 (2): 467–95.

Minten B., Randrianarison L. (2003): 'Ètude sur la formation des prix du rix local à Madagascar,' in *A Paper Prepared for the Conference on 'Agriculture et Pauvrete'*, Antananarivo, Madagascar.

Pesaran M. H. (2007) 'A Simple Panel Unit Root Test in the Presence of Cross-Section Dependence', *Journal of Applied Econometrics*, 22 (2): 265–312.

Pesaran M. H., Smith L. V., Yamagata T. (2013) 'Panel Unit Root Tests in the Presence of a Multifactor Error Structure', *Journal of Econometrics*, 175 (2): 94–115.

Pomfret R., Sourdin P. (2010) 'Why Do Trade Costs Vary?', *Review of World Economics*, 146 (4): 709–30.

Prakash A. (2011) *Why Volatility Matters*. Rome: FAO, pp. 3–26.

Qin Y., Zhang X. (2016) 'The Road to Specialization in Agricultural Production: Evidence from Rural China', *World Development*, 77: 1–16.

Rapsomanikis G., Mugera H. (2011) 'Price Transmission and Volatility Spillovers in Food Markets of Developing Countries', in *Methods to Analyse Agricultural Commodity Price Volatility*. New York: Springer, pp. 165–79.

Roehner B. M. (1996) 'The Role of Transportation Costs in the Economics of Commodity Markets', *American Journal of Agricultural Economics*, 78 (2): 339–53.

Samuelson P. A. (1952) 'Spatial Price Equilibrium and Linear Programming', *The American economic review*, 283–303.

Shepherd B., Wilson J. S. (2007) 'Trade, Infrastructure, and Roadways in Europe and Central Asia: New Empirical Evidence', *Journal of Economic Integration*, 723–47.

Shively G. (1996) 'Food Price Variability and Economic Reform: An ARCH Approach for Ghana', *American Journal of Agricultural Economics*, 78: 126–36.

Stifel D., Minten B. (2008) 'Isolation and Agricultural Productivity', *Agricultural Economics*, 39 (1): 1–15.

Van de Walle D. (2002) 'Choosing Rural Road Investments to Help Reduce Poverty', *World Development*, 30 (4): 575–89.

Williamson O. E. (1979) 'Transaction-Cost Economics: The Governance of Contractual Relations', *The journal of law & economics*, 22 (2): 233–61.