Essays on Food Security in Sub-Saharan Africa : the role of food prices and climate shocks

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ESSAYS ON FOOD SECURITY IN SUB-SAHARAN AFRICA

The role of food prices and climate shocks

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Acronyms and Abbreviations

ADF	Augmented Dickey-Fuller
CAADP	Comprehensive Africa Agriculture Development Program
CEMAC	*Communauté Economique et Monétaire d'Afrique Centrale*
CILSS	*Comité Inter-États de Lutte contre la Sécheresse au Sahel*
CGIAR	Consultative Group on International Agricultural
FAO	Food and Agriculture Organization of the United Nations
ECOWAS	Economic Community of West African States
ENIAM	*Etude Nationale sur l'Insécurité Alimentaire et la Malnutrition*
EWS	Early Warning System
FEWSNET	Famine Early Warning Systems Network
GDP	Gross domestic product
GIEWS	Global Information and Early Warning System
GLS	Generalized least squares
HAZ	Height-for-age
IMF	International Monetary Fund
IFPRI	International Food Policy Research Institute
IFS	International Financial Statistics
LOP	Law of one price
MIS	Market information system
NEPAD	New Partnership for Africa's Development
RLOP	Relative version of the law of one price
RPCA	*Réseau de Prévention des Crises Alimentaires*
TLU	Tropical livestock units
UNCTAD	United Nations Conference on Trade and Development
UNECA	United Nations Economic Commission for Africa
USAID	U.S. Agency for International Development

USDA	U.S. Department of Agriculture
VAM	Vulnerability Analysis and Mapping
WAEMU	West African Economic and Monetary Union
WATH	West Africa Trade Hub
WHO	World Health Organization
WFP	World Food Program

General introduction

From 2010 to 2012, about 870 million people are estimated to have been undernourished representing 12.5 percent of the global population and 14.9 percent of the developing world (FAO *et al.*, 2012). The rate of progress in the reduction of undernourishment has been higher in Asia and in Latin America than in Africa where 22.9 percent of the population still suffers from undernourishment. Most of the progress in reducing hunger has been achieved before the 2007-2008 global food price crisis. If the consequences of the food and economic crises on hunger have been less important than initially expected, Sub-Saharan Africa has been strongly affected by the global recession and achieving food security continues to be a challenge.

This doctoral thesis is in line with the renewed interest in research on agriculture and food security following the 2008 global food crisis. This doctoral thesis aims to contribute to a better understanding of the complex issues surrounding food security.

The general background of the dissertation

Food security is a multi-dimensional phenomenon.

Hunger can take many forms, from chronic under-nutrition to famine. Famine has been eradicated in several historically famine-prone countries such as Bangladesh, Russia, China and India. With almost 234 million people chronically undernourished in 2010-2012 (FAO *et al.*, 2012), Sub-Saharan Africa is the only region in the world in which threats of famine persist.

The most recent famine on the African continent hit Somalia in 2011 and is a good example of the complex dynamics underlying the global problem of food insecurity. In 2011 the Horn of Africa faced a severe food security crisis that threatened the lives and livelihood of over twelve million people (FAO, 2011a). Somalia has been hit worst of all countries in the region with more than 40 percent of the country's population in crisis. Out of the four million of Somalis suffering from the food crisis, 750,000 were officially declared as experiencing famine in September 2011.

A food crisis results from a combination of various factors. The severe drought that affected the Horn of Africa between July 2011 and mid-2012 emerges as the major trigger of the famine. The drought was characterized by the lowest levels of rainfall recorded in 50 years in some of the affected areas (Maxwell and Fitzpatrick, 2012). Although the food crisis was largely a result of the drought, rising food prices have also contributed to a large extent to the crisis. High cereal prices (both imported and local) coupled with reduced incomes as a result of limited labour opportunities and low livestock sales decreased households' ability to access food (WFP, 2011). In addition to the production and access failures, the longstanding conflict in Somalia played an important role in people's vulnerability. The prolonged conflict led to large scale displacements of civilians and often prevented people from cultivating their land and moving their herds (Jaspars and Maxwell, 2008). Finally, the conflict reduced the ability of aid organizations to provide assistance to affected households. Access to people in need was significantly restricted by the Al-Shabaab[1] islamist group, as the group controls much of the south of the country. In February 2010, Al-Shabaab banned World Food Program (WFP) operations in Somalia and 16 additional aid groups were banned from operating in the country in November 2011.

The 2011 famine and the prevailing level of food insecurity in the region are the result of recurrent droughts as well as socio-economic factors. As described by Sen (1981), famines are not necessarily caused by a reduction in the availability of food. Sen (1981) developed a new approach to famines which focuses on people's ability to command food. Before Sen, famines were seen as the inevitable consequence of sudden food shortages resulting from unavoidable exogenous shocks such as persistent droughts, floods and other natural disasters (Plümper and Neumayer, 2011). By introducing the 'entitlement approach', Sen shows that famines happen when people are no longer able to have access to sufficient amounts of food. Following Sen's work, Ravallion (1997) emphasizes the role played by market and institutional failures to explain famines. He showed that the 1974 famine in Bangladesh was partly caused by speculative hoarding by farmers and traders as well as a general mistrust of the people with regards to the government's ability to provide a suitable response to the crisis. De Waal (1990) argues that Sen's approach neglects the role played by social disruption in explaining famine. He argues that natural disasters or economic crisis can cause social disruption that in turns leads to health crises which cause excess deaths. He lays stress on the effects of wars, unhygienic living conditions and diseases on morbidity and mortality.

Although there is some disagreement about what actually causes famine, this debate has led to the recognition that food availability does not ensure households' access to food: food security is "*when all people, at all times, have physical, social and economic access to*

[1] *Al-Shabaab* is the largest militant organization fighting the *transitional government* in Somalia. The group controls much of the south of the country.

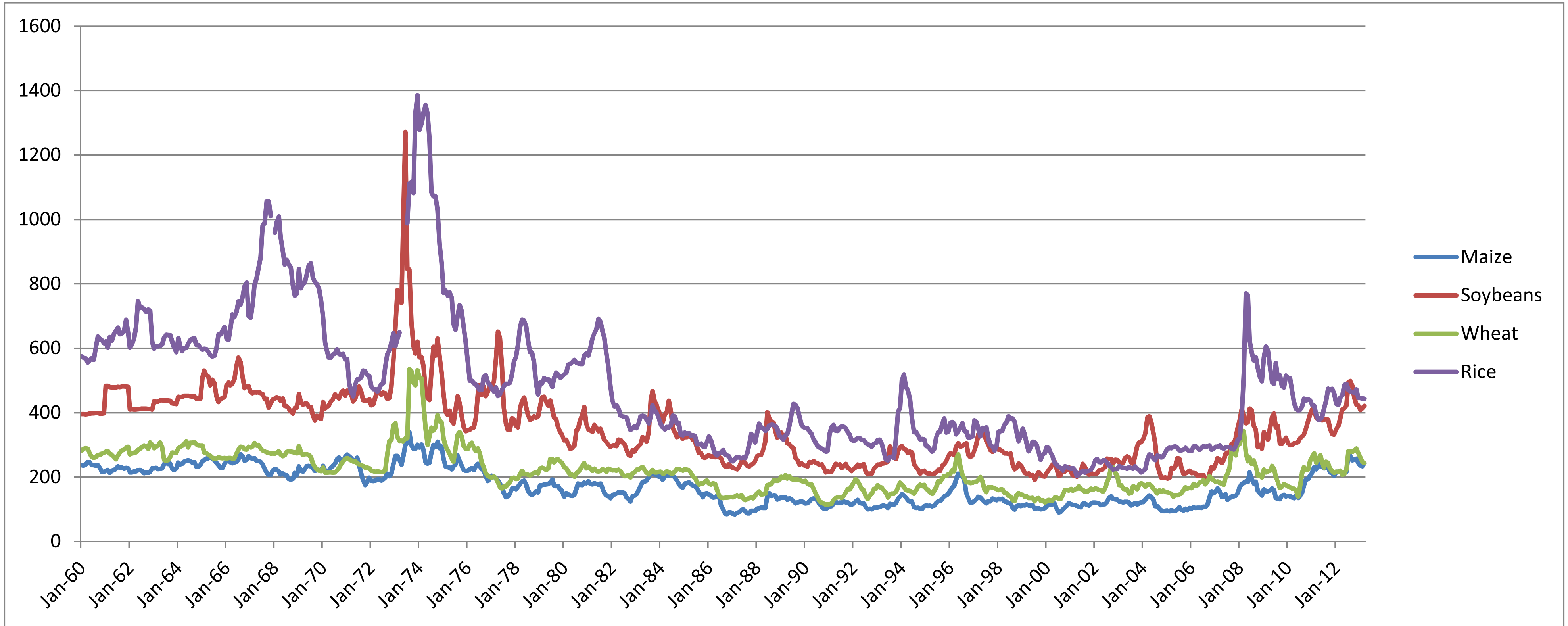
sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 1996). At the World Summit of Food Security in 2009, the concept was extended by adding that the "*four pillars of food security are availability, access, utilization, and stability*" and stated that "*the nutritional dimension is integral to the concept*" (FAO, 2009).

High food prices may threaten food security

Access to food may be threatened by the current high level of global food prices. Between 2006 and 2008, world food prices increased dramatically, raising concerns about food access for poor households in developing countries. International prices of several commodities such as maize, rice and wheat increased significantly, reaching their highest levels in nearly thirty years. The world prices of wheat, soybean and maize more than doubled, while the price of rice tripled. As the majority of smallholders are net buyers of the food crops they produce (Barrett, 2008), large price increases can cause temporary reductions in disposable income. Food represents a large share of the budget of poor consumers in developing countries and a reduction in purchasing power due to price shocks can force poor households to cut back on the quantity or quality of their food. Poor households may also sell assets in order to cope with sharp changes in prices, which can trap them into poverty. In addition, poor households are less able to take advantage of high prices due to their limited access to productive assets and credit and their remoteness from markets.

The jump in global food prices can have adverse effects at the national level too, through a rise in the food import bill. The 2008 sharp rise in world prices put an end to a downward trend that lasted more than 30 years (Figure 1). After peaking in 1974, prices of most basic grains decreased continuously to reach historically low levels in the early 2000s. The long-term downward trend in agricultural commodity prices discouraged countries to invest in agriculture. According to the FAO, the agricultural trade balance of African countries has deteriorated massively since 1980. In 1980, the African agricultural trade was almost balanced whereas in 2010 its agricultural imports exceeded agricultural exports by about USD 35 billion (FAOSTAT, 2013). The trade deficit is much larger for food trade. Africa's food trade deficit started in 1974 with the rise in food prices and has not stopped growing until 2008 when it reached a peak at USD 31 billion (FAOSTAT, 2013).

Figure 1: Trend in real international prices of key cereals in US$ per metric ton (January 1960 – March 2013)



Source: IFS for the nominal prices of maize, soybeans and wheat and for the Unit Value of Exports; UNCTAD for the nominal price of rice. Note: Prices are adjusted for inflation using the World Export Unit Values. Maize is US No. 2 Yellow, wheat is US No. 2 Hard Red Winter, soybeans are US No. 1 Yellow, and rice is White Thai 5% broken.

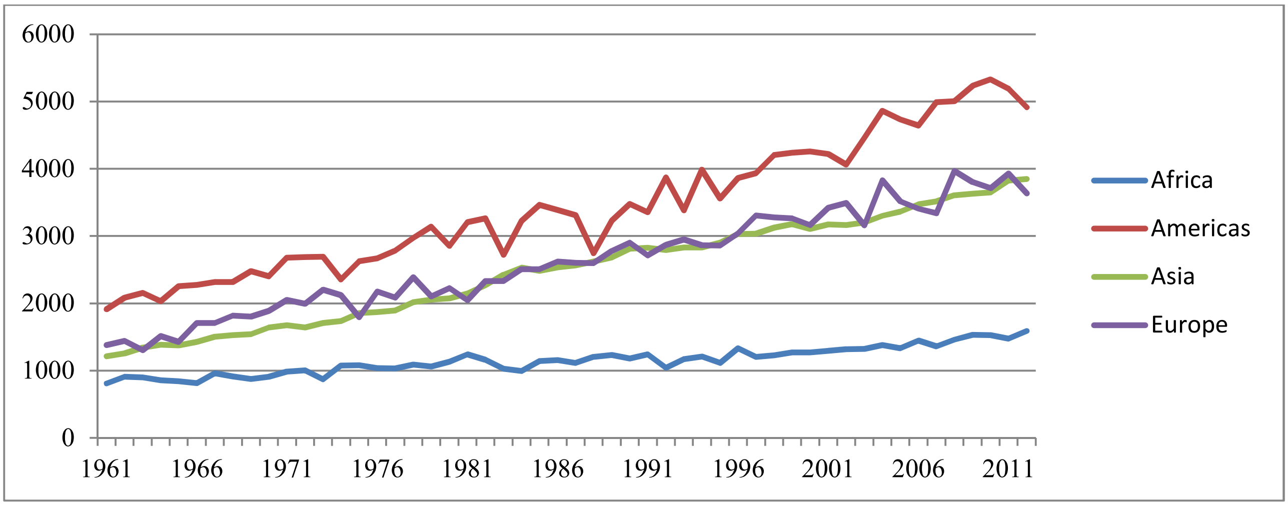
The increase in food imports is driven by basic food staple such as dairy products, vegetable oils, sugar and especially cereals (FAO, 2011b), implying that food imports have been increasingly important in ensuring food security. Food imports dependency does not threaten food security in periods of low prices but it becomes problematic in a context of high world prices. The situation is especially worrying in countries with no stable source of foreign currency. According to the FAO (2011b), only 19 African countries out of 53 had enough agricultural export revenues in 2007 to pay for their food import bill.

Enhancing food security in Africa will require an increase in agricultural productivity

Rising food imports reflects that growth in domestic food supply has been unable to match the rise in demand. Although Africa's total cereal production has increased over the past twenty years, the production per capita has stagnated. Over the period 1990-2011, Africa's total cereal production increased on average by 3.1 percent per year but its per capita cereal production rose only by about 0.7 percent per year (FAOSTAT, 2013). Production growth was based almost entirely on extending the area under cultivation (Evenson and Gollin, 2003a). On average in Africa, the level of cereal produced on a per capita basis is about 156 kg in 2011, compared with 306 kg per capita in Asia and 371 kg per capita in the world (FAOSTAT, 2013). This low and stagnated level of cereal production per capita can be attributed to slow productivity growth.

Figure 2 compares cereal yield levels and shows the huge productivity gap between Africa and the rest of the world. Between 1961 and 2011, Asia's cereal yields tripled from 1.2 to more than three tons per hectare, while Africa's yields stayed at less than 1.6 tons per hectare (FAOSTAT, 2013). When considering the agricultural value added per worker as a measure of agricultural productivity, it appears that the agricultural value added per worker remains low in most African countries. According to Gollin *et al*. (2012), the value added per worker is approximately four times higher in non-agriculture than in agriculture in developing countries. Africa's low and stagnating agricultural productivity has many causes including among other things land degradation, limited access to inputs, slow adoption of technology and improved practices and low access to agricultural credit.

Figure 2: Cereal yield in kilogram per hectare



Source: FAOSTAT

Although large areas of fertile land in Sub-Saharan Africa remain idle, per capita arable land and farm sizes are declining over time in the face of the high population growth (IFPRI, 2011; Jayne *et al.*, 2003). Population pressure may also force people to move from high agricultural potential areas with fertile soils to marginal or fragile lands (Muchena, 2005). The relationship between population density and land degradation is not clear; the debate over whether population density leads to land improvement or to land degradation continues today (Von Braun *et al.*, 2012). It is nevertheless true that Sub-Saharan Africa is impacted by land degradation, especially Africa south of the Equator (Bai *et al.*, 2008). Land degradation as well as poor land quality (Wiebe, 2003) are major constraints to higher agricultural productivity (Pender, 2009). Some differences in land quality and some forms of land degradation such as soil nutrient depletion can be mitigated through the use of organic and inorganic fertilizers. On the other hand, soil erosion or salinization are more costly to reverse but can be slowed through appropriate management practices.

The literature on agricultural stagnation in Sub-Saharan Africa draws attention to the slow adoption of technology including fertilizer usage, mechanical inputs, and high-yielding seed varieties (O'Gorman, 2012). The intensity of fertilizer use remains low in Africa compared to the rest of the world. In 2002, the average intensity of fertilizer use was height kilograms per hectare in Sub-Saharan Africa compared with 78 kg per ha in Latin America and 101 kg in South Asia (Morris *et al.*, 2007). Fertilizer use must increase in Africa as fertilizer use is critical to restore soil fertility and can contribute to closing the gap between actual and potential crop yields that is very high in Sub-Saharan Africa.

Agricultural mechanization is an important part of the modernization of agriculture. In Africa, the use of mechanical implements lags far behind other regions of the world due to the high cost of energy and the high price of equipment. In addition, the average African farm is often too small and fragmented to make the use of tractors economically viable.

Agricultural sectors in many countries have widely benefited from crop genetic improvement. Over the period from 1960 to 1980, modern varieties contributed substantially to food production growth in Asia and Latin America. In contrast, high yielding crop varieties contribution to productivity growth was extremely low before the 1990's in Sub Saharan Africa (Evenson and Gollin, 2003a). The differences between regions in the impact of modern varieties to yield may reflect the disparities in the availability of suitable varieties across different agroecological zones. At the global scale, most of the yield gains were achieved by using crop varieties that performed well under irrigation and intensive use of fertilizers. By contrast, varietal improvement was more limited in other growing environments; there was indeed very limited research on crops such as sorghum, millet and cassava until the 1970's or even on rice in West Africa until the 1980's (Evenson and Gollin, 2003b).

Adoption of modern inputs is constrained by supply-side factors but also by demand-side factors such as lack of access to credit. The literature on rural credit markets in developing countries emphasizes limited access to credit as a major constraint to higher levels of productivity (Eswaran and Kotwal, 1986; Kochar, 1997). Low access to credit may affect farmers in different ways. First, credit constraints may prevent smallholders from making investments in a new technology. Second, credit constrained households may engage in low risk–low return activity portfolios (Dercon, 2005). Third, household are likely to hold high levels of stocks to protect against shocks. For Ethiopia, Ali and Deiniger (2012) found that eliminating credit constraints would increase productivity by roughly eleven percent in surplus producing areas. By contrast, credit rationing does not have any impact on agricultural productivity in drought prone areas where loans are rarely used to buy agricultural inputs.

Given that many smallholders market their produce right after the harvest (when prices are at their lowest) and buy food from the market when their stock are depleted (when prices reach their peaks), a reduction in food losses could have a significant impact on their livelihoods. Food losses are difficult to estimate due to limited data. In a recent study, Gustavsson *et al.* (2011) estimate that one-third of the edible parts of food produced for human consumption is wasted globally each year. On a per-capita basis, the food waste by consumers in Europe and North-America is 95-115 kg per year compared with only 6 kg per year in Sub-Saharan

Africa and 11 kg in South/Southeast Asia. In developing countries food is mostly lost during the production to processing stages of the food supply chain whereas in high-income countries food losses occur mostly at retail and consumer levels (Gustavsson *et al.*, 2011). In developing regions, agricultural production and postharvest handling and storage are stages in the food supply chain with the highest food losses. Improving the efficiency of the food supply chain would require large scale investment in harvesting, transport, storage facilities and packaging equipment. For decades, research has focuses on boosting agricultural production and productivity. It is time to address the tensions between production and access to food by increasing research and funding on postharvest activities in order to decrease the cost of food to the consumer and thus increase access.

After decades of neglect, the food price crisis of 2008 has put agriculture and food security back on the African development agenda.

Both domestic and international policy makers failed to predict the 2008 food price crisis which suggests that that no lessons have been learned from the 1974 food crisis. In response to the 1974 crisis, new institutions were created such as the World Food Program for food aid, the Consultative Group on International Agricultural (CGIAR) for Research, the Global Information and Early Warning System (GIEWS) for preventing food crises. Although the 1974 food crisis raised policy interest in predicting and preventing future crises, subsequent responses have not been adequate to address and prevent them.

Over the last 30 years, public spending in the agricultural sector (including foreign aid) have been extremely low (Bezemer and Headey, 2006). African governments spend on average much less on the agricultural sector than Asian and Latin American countries (O'Gorman, 2012). African public investment in the agricultural sector fell from 6.4 percent in 1980 to 4.5 percent in 2002 (Somma, 2008). The share of development assistance devoted to agricultural investments has followed the same trend; it decreased from 26 percent in the late 1980's to 4 percent in 2007 (Somma, 2008).

In 2003, African heads of state ratified an initiative called the Comprehensive Africa Agriculture Development Program (CAADP). All member states of the African Union committed to invest at least ten percent of their national budgets in the agricultural sector by 2008. Only height out of 53 African countries met their ten percent target of agricultural spending as a share of the national budget and nine countries invested about five percent (NEPAD, 2011). That ten percent commitment, also known as the Maputo Declaration Target, was designed to stimulate agricultural growth, reduce poverty, and achieve food security. Although the numbers may vary depending on how agricultural spending is defined, many experts agree to recognize that some progress have been made towards meeting the ten percent target but there is more to be done.

After decades of neglect of the agricultural sector in developing countries, African policy makers and the international community show a renewed interest in agriculture for development. In 2012, the G8 launched a New Alliance for Food Security and Nutrition that is a joint initiative between African leaders, the private sector and development partners to mobilize national and international private investment in African agriculture. The stakeholders committed to specific policy reforms and investments that will accelerate the implementation of country food security strategies under the CAADP. These commitments are captured in New Alliance Cooperation Frameworks for each country. To date, ten countries have agreed New Alliance Cooperation Frameworks. In 2012, over 80 companies made investment commitments covering 6 out of those 10 countries. The New Alliance has already leveraged more than $3.7 billion in private investment in African agriculture.

At a sub-regional level, West African regional organizations and their global partners have launched the Global Alliance for Resilience Initiative–Sahel (AGIR) in December 2012. The Sahel region has faced three food and nutritional crisis over the past decade and is characterized by high acute malnutrition rates. The purpose of this initiative is to help build resilience of vulnerable communities through social safety nets, emergency food reserves, and enhancement of the households' production capacity (IFPRI, 2012).

Ministers of food and agriculture from the Economic Community of West African States (ECOWAS) member states as well as Chad and Mauritania adopted a charter on food crisis prevention and management in 2011 that aims to improve the effectiveness and the efficiency of food crises prevention and response mechanisms in West Africa. The charter recognizes the need to promote dialogue and coordination between the stakeholders and to increase the information quality and analysis of the food and nutrition situation.

One of the key elements of the food crisis prevention system is the creation of a regional emergency food reserve that is the third defense line in addition to the local stocks managed at community or village level and the national food security stocks. The reserves will involve an intervention capability of 410,000 tons: 140,000 tons of physical stocks and a financial reserve equivalent to 270,000 tons. Funding of the regional food security reserve will be provided by governments, regional institutions and financial partners including the G20 members. The governments and the regional institutions are expected to provide two-thirds of the funding ensuring the regional sovereignty over the reserve.

If we must applaud the recent efforts made by some countries and their global partners to invest in agriculture and to reform the food crisis prevention system, we have to ensure that these efforts will be translated into tangible results.

Thesis outline and main results

The thesis does not aim to cover all aspects of food security. This research focuses mainly on the role of food prices and rainfall shocks. The dissertation is divided in four chapters that intend to:

- Understand how price signals are transmitted from the world market to domestic markets (Chapter 1)
- Analyze the nature of the hurdles to food commodities trade in Western and Central Africa (Chapter 2)
- Improve the food crisis alert and prevention systems in the Sahel region (Chapter 3)
- Assess how households are affected by and cope with climate shocks in rural areas of Burkina Faso (Chapter 4)

The first chapter investigates whether changes in the international price of rice are transmitted to the domestic prices of imported and local rice in Senegal, Mali and Chad. The 2008 sharp rise in world food prices raised great concerns about the food situation of poor people in developing countries. If the surge in world food prices has a direct impact at the national level on the food import bill of countries relying massively on import to meet their food needs, the effects at the household level are less obvious. Measuring the degree of price transmission helps us assess the actual impact of the increase in world prices for households. A common concern of both policy makers and consumers is asymmetry in price transmission; this chapter aims at testing whether domestic prices of imported and local rice respond faster to an increase or to a decrease of the international price of rice. Results indicate that the rice markets considered in the analysis are integrated with the world market in the long run, apart from the market of local rice in Dakar. This result is not surprising considering that the local rice market is essentially a thin residual market in Dakar. Results indicate that the domestic prices of imported rice in Dakar and of local rice in Bamako react differently to changes in the world price depending on whether the world price is rising or falling. The price of imported rice in Dakar is more responsive to a world price increase than to a decrease that may reflect a situation of market power in the distribution chain. On the other hand, the government interventions in rice market in Mali are found to result in asymmetric adjustment to international price changes; the price of local rice in Bamako adjusts more rapidly to a world price decline than to a world price rise.

Chapter 2 analyses the incidence of the different impediments to trade of food staples in Western and Central Africa. Although a large number of African countries committed to a process of regional integration, uneven application of the rules and poor road conditions continue to hinder regional trade. The chapter aims at identifying the impact of road infrastructure and country borders on the regional integration of food staples markets using a unique dataset of food commodity prices on 173 markets located in 14 countries and covering the period January 2007 to January 2013. Results highlight the role played by borders in explaining price deviations between markets. However, borders appear as a smaller impediment to trade for countries members of the West African Economic and Monetary Union (WAEMU) or ECOWAS. Our results argue in favour of deepening regional integration within Western and Central African countries. Additionally, our research stresses the importance of providing adequate hard infrastructure in order to reduce the role played by the distance.

The third chapter aims at providing new early warning indicators based on food prices. In the 1980s, market information systems have been implemented in many African countries to collect and disseminate food prices. Until recently, food prices were not analysed extensively and early warning systems relied heavily on crop harvest monitoring. This chapter aims at exploiting grain price data to detect the warning signs of looming food crises in Mali, Burkina Faso and Niger using millet prices from 44 markets. We first identify markets which play a leading role at the national and regional level and then analyze price movements preceding a price crisis. Our analysis provides evidence that price crises can be predicted about 6 months in advance through the observation of past price movements.

Chapter 4 focuses on the analysis of children's vulnerability to climate shocks in Burkina Faso. If climate shocks are inevitable, human vulnerability to these shocks is not. To reduce people's vulnerability, we first need to strengthen our knowledge of vulnerability. By combining health data originating from a 2008 household survey with meteorological data, we identify the critical period in a child's life during which deprivation has the most severe consequences. Results show a strong relationship between rainfall shocks during the prenatal period and child health. The period in utero to twelve months is a critical period during which exposure to nutritional shortfall will have long lasting effects. Results provide evidence that neither rich nor poor households manage to smooth consumption in case of large negative rainfall shocks. Lastly, rainfall shocks have no significant impact on acute malnutrition suggesting that even low endowed households are able to set-up survival strategies to protect the more vulnerable children.

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Chapter 1

Price transmission and asymmetric adjustment: the case of three West African rice markets

1.1. Introduction

The 2008 food crisis raises the question of the implications of West Africa's dependency on global food markets. The international price of nearly every food commodity sharply increased in 2007 and 2008, raising concerns about the food situation of poor people in developing countries. The international prices of traditional staple foods such as maize, rice and wheat increased significantly, reaching their highest levels in nearly thirty years (FAO, 2009). Dairy products and palm oil also experienced sharp price hikes.

Countries with high food import dependency are highly vulnerable to rising international food prices. The large majority of West African countries are net food importers (FAO, 2011a). Cereals imports in West Africa are dominated by rice and wheat (FAOSTAT, 2013). Over the last two decades, there has been a shift in consumption from traditional cereals to rice, partly because people prefer its cooking qualities and minimal preparation time (Balasubramanian *et al*., 2007). In coastal countries like Guinea, Guinea Bissau, Liberia, Senegal and Sierra Leone, rice is the major source of calories (FAOSTAT, 2013). As domestic rice consumption increased faster than local rice production, West African countries became increasingly dependent on imports to meet their domestic needs. It does not threaten food security in periods of low prices of imported rice but it becomes problematic in a context of high world prices of rice. Global rice prices rose to record highs in the spring of 2008, with trading prices tripling from November 2007 to May 2008. The causes of this price spike are complex and the price increase of rice was not due to crop failure or a particularly tight global rice supply situation (FAO, 2011b). The rise in rice prices is the result of the combined effects of trade restrictions by major suppliers (India), panic buying by several large importers, a weak dollar, and high oil prices.

The effects of the food crisis have varied between developing countries according to their food import dependency and the degree to which prices on world markets were passed through to domestic prices. Indeed, the magnitude of the impact of increasing world food prices depends directly on the extent to which world prices are transmitted to domestic markets. The purchasing power of households depends on the level of domestic food prices, not on the level of international food prices. The degree to which prices on world markets are passed through to domestic prices is a crucial issue as it influences the behaviour of producers and consumers. Prices serve at signals about what should be produced and consumed and they provide incentives to people to alter their production and consumption. The transmission of world prices to domestic markets may provide strong incentives for African smallholders to increase production or may lead to the substitution of imported grains with locally produced cereals.

Price transmission between the world prices and the domestic prices has been widely analyzed in the literature (see Baffes and Gardner, 2003; Conforti, 2004; Gilbert, 2010). A recent FAO study (Rapsomanikis, 2011) analyses the relationship between the world market and the domestic markets in six developing countries including two in sub-Saharan Africa. The study shows that domestic markets are integrated with the world market in the long run but the degree of adjustment of domestic food prices to world market changes is slow. In most of the food importing countries included in the study, domestic prices fully adjust to changes in the international prices after a period of nine to ten months. Meuriot (2012) studies the transmission of the fluctuations in the world price of rice to the domestic prices of imported rice in Dakar and Mpal and to the domestic price of local and imported rice in Bamako. She finds that the prices of imported rice in Dakar and Mpal are integrated in the long-term with the world price of rice whereas she provides evidence of the absence of integration between the Malian markets and the international market of rice.

The current paper investigates price transmission between the international price of rice and the domestic prices of imported rice and local rice in three West African markets in an attempt to determine the impact of increasing world rice prices on West African markets. In this paper, we restrict our attention to three countries: Senegal, Mali and Chad. These three countries are characterized by different consumption and production profiles and by different market structures. Hence, studying the price transmission between the world price of rice and the domestic prices of rice in these three distinct contexts can be instructive. It can help us to understand how the production profile and the market structure influence the degree of price transmission. We focus our analysis on the price of rice in the capital cities: Dakar, Bamako and N'Djamena. Besides the issue of the quality of rice, two types of rice are available on these three markets: the imported rice and the local rice. We thus examine the relationship between the international price of rice and the domestic prices of imported and local rice.

After the 2008 sharp rise in the international price of rice, the West African domestic prices of rice increased strongly after a delay of a few months varying with the policies implemented by the countries, the grain supply level and the exchange rate. It took 12 and 8 months respectively to the imported rice prices in N'Djamena and Dakar to go down. These delays are consistent with the general consumers feeling that retail food prices respond faster to an increase in global food prices than to a decrease. If the domestic prices of imported and local rice respond more fully or rapidly to an increase in the international price of rice than to a decrease, the asymmetry is said positive whereas in the opposite case the asymmetry is said negative. This issue of asymmetric adjustment has been widely discussed in economic literature (see Balke and Fomby, 1997; Enders and Siklos, 2001) but only few studies have analyzed asymmetric price transmission of agricultural commodities. Among these articles, a few analyze asymmetric vertical price transmission (see Goodwin and Harper, 2000; Stigler and Tortora, 2011; Araujo-Bonjean and Brun, 2010; Badolo, 2012) but none of them focus on the behaviour of grain prices in several West African countries.

The purpose of this research is twofold. Firstly, we investigate whether the international price of rice is transmitted domestically in three West African countries: Senegal, Chad and Mali. Secondly we investigate whether domestic prices of imported and local rice respond faster to an increase or to a decrease in the international price of rice.

The remainder of the paper is organized as follows. The next section presents the characteristics of rice markets in Senegal, Mali and Chad. Section 3 details the econometric approach used in the empirical analysis. The results of the empirical analysis are shown in section 4 and the last section concludes.

1.2. Characteristics of rice markets in Senegal, Mali and Chad

1.2.1. Rice

Rice has become a commodity of strategic significance across much of Africa. Driven by changing food preferences in the urban and rural areas, by the rapid urbanization and population growth, rice consumption in sub-Saharan Africa increased steadily over the last decade. Grain consumption profiles vary a lot between Senegal, Mali and Chad. Rice provides more than one third of cereal calorie intake in Senegal, 22 percent in Mali and 5 percent in Chad (FAOSTAT, 2013). Even if rice plays a relatively minor role in the diet in Chad, its consumption is rising (see Table A1 in appendix). It is worth noting that 88 percent of the domestic supply of rice is consumed in urban centres in Chad (Bricas *et al.,* 2009) suggesting that rice plays an important role in urban food security.

West Africa's rice production has not been able to match growth in demand resulting in a significant increase in imports. With regional rice imports totalling almost 19 percent of world rice imports (FAOSTAT, 2013), West Africa has become a significant player in world rice markets. Senegal is the third largest West African importers of rice representing 12 percent of regional rice imports and 2.3 percent of world rice imports (FAOSTAT, 2013). The increase in rice imports results from changing food preferences as well as from trade liberalization. At the end of the eighties there was a shift from state-led development to a gradual liberalization of the rice economy making imported rice cheaper and leading to increased imports.

Senegal relies mainly on imported rice to cover its needs. In Senegal, only 30 percent of domestic rice is sold in urban centers (USAID, 2009a). Local rice enters commercial market channels through large transactions following each harvest and through smaller and irregular transactions throughout the year when farmers are short of cash (USAID, 2009c). Farmers produce rice primarily for subsistence and most of them are not commercially oriented. Such a marketing scheme results in a fragmented and informal rice value chain characterized by a high degree of uncertainty. It is unclear whether the strong preference for imported rice is due to the poor quality of local rice, to a lack of communication promoting local rice or to the lack of availability of local rice on the market.

Conversely, Mali and Chad are among the few West African countries which meet close to 90 percent of domestic needs in rice through national production (Table A1). In Mali large volumes of local rice reach urban markets through collectors, semi-wholesalers and retailers.

In spite of the process of liberalization, the rice market is not an integrated market. The West African rice market is segmented on the basis of the rice quality. This segmentation has important implications in terms of price transmission. In many countries, local rice is considered to be of lower quality than imported rice. Hence, rice producers have to set their price below the price of imported rice to make their product attractive. The price of imported rice puts a cap on the price of locally produced rice. Local rice has to compete with imported rice and the price of local rice may be affected by changes in the world price of rice. However, local rice is an imperfect substitute for imported rice and in some rare cases consumers perceive local rice as a product with specific attributes that cannot be found in imported rice. These qualities allow farmers to sell their rice at a higher price. In those rare cases, local rice does not directly compete with imported rice and then the price of these types of local rice may be less affected by the volatility of the world price of rice. In Mali, both urban and rural consumers strongly prefer local rice for its freshness and taste (USAID, 2009a). The market for local rice is divided into two distinct segments: a segment where a rice of high quality is sold, consisting exclusively of local rice that has been polished and cleaned, and a mass market segment consisting of imported rice and un-cleaned and heterogeneous local rice (USAID, 2009b).

1.2.2. The domestic rice markets characteristics explaining asymmetric price transmission

To date, the literature (see Meyer and Von Cramon-Taubadel, 2004, for a review) has examined a variety of factors that can explain the existence of asymmetric price transmission from world prices to domestic markets. We restrict here the potential causes of weak price transmission and asymmetric adjustment to the factors that seem plausible in the context of West African rice markets.

The relationships linking importers, wholesalers and retailers may be characterized by high transactions costs that may prevent agents from adjusting prices continuously (Blake and Fomby, 1997). If adjustment is costly, traders may respond to small changes in world prices by increasing or reducing their margins, leading to a zero pass through of small movements in world prices to domestic markets. In Dakar, importers typically maintain a one to three month stock of rice (USAID, 2009a).This reflects not only the relatively long order-cycle (one month or more) but also the need to deal with demand variations. This may imply that small transitory changes in the world price of rice are not transmitted to the domestic price of imported rice. Additionally, retail prices may not adjust fully due to menu costs such as costs of informing market partners as well as the risk to the retailer's reputation if its price changes are too frequent. Finally, sellers may be reluctant to adjust their prices if they ignore whether the price change is permanent or transitory.

Different costs of adjustment, depending on whether prices rise or fall, might be a cause of price asymmetries. For example, the 2008 rise in the international price of rice and the uncertainty about the ability of Asian markets to export sufficient quantities of rice led the West African countries to look for other sources of rice supply. It entails search costs for importers and these costs do not exist in periods of low world price of rice.

Imperfect competition in the processing/distribution chain is frequently reported as a major source of asymmetric price transmission. If some agents have the ability to influence directly or indirectly market prices, they may respond more quickly to shocks that reduce their marketing margins than to shocks that raise them. Imperfect competition may refer to the exercise of market power by a small group of middlemen. In Mali and Senegal, rice imports are highly concentrated among few actors. Two or three main importers make up two-third of all imports in Mali (Baris *et al.*, 2005) while 66 percent of all rice imports flow through only 4 importers in Senegal (USAID, 2009c). The high concentration in rice imports may result in non-competitive situations and asymmetric price transmission. At the wholesale level, margins are the result of what could be described as competitive collusion: wholesalers agree to a standard mark-up that is small and driven by a high turnover strategy. As pointed out by Meyer and Von Cramon-Taubadel (2004), market power can lead to positive or negative asymmetry.

Lastly, asymmetric price adjustment may be caused by political intervention in the form of price support or marketing quotas. Although most West African countries have officially stopped intervening in rice production and marketing following the structural adjustment reforms of the eighties and nineties, governments continue to intervene. In response to the 2008 crisis, the Senegalese government removed temporarily custom duties on rice imports while the Government of Mali grants a temporary VAT exemption for imported rice (Mendez del Villar *et al*., 2010). In addition, a price control has been imposed over imported rice both in Mali and Senegal in 2008.

1.3. Model for measuring price transmission

1.3.1. Cointegration analysis

The first step of the analysis consists in determining whether price series are cointegrated. The Johansen cointegration test is applied to examine whether long-run equilibrium exists between the world price of rice and the domestic prices of local and imported rice.

The long run relationship is given as:

$$P^{D}_{t} = \alpha_0 + \alpha_1 P^{W}_{t} + \mu_t \qquad (1)$$

where P^{D}_{t} is the price in domestic market and P^{w}_{t} the world price of rice. P^{D}_{t} may either be the domestic price of imported rice or the domestic price of local rice. If μ_t is stationary, then market prices are said to be cointegrated. Co-integration implies that prices move together in the long run, although in the short run they may drift apart.

If P^{D}_{t} and $P^{w}t$ are co-integrated we can estimate the following error correction model:

$$\Delta P^{D}_{t} = \beta_0 + \beta_1 \mu_{t-1} + \sum_{i=1}^{p} \lambda_i \Delta P^{W}_{t-i} + \sum_{i=1}^{p} \delta_i \Delta P^{D}_{t-i} + \varepsilon_t \qquad (2)$$

μ_{t-1} is the lagged value of the residual derived from equation (1) and ε_t is a white noise. The error correction coefficient (β_1) measures the speed of adjustment.

In the standard model of cointegration, the autoregressive process follows a linear AR model. An implicit assumption is that the adjustment to equilibrium is a constant proportion of the error regardless of the size of this deviation. Recent research has recognized that the speed of adjustment may depend on the magnitude of the deviation. Large shocks may imply a different response than small shocks. The autoregressive process may be non-linear due to the presence of asymmetric costs of adjustment, transactions costs, and other forms of rigidities. Then the adjustment process can be represented through threshold autoregressive (TAR) model in which the speed of adjustment to equilibrium switches depending on the magnitude of the deviation.

1.3.2. Estimating a TAR model

Threshold autoregressive models (TAR) consist of m, AR(p) parts where one process changes to another according to the value of an observed variable, a threshold. TAR models are usually referred to as TAR (m,p) where p is the autoregressive order in each regime. The simplest class of TAR models is the Self Exciting Threshold Autoregressive (SETAR) models of order p introduced by Tong (1983) and specif ed by the following equations:

$$\mu_t = \begin{cases} \omega^m + \sum_{i=1}^{p} v_i^m \mu_{t-i} + \varepsilon_t^m & \text{if } \mu_{t-d} \geq \theta_{m-1} \\ \dots & \text{if } \theta_{m-1} \geq \mu_{t-d} \geq \theta_{m-2} \\ \omega^2 + \sum_{i=1}^{p} v_i^2 \mu_{t-i} + \varepsilon_t^2 & \text{if } \theta \dots \geq \mu_{t-d} \geq \theta \dots \\ \omega^1 + \sum_{i=1}^{p} v_i^1 \mu_{t-i} + \varepsilon_t^1 & \text{if } \theta_1 \geq \mu_{t-d} \end{cases} \tag{3}$$

where m is the number of regimes separated by m-1 thresholds: θ_1 to θ_{m-1}. $\omega^1 \dots \omega^m$ are the intercepts in each regime. d is the delay of the transition variable and μ_{t-d} is the transition variable.

The SETAR model is a special case of the TAR model where the threshold variable is a certain lagged value of the series itself, an endogenous variable. The main problems in estimating SETAR models are the selection of the correct order of the model and the identif cation of threshold values and delay parameters. The lag order is selected prior to building a nonlinear model, using suitable information criterion. The Akaike information criterion is used here. The estimation procedure of the delay parameter is done for each potential value of the delay with $d \leq p$ (Ben Salem and Perraudin, 2001). The model that yields the smallest residual sum of squares gives the most consistent estimate of the delay parameter.

SETAR models with one or two thresholds:

We estimate a SETAR model with one or two thresholds. The SETAR (2, p) model posits that the cointegration dynamics are different for deviations below or above the threshold θ.

The SETAR (2, p) model takes the form:

$$\mu_t = \begin{cases} \omega^2 + \sum_{i=1}^{p} v_i^2 \, \mu_{t-i} + \varepsilon_t^2 & \text{if } \mu_{t-d} > \theta \\ \omega^1 + \sum_{i=1}^{p} v_i^1 \, \mu_{t-i} + \varepsilon_t^1 & \text{if } \mu_{t-d} \leq \theta \end{cases} \tag{4}$$

The corresponding error correction model is given by:

$$\Delta P^D_t = \begin{cases} \rho^2 + \beta^2 \mu_{t-1} + \sum_{i=1}^{p} \lambda_i^2 \, \Delta P^W_{t-i} + \sum_{i=1}^{p} \delta_i^2 \Delta P^D_{t-i} + \varepsilon_t^2 & \text{if } \mu_{t-d} > \theta \\ \rho^1 + \beta^1 \mu_{t-1} + \sum_{i=1}^{p} \lambda_i^1 \, \Delta P^W_{t-i} + \sum_{i=1}^{p} \delta_i^1 \Delta P^D_{t-i} + \varepsilon_t^1 & \text{if } \mu_{t-d} \leq \theta \end{cases} \tag{5}$$

The SETAR (3, p) model is easier to interpret as the outer regime correspond to large deviations from the long-run equilibrium. The inner regime can be interpreted as containing the small deviations from the long-term equilibrium that are not leading to a price adjustment. Goodwin and Piggott (2001) call this interval the 'neutral band'. This neutral band may result from the existence of transaction costs. Trade may be profitable only outside the band when the transaction costs are lower than the price difference.

The SETAR(3,p) takes the form:

$$\mu_t = \begin{cases} \omega^3 + \sum_{i=1}^{p} v_i^3 \, \mu_{t-i} + \varepsilon_t^3 & \text{if } \mu_{t-d} > \theta_2 \\ \omega^2 + \sum_{i=1}^{p} v_i^2 \, \mu_{t-i} + \varepsilon_t^2 & \text{if } \theta_1 < \mu_{t-d} \leq \theta_2 \\ \omega^1 + \sum_{i=1}^{p} v_i^1 \, \mu_{t-i} + \varepsilon_t^1 & \text{if } \mu_{t-d} \leq \theta_1 \end{cases} \tag{6}$$

The corresponding error correction model can be written as:

$$\Delta P^D_t = \begin{cases} \rho^3 + \beta^3 \mu_{t-1} + \sum_{i=1}^{p} \lambda_i^3 \, \Delta P^W_{t-i} + \sum_{i=1}^{p} \delta_i^3 \Delta P^D_{t-i} + \varepsilon_t^3 & \text{if } \mu_{t-d} > \theta_2 \\ \rho^2 + \beta^2 \mu_{t-1} + \sum_{i=1}^{p} \lambda_i^2 \, \Delta P^W_{t-i} + \sum_{i=1}^{p} \delta_i^2 \Delta P^D_{t-i} + \varepsilon_t^2 & \text{if } \theta_1 < \mu_{t-d} \leq \theta_2 \\ \rho^1 + \beta^1 \mu_{t-1} + \sum_{i=1}^{p} \lambda_i^1 \, \Delta P^W_{t-i} + \sum_{i=1}^{p} \delta_i^1 \Delta P^D_{t-i} + \varepsilon_t^1 & \text{if } \mu_{t-d} \leq \theta_1 \end{cases} \tag{7}$$

1.3.3. Testing for threshold cointegration

Before estimating a SETAR model, we test for the existence of threshold-type non linearity first following Hansen's procedure (1997). The advantage of Hansen's procedure is that the thresholds can be estimated together with other model parameters and valid confdence intervals can be constructed for the estimated thresholds.

To test the null hypothesis of SETAR (1, p) against the alternative hypothesis of SETAR (2, p), the likelihood ratio test assuming normally distributed errors can be used:

$$F_{(12)} = n\left(\frac{RSS_1 - RSS_2}{RSS_2}\right)$$

where RSS_1 is the residual sum of squares from SETAR(1,p) and RSS_2 is the residual sum of squares from SETAR(2,p) given the threshold θ.

Since the threshold θ is usually unknown, Hansen (1997) suggests to compute the following sup-LR test: $F_s = \sup F(\theta)$; $\theta \in \Gamma$ by searching over all the possible values of the threshold variable. In practice, to ensure the model is well identified, a certain percentage of Γ at both ends are trimmed and not used.[2] If ε_t is not independent and identically distributed (i.i.d), the F test needs to be replaced by heteroskedasticity consistent Wald or Lagrange multiplier test.

As the transition and threshold parameters appear only under the alternative hypothesis, testing for threshold nonlinearity is a complicated issue. This problem is known as the nuisance parameters problem (Davies, 1987). To deal with the nuisance parameter problem, Hansen shows that the asymptotic distribution may be approximated by a bootstrap procedure.

In the remainder of the paper, we test the null hypothesis of one regime against two, then the null of one regime against three and finally the null of two regimes against three. This strategy allows to determinate the number of thresholds.

1.4. Data and estimation

1.4.1. Data and stationary tests

The empirical analysis utilizes monthly retail prices of local and imported rice in three West African countries namely: Senegal, Mali and Chad. Thailand is the major world rice exporter and Senegal and Mali are principally buyers of 100 percent broken rice (USAID, 2009a), so we use the export price of the 100% broken rice in Bangkok as an estimate of the relevant world price. The period of study differs according to the data availability (see Table 1.1).

[2] In the following estimations, 15% of extreme values are excluded.

Domestic price data are coming from the World Food Program[3] and the international price of rice is coming from the Osiriz Infoarroz database[4].

Since the three countries considered are small in terms of rice supply and demand, we make the hypothesis that the prices of rice in these countries have no effect on the price of rice in land and we examine exclusively the transmission of the international price of rice to domestic prices.

Table 1.1: Prices characteristics

Country	Market	Price type	Period of study	No Obs.	Max	Min	Mean
Senegal	Dakar	Imported rice	2000.01 - 2010.12	132	450	163	245
		Local rice	2000.01 - 2010.04	124	377	146	205
Mali	Bamako	Imported rice	1993.02 - 2011.11	216	400	167	277
		Local rice	1993.02 - 2009.01	192	406	151	264
Chad	N'Djamena	Imported rice	2003.10 - 2011.11	98	618	350	434
		Local rice	2003.10 - 2011.11	98	588	259	388
Thailand	Bangkok	FOB price	1993.01 - 2012.02	230	432	54	175

Prices are expressed in CFA Francs /Kg

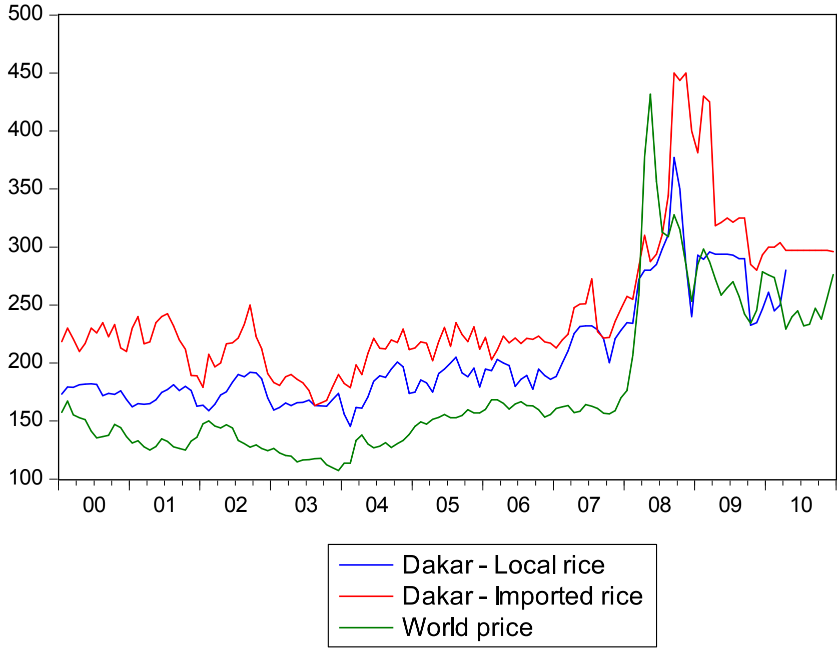
For each market, the time series of the domestic retail prices and the international price of rice are displayed in Figure 1.1. For each country, domestic prices of local and imported rice are well above the level of the international price of rice excepted in early 2008 when the international price of rice sharply increased. The difference between the price of the Thai export price and the domestic price of imported rice can be attributed to the costs of freight transport and insurance, importers and retailers margins, custom duties and handling charges.

Domestic prices of local rice are on average below the domestic prices of imported rice. The price discount between imported and local rice is higher in Dakar and N'Djamena than in Bamako. Local rice has to overcome a quality image problem in most West African markets (except in Mali), and in such cases, a price discount may be needed to entice consumers. The situation is different in Mali where consumers prefer local rice making the price difference between local and imported rice lower than in Senegal and Chad. Considering that rice consumption in Mali is mainly supplied by local rice, the strong preference for local rice results in larger seasonal variation in the price of local rice in Mali compared to the other countries. Occasionally, the government of Mali grants temporary VAT exemption on rice

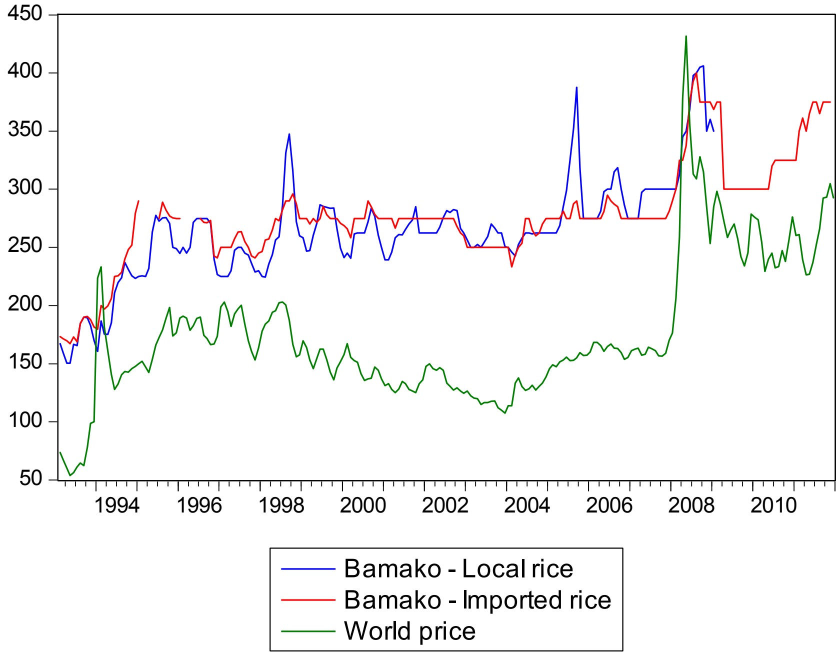
[3] See VAM Food and Commodity Prices Data Store : http://foodprices.vam.wfp.org/Default.aspx
[4] See : http://www.infoarroz.org

imports to stabilize the price of local rice during the hunger season through increased imports of rice.

Figure 1.1: Prices in CFA Francs per kilogram

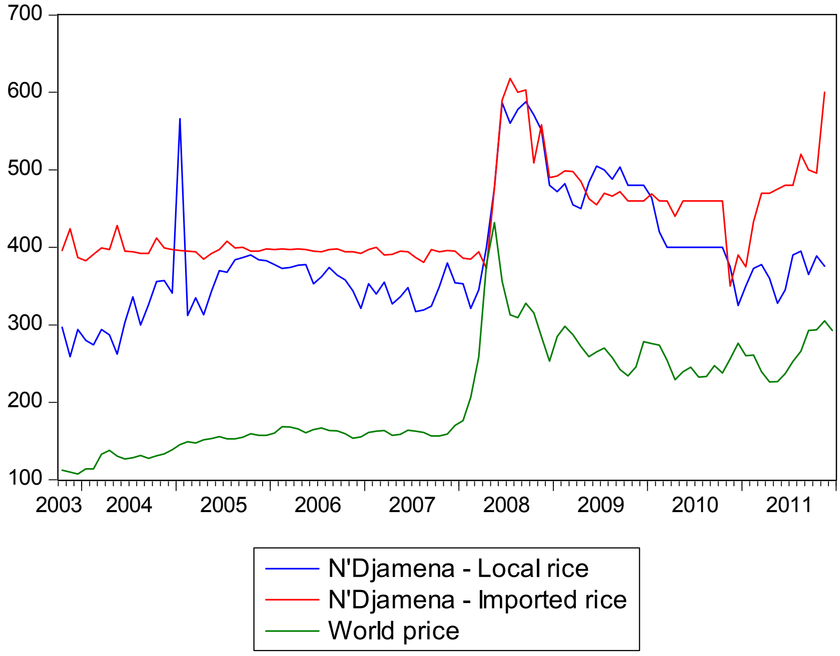


The world price refers to the Thai export price



The world price refers to the Thai export price

Figure 1.1 continued



The world price refers to the Thai export price

The hypothesis that the price series are non-stationary is tested using the augmented Dickey-Fuller (ADF) test. ADF tests confirm the presence of a unit root in all price series. Stationarity cannot be rejected for all the differenced series indicating that the price series are I(1) (Table 1.2).

Table 1.2: Results of ADF unit root tests

			Dakar			**Bamako**			**N'Djamena**			**World price**	
			ADF	Prob		ADF	Prob		ADF	Prob		ADF	Prob
IR	Level	[3]	-2.57	0.30	[3]	-3.25	0.08	[3]	-3.04	0.13	[2]	-1.94	0.31
	First diff,	[1]	-9.08	0.00	[1]	-6.79	0.00	[1]	-9.63	0.00	[1]	-7.49	0.00
LR	Level	[3]	-2.71	0.24	[3]	-3.15	0.10	[2]	-2.43	0.14			
	First diff,	[1]	-6.00	0.00	[1]	-3.71	0.00	[1]	-13.65	0.00			

IR: Imported rice; LR: Local rice;
[1]: Model without constant nor determinist trend, critical value = - 1.95; [2]: Model with constant without determinist trend, critical value = -2.89; [3]: Model with constant and determinist trend, critical value = -3.45

1.4.2. Cointegration tests

Johansen cointegration tests indicate the existence of a cointegration relationship among all pairs of prices at 10% level of confidence (Table 1.3). It indicates that there exists a long-run relationship between the domestic prices of local and imported rice and the world price of rice. In the short run, the domestic prices may drift apart, as shocks affecting the world price of rice may not be instantaneously transmitted to domestic prices. However these divergences are transitory and the world price of rice and the domestic prices of rice move together in the long-run. The null hypothesis of no-cointegration is not rejected in two cases at 5% level. As the test statistics are close to the 5% critical values, we still proceed to the threshold cointegration tests for all the market pairs. Lag orders for cointegration tests are selected using Akaike Information Criteria (AIC). The long term relationship is then estimated using ordinary least squares (Table A2).

Table 1.3: Johansen cointegration tests

		Hyp	Trace statistic	Critical value 5%	Maximum Eigen Value	Critical value 5%
Dakar	Imported rice	None	68.18***	15.49	67.26***	14.26
		At most 1	0.92	3.84	0.92	3.84
	Local rice	None	24.03*	25.87	17.72*	19.39
		At most 1	6.31	12.52	6.31	12.52
Bamako	Imported rice	None	25.49*	25.87	18.99*	19.39
		At most 1	6.49	12.52	6.49	12.52
	Local rice	None	50.64***	25.87	45.68***	19.39
		At most 1	4.97	12.52	4.96	12.52
N'Djamena	Imported rice	None	19.93**	15.49	16.94**	14.26
		At most 1	2.99	3.84	2.99	3.84
	Local rice	None	31.22***	25.87	25.96***	19.39
		At most 1	5.26	12.52	5.26	12.52

* indicates significance at 10% level; ** at 5% level and *** significant at 1% level of confidence.

1.4.3. Testing for linearity

Hansen's tests are conducted for assessing the presence of regime-specif c nonlinearities within the cointegration relationships of the market pairs. We follow Hansen's methodology (Hansen, 1999) by testing successively the null hypothesis of linearity against one threshold, the null of linearity against two thresholds and finally the null of one threshold against two. The first two tests are testing for linearity whereas the last one can be considered as a specification test. As discussed above, the tests reject H0 for large values of F_{ij}. Hansen's procedure estimates the thresholds θ and selects the delay parameter d. The results are presented in Table 1.4 and reject the null hypothesis of linearity for all pairs of prices. There are only two pairs for which the null of one threshold is rejected in favour of the two thresholds hypothesis. In those two cases, the two thresholds values are displayed.

Table 1.4: Hansen's tests of linearity

				Testing SETAR(1) against SETAR(2) [a]			Testing SETAR(1) against SETAR(3) [a]				Testing SETAR(2) against SETAR(3) [a]			
		p	d	F12	P.Value [b]	θ	F13	P.Value [b]	θ_1	θ_2	F23	P.Value [b]	θ_1	θ_2
Dakar	IR	4	3	30.92	0.00	18.68	73.70	0.00	-15.98	18.68	34.46	0.00	-15.98	18.68
	LR	6	4	36.81	0.00	5.39	67.85	0.00	-7.93	5.39	23.66	0.18		
Bamako	IR	3	1	22.19	0.01	9.80	26.38	0.16	-18.11	9.80	3.79	0.96		
	LR	3	3	34.05	0.00	10.55	76.75	0.00	-14.53	10.55	36.18	0.00	-14.53	10.55
N'Djamena	IR	3	2	22.14	0.03	-10.66	37.60	0.09	-23.03	-0.82	12.53	0.35		
	LR	3	3	29.34	0.01	12.24	52.45	0.02	12.24	33.74	17.66	0.13		

IR: Imported rice ; LR: Local rice
[a] Testing SETAR(1) against SETAR(2) H0 : Linearity HA: One threshold
Testing SETAR(1) against SETAR(3) H0 : Linearity HA: Two threshold
Testing SETAR(2) against SETAR(3) H0 : One threshold HA: Two threshold
[b] Bootstrapped P-value for 1000 replications.
p : number of lags (the same number of lags is included in each regime)
d: delay of the transition variable
θ : the threshold value

Table 1.5 reports the results of the estimation of the SETAR models. The pairs imported rice/Dakar versus the Thai export price and local rice/Bamako versus the Thai export price are the only two pairs characterized by three regimes autoregressive processes. Regime 3 corresponds to large positive deviations that exceed the higher threshold while regime 1 corresponds to large negative errors that are below the lower threshold. In the two cases with three regimes, the thresholds are not symmetric around zero. In Dakar, the positive deviations from the long term equilibrium have to reach a higher level than the negative deviations before leading to a change in the domestic price of imported rice. The opposite is true in Bamako where the negative threshold is larger than the positive one. In the case of Bamako, the higher and the lower regimes contain approximately the same number of observations while in the Dakar case, the lower regime includes a larger number of observations than the higher regime.

Positive deviations from the long-run equilibrium are due to the decrease of the international price whereas negative deviations from the long-run equilibrium result from the world rice price increase.

The Figures A1 and A2 in appendix illustrate the timing of jumps among the regimes for respectively the imported rice in Dakar and the local rice of Bamako. In the case of Dakar, one third of the observations included in the upper regime take place between December 2008 and June 2009 corresponding to the decline in the international price of rice that followed the 2008 price spike. Even if the regime 2 is dominant, jumps between regimes are very common reflecting the high degree of instability of the imported price of rice in Dakar. Similarly jumps between regimes occur very often in the case of Bamako suggesting that large negative/positive deviations from the long run equilibrium are quickly corrected.

Table 1.5: Estimates of the SETAR models

	Dakar - Imported rice						Dakar - Local rice			
	$\mu_{t-3} \leq -15.98$		$-15.98 < \mu_{t-3} \leq 18.68$		$\mu_{t-3} > 18.68$		$\mu_{t-4} \leq 5.39$		$\mu_{t-4} > 5.39$	
	ν_3	s.e	ν_2	s.e	ν_1	s.e	ν_2	s.e	ν_1	s.e
Const.	-7.76*	(4.65)	-1.48	(1.78)	-23.91***	(6.44)	-1.78	(1.86)	-11.82***	(3.21)
μ_{t-1}	0.54***	(0.14)	1.21***	(0.12)	0.57***	(0.14)	0.64***	(0.13)	0.91***	(0.13)
μ_{t-2}	-0.03	(0.20)	-0.04	(0.16)	-0.15	(0.15)	0.12	(0.20)	-0.15	(0.14)
μ_{t-3}	0.13	(0.20)	-0.11	(0.22)	0.85***	(0.19)	0.19	(0.16)	-0.15	(0.16)
μ_{t-4}	-0.61***	-0,14	-0.11	(0.11)	-0.33*	(0.14)	-0.57***	(0.18)	0.79***	(0.20)
μ_{t-5}							-0.06	(0.14)	-0.73***	(0.17)
μ_{t-6}							0.03	(0.12)	0.62***	(0.15)
Nb of obs	29		82		21		77		47	

Standard error in parentheses. * indicates significance at 10% level; ** at 5% level and *** significant at 1% level of confidence.

	Bamako - Imported rice				Bamako - Local rice					
	$\mu_{t-1} \leq 9.80$		$\mu_{t-1} > 9.80$		$\mu_{t-3} \leq -14.53$		$-14.53 < \mu_{t-3} \leq 10.55$		$\mu_{t-3} > 10.55$	
	ν_2	s.e	ν_1	s.e	ν_3	s.e	ν_2	s.e	ν_1	s.e
Const.	-1.90	(1.20)	13.18***	(3.11)	2.17	(3.46)	0.52	(1.21)	0.18	(3.356)
μ_{t-1}	0.91***	(0.09)	0.61***	(0.15)	0.94***	(0.12)	1.79***	(0.14)	0.67***	(0.10)
μ_{t-2}	-0.24*	(0.12)	-0.22	(0.15)	-0.17	(0.17)	-0.90***	(0.24)	-0.03	(0.13)
μ_{t-3}	0.11	(0.09)	-0.06	(0.11)	-0.04	(0.15)	0.25	(0.23)	-0.14	(0.11)
Nb of obs	135		81		50		93		49	

Standard error in parentheses. * indicates significance at 10% level; ** at 5% level and *** significant at 1% level of confidence.

	N'Djamena - Imported price				N'Djamena - Local rice			
	$\mu_{t-2} \leq -10.66$		$\mu_{t-2} > -10.66$		$\mu_{t-3} \leq 12.24$		$\mu_{t-3} > 12.24$	
	ν_2	s.e	ν_1	s.e	ν_2	s.e	ν_1	s.e
Const.	-16.82	(10.28)	13.92	(8.45)	-8.08	(5.98)	18.79	(12.04)
μ_{t-1}	1.06***	(0.26)	0.09	(0.11)	0.77***	(0.12)	-0.08	(0.16)
μ_{t-2}	-0.73*	(0.31)	0.04	(0.12)	-0.03	(0.12)	0.78***	(0.22)
μ_{t-3}	-0.04	(0.16)	0.13	(0.14)	-0.26	(0.15)	-0.24	(0.17)
Nb of obs	50		48		64		34	

Standard error in parentheses. * indicates significance at 10% level; ** at 5% level and *** significant at 1% level of confidence.

1.4.4. Threshold error correction models

As Hansen's tests suggest that the market pairs follow a nonlinear relationship, we use threshold error correction models to estimate the speed at which domestic prices returns to equilibrium after a deviation has occurred. The estimated values of the error correction terms of each regime and the Wald tests of equality of the coefficients are presented in Table 1.6.

Model (5) and (7) allow all the parameters of the model to switch between regimes. We could as well use a more parsimonious specification where only the error correction terms vary with the regimes. Hence, we test the equality of the error correction terms across regimes (Table 1.6) as well as the equality of the short and long-run parameters across regimes (not reported here). According to these results, we estimated models that allow asymmetries of every parameter or of only the error correction term. The estimated model including the imported rice in Dakar is the only one for which the Wald tests reject by a majority the equality of the short and long-run parameters across regimes. Hence, only the model of the imported rice in Dakar allows asymmetries for all the parameters to be captured.

Table 1.6: Results of asymmetric error correction models

		Error correction terms			Wald tests of equality of the error correction terms [a]		
		β_1	β_2	β_3	$\beta1 = \beta2\ (=\beta3) = 0$	$\beta1 = \beta2\ (= \beta3)$	$\beta1 = \beta3$
		(1)	(2)	(3)	(4)	(5)	(6)
Dakar	Imported rice	-0.90***	-0.05	-0.16**	16.94	13.26	23.71
		(0.13)	(0.16)	(0.07)	[0.00]	[0.00]	(0.00]
	Local rice	-0.18)	-0.36*		1.7	1.71	
		(0.13)	(0.2)		[0.18]	[0.19]	
Bamako	Imported rice	-0.11**	-0.14		6.4	0.07	
		(0.05)	(0.1)		[0.00]	[0.79]	
	Local rice	-0.19***	0.07	-0.54***	13.95	11.91	8.76
		(0.07)	(0.08)	(0.1)	[0.00]	[0.00]	(0.00]
N'Djamena	Imported rice	-0.39***	-0.29		4.28	0.49	
		(0.13)	(0.18)		[0.02]	[0.49]	
	Local rice	-0.21	-0.56***		8.08	1.82	
		(0.13)	(0.19)		[0.00]	[0.18]	

White Heteroscedasticity-consistent standard error in parentheses.
* indicates significance at 10% level; ** at 5% level and *** significant at 1% level of confidence.
[a:] Entries in the last three columns are the sample F statistics for the null hypothesis of equality of the coefficients. Significance levels are in square bracket below.

The Wald tests of equality of the error correction terms (Table 1.6, columns 4 to 6) do not reject the null hypothesis of linear adjustment in four cases out of six: Dakar (local rice), Bamako (imported rice) and N'Djamena (imported and local rice).

In the case of the local rice in Dakar, the Wald test even rejects the hypothesis of cointegration. This result is not surprising considering that the Johansen's test was not significant at 5% level. The price of local rice in Dakar is not linked with the world price of rice by a long run relationship. This can be attributed to the small quantities of local rice marketed in Dakar and to the low awareness of urban consumers that quality local rice even exists (Rizotto and Demont, 2010). Many Senegalese still consider local rice as inferior in quality to imported rice suggesting that there is very little substitutability between imported and local rice. In addition, local rice may be available only seasonally; local rice is rarely available in domestic markets from November to January (USAID, 2009c).

In the cases of Bamako (imported rice) and N'Djamena (imported and local rice), the adjustment process between the domestics prices and the world market appears to be linear (Table 1.6, column 5). It means that a constant proportion of the error is corrected each month regardless of the size of this deviation. Positive and negative deviations from the long-run equilibrium are transmitted to the same extent and at the same speed. Table 1.7 provides the estimation of the error correction terms in the three cases in which threshold cointegration is rejected. The estimated error correction models suggest that the adjustment processes are relatively fast in N'Djamena with about 33 percent of divergence from the long run equilibrium being corrected each month in the case of the imported rice and 42 percent in the case of the local rice. The adjustment is slower in Mali; the price of imported rice in Bamako will fully adjust to changes in the international price in a period equal to almost 8 months. Such a low rate of adjustment can be attributed to policies including temporary VAT/customs tariff exemptions on rice imports and national security stock of rice management implemented by the government to ensure food security.

Table 1.7: Transmission of world price of rice to domestic markets in Mali, Senegal and Chad

				Speed of adjustment			
				Linear adjustment	Non-linear adjustment		
Location	Commodity	Long term relationship?	Asymmetric transmission?		Down	Middle	Up
Senegal - Dakar	Imported rice	Yes	Yes		-0.90***	-0.05	-0.16***
Senegal - Dakar	Local rice	No	No				
Mali - Bamako	Imported rice	Yes	Yes	-0.13***			
Mali - Bamako	Local rice	Yes	No		-0.19***	0.07	-0.54***
Chad - N'Djamena	Imported rice	Yes	No	-0.33***			
Chad - N'Djamena	Local rice	Yes	No	-0.42***			

* indicates significance at 10% level; ** at 5% level and *** significant at 1% level of confidence.

Asymmetry is not rejected for the pairs of markets characterized by three regimes of adjustment. The Wald tests reject the hypotheses of linear and symmetric adjustment in two cases: Dakar (imported rice) and Bamako (local rice). The imported rice and the local rice are the main staple food respectively in Senegal and Mali. The prices of these two staple cereals appear to be affected by large fixed transactions costs. Price deviations contained in the interval [θ1, θ2] are too small compared to the adjustment costs that they will not lead to a price adjustment. Indeed the coefficients of the error correction terms are not significant in regime 2 in both cases.

In the case of Bamako, there appears to be adjustment both in periods of large positive and negative change from the long term equilibrium. The speed of adjustment is larger in the upper regime. The price of local rice is Bamako will return more quickly to the value consistent with the long-run relationship to the world price in case of positive deviations than in case of negative deviations from the long term equilibrium. The positive deviations from the long term equilibrium have to reach a level of 10.55 CFA Francs per kilo before leading to a change in the domestic price of local rice.

Positive deviations from the long-run equilibrium are caused by a decrease in the world price of rice. Hence, the adjustment occurs more rapidly when the domestic price of local rice drift too far away from the long term equilibrium following a drop in the world price of rice. Conversely, the domestic price of local rice increased slowly in response to a world price spike suggesting that price of local rice in Bamako cannot increase excessively. Indeed, the Government of Mali intervenes regularly on the market to prevent high increase in the domestic prices of local rice through temporary exemption on customs tariffs and VAT. The government of Mali exempted 40 000 metric tons (MT) of rice from VAT in 2002, 201,194 MT in 2005, 5,504 MT in 2007 and 105,789 MT in 2008 (USAID, 2009b). These exemptions may discourage private actors to invest in the domestic market channel as they provide regular opportunities for wholesalers to have access to large quantities of cheap imported rice. In this way, exemptions have a strong effect on the prices of local rice. This is worth noting that the surges in domestic prices of local rice are not necessarily related to increase in the world price. Indeed in 1998 and 2005, the price of local rice increased due to a tight supply situation at the regional level rather than following the world price trend. Whatever the causes may be, government interventions allowing massive imports of cheap rice prevent the price of local rice to increase excessively compared to the world price of rice.

For Dakar, error correction terms are significant in the outer regimes but the coefficient is larger in the lower regime. Negative deviations from the long term equilibrium have to reach almost 16 CFA Francs per kilo before leading to a change in the domestic price of imported rice. Large negative deviations result from large increases in the world price of rice. It suggests that the price of imported rice in Dakar adjust very well to changes in the international price when the world price increases. This result is consistent with the high degree of dependency on rice imports in Dakar. The domestic price of imported rice adjusts well to an increase in the world price of rice as consumers are reticent to substitute rice with other grains. The asymmetric adjustment may also reflect a situation of market power in the distribution chain or high fixed costs in the distribution industry.

1.5. Conclusion

Our results indicate that the world price of rice and the domestic prices of imported and local rice in Senegal, Mali and Chad are integrated in the long-run, with the exception of the local rice in Dakar. The changes affecting the world price of rice do not have any impact on the price of local rice in Dakar. This may be due to the low quality of local rice in comparison to the imported rice. Structurally, the market for local rice is essentially a thin residual market. Consumers may be unwilling to substitute from imported rice to local rice. Since 2008, the Senegalese government has launched national programs to boost local rice production in order to achieve complete food self-sufficiency by 2015. Achieving rice self-sufficiency requires greater recognition that the rice market is not driven exclusively by price. Local rice must improve its awareness among consumers and make significant efforts in improving appearance, packaging and cleanliness in order to compete more effectively with imported rice.

We find that the domestic price of imported rice in Bamako and the domestic prices of imported and local rice in N'Djamena are integrated with the world price of rice. In those three cases, domestic prices are affected in similar ways by changes in the world price regardless of the size of the deviation. For the Chadian rice markets, the adjustment process is fast; rice prices in Ndjamena adjust fully to price changes in the international market in two or three months. Conversely, it would take about height months for prices of imported rice in Bamako to fully adjust to a change in the international rice price, reflecting the policies implemented by the government to ensure food security.

The price of local rice in Bamako responds asymmetrically to large changes from the long term equilibrium. Our results provide evidence that increases in the world price are incompletely and slowly passed-through to the domestic market, as compared to decreases. The negative asymmetric price transmission can be attributed to governmental interventions intended to protect consumers. The government intervenes regularly through tax exemptions and food security stock management as to prevent local price to increase excessively. If this policy favors consumers, it may discourage private actors to invest in the domestic market channel. The relationship between the world price of rice and the domestic price of local rice in Bamako may change in the coming years under the influence of the Rice Initiative launched in 2008 by the Malian Government. This initiative aims at boosting rice production through various means including subsidies for rice production so as to make the country a net exporter of rice.

The price of imported rice in Dakar is not affected by small changes in the world price of rice. High transaction costs of importing rice and moving it from the port to consumption centers are likely to exist. Price deviations have to exceed a certain threshold before leading to a change in the domestic price of imported rice. The price of imported rice in Dakar is more responsive to the world price of rice spike than to the world price drop. This positive asymmetric price transmission is likely to reflect a situation of market power in the distribution industry.

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Appendix A:

Table A1: Area Harvested, Production, Imports and Consumption

	Area Harvested (1000 HA)			Milled Production (1000 MT)			Imports (1000 MT)			Consumption (1000 MT)		
	Chad	**Mali**	**Senegal**	**Chad**	**Mali**	**Senegal**	**Chad**	**Mali**	**Senegal**	**Chad**	**Mali**	**Senegal**
2001	51	350	95	47	492	140	2	39	735	49	531	850
2002	90	365	88	87	637	159	0	76	916	87	713	890
2003	105	370	76	92	462	112	0	175	875	92	637	930
2004	95	385	87	86	620	150	0	156	825	86	776	980
2005	95	370	83	62	475	151	19	130	750	81	605	982
2006	110	390	95	90	624	181	14	125	660	104	749	981
2007	80	414	97	70	684	144	15	105	675	85	789	950
2008	80	377	99	67	703	118	15	100	820	82	803	940
2009	111	433	125	104	860	277	16	100	683	120	945	980
2010	133	580	131	79	1027	345	20	120	690	99	1 075	1055
2011	154	686	147	125	1500	408	10	80	775	135	1400	1130
2012	165	500	110	103	1132	299	20	150	1150	123	1420	1250

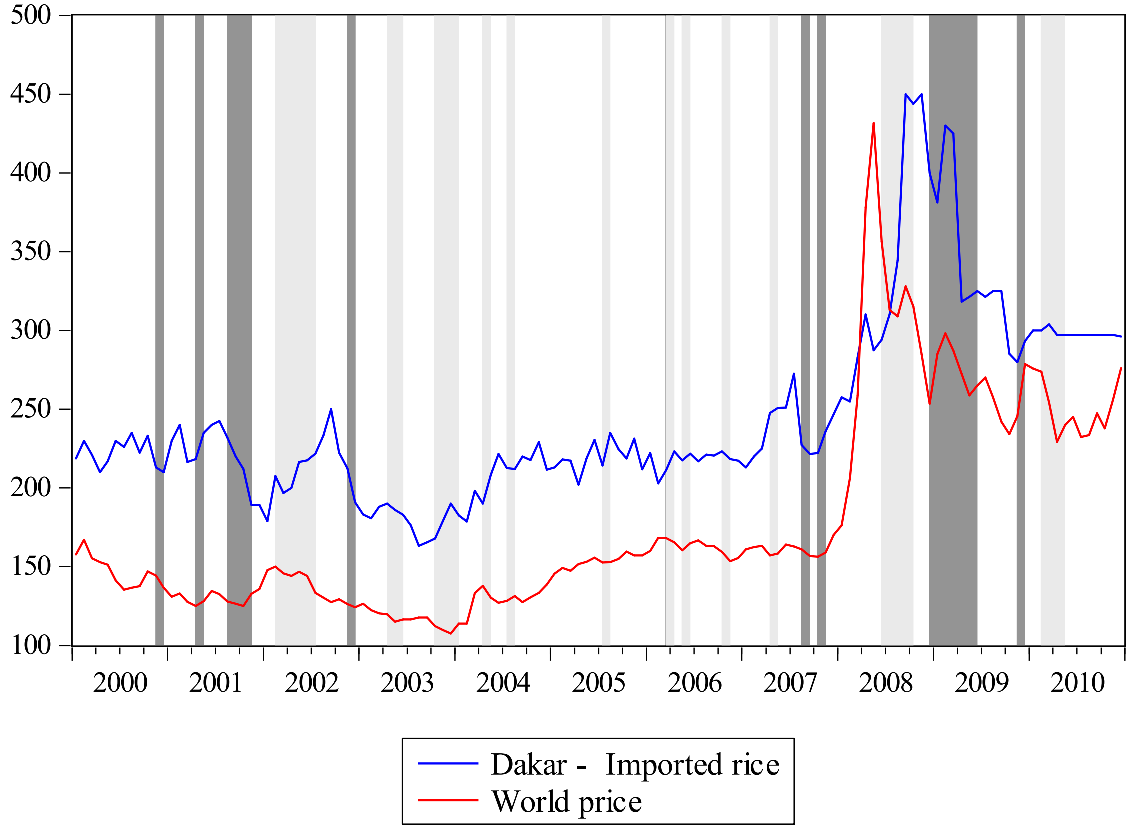
Source : USDA statistics (http://www.fas.usda.gov/psdonline/)

Table A2: Estimation of the long-term relationship

		α0	α1	α2	Adj R²	SBC	AIC
Dakar	IR	108.44 (13.1)	0.77*** (17.5)		0.70	9.86	9.82
	LR	64.8 (9.21)	0.50*** (13.24)	0.37*** (5.55)	0.84	8.78	8.74
Bamako	IR	177.05 (38.72)	0.37*** (12.15)	0.30*** (10.65)	0.74	9.08	9.03
	LR	157.76 (26.72)	0.37*** (10.21)	0.49*** (14.7)	0.71	9.28	9.23
N'Djamena	IR	308 (24.33)	0.61*** (10.46)		0.53	10.25	10.20
	LR	304.85 (8.20)	1.02*** (8.31)	-0.72*** (-2.43)	0.52	10.88	10.8

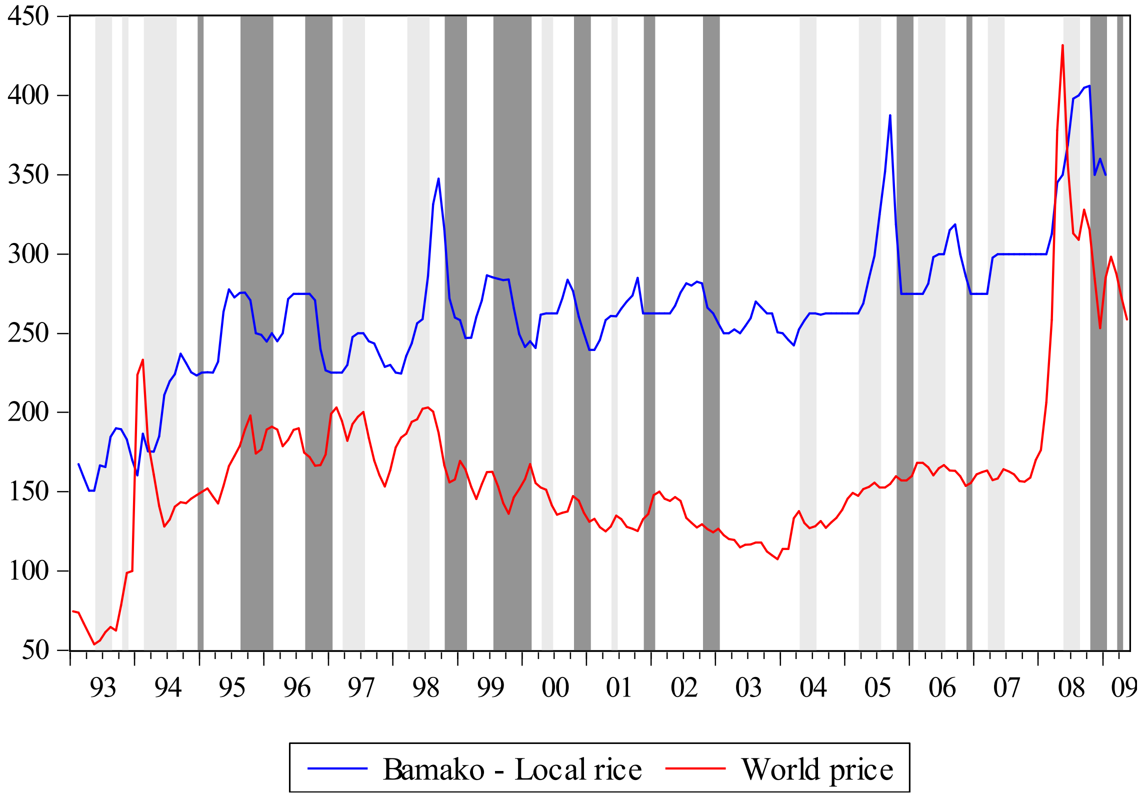
The estimated long run relationship can be written as: $P^D_t = \alpha_0 + \alpha_1 P^W_t + \alpha_2 T_t + \mu t$ where T is the time trend and is included only when the variable is significant;
IR: Imported rice; LR: Local rice; AIC: Akaike criterion; SBC: Schwartz criterion; t-Statistic between parentheses. * indicates significance at 10% level; ** at 5% level and *** significant at 1% level of confidence.

Figure A1: Timing of regime switching - Dakar imported rice



The period corresponding to regime 3 are shaded in dark grey whereas the periods corresponding to regime 1 are in light grey.

Figure A2: Timing of regime switching - Bamako local rice



The period corresponding to regime 3 are shaded in dark grey whereas the periods corresponding to regime 1 are in light grey.

Chapter 2

Food markets and barriers to regional integration in West and Central Africa[†]

[†] This chapter is a version of a paper co-authored with Alberto Portugal-Perez within the context of the project 'Integrating Regional Markets in Food Staples in West Africa: An Agenda for Evidence Based Policy Analysis' initiated by the World Bank.

2.1. Introduction

African countries have become increasingly dependent upon imports from the global market to meet their food needs. Since 1974, food imports have grown consistently faster than food exports and in 2008 reached a record high of USD 51 billion (FAOSTAT, 2013), yielding a deficit of about USD 31 billion. In the actual context of high world food prices, Africa's food import dependency is a matter of great concern. However, as the World Bank (2012) shows in its report, '*Africa Can Help Feed Africa'*, Africa has an enormous potential for boosting agricultural production. The production of food staples for growing urban markets represents the largest growth opportunity for Africa's farmers. Facilitating expansion of these markets will therefore be critical to provide the appropriate incentives to smallholders to increase investments and hence agricultural productivity.

Intra-African trade remains low in comparison with the total African trade volume. Total intra-African trade represented 11.3 percent of African trade with the world in 2011 (UNCTAD, 2013). Intra-African trade of food products has been dominated by cereals (22%) and vegetable and fruits (15%) over the period 2004-2007 (FAO, 2011). According to the World Bank, only 5% of Africa's imports of cereals come from other African countries. Although cereals are staple foods for the majority of African households, smallholders face significant challenges that hinder their participation in new marketing opportunities. Markets in the developing world are characterized by pervasive imperfections such as high transport costs between the household's village and the relevant market, lack of information on prices, non-competitive behaviour among local traders and lack of competition in the trucking sector. Additional barriers are present in the case of international trade, such as tariffs, quotas, seasonal export bans, documentary requirements, borders procedures, and other non-tariff barriers, etc. Those trade barriers reduce the incentive for farmers to invest more in improved seeds and fertilizer that would enable them to produce more.

Although West African leaders recognized the importance of improving regional integration, progress has been slow since the creation of the Economic Community of West African States (ECOWAS)[5] in 1975. The creation of the customs union within the West African Economic and Monetary Union (WAEMU)[6] in 2000 was an important step toward greater regional integration in western Africa. Agricultural products can circulate freely within ECOWAS and

[5] Today ECOWAS is a group of fifteen countries including Benin, Burkina Faso, Cape Verde, Gambia, Ghana, Guinea, Guinea Bissau, Cote d'Ivoire, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo.

[6] WAEMU is an organization of height countries : Benin, Burkina Faso, Cote d'Ivoire, Guinea Bissau, Mali, Niger, Senegal and Togo

WAEMU country members and a common external tariff is applied to imports from other countries. Government of Central African countries also committed themselves to the process of integration through the creation of a custom and monetary union, the *Communauté Economique et Monétaire d'Afrique Centrale* (CEMAC)[7].

Although the majority of instruments of trade policy have been harmonized within WAEMU and CEMAC, the implementation may vary by country. According to trade policy reviews conducted by the World Trade Organization (2010), countries like Benin, Burkina Faso and Mali do not implement the community customs code in the same way. Implementation of the unions' current trade regime remains a challenge, especially the implementation of rule of origin (Goretti and Weisfeld, 2008). In addition to the uneven application of the rules, roadblocks, customs or police checkpoints along trade corridors continue to hinder regional trade. Data collected by the West Africa Trade Hub (WATH) indicates for example that the route between Ouagadougou to Bamako has the highest density of checkpoints (around 30 stops along the 790 kilometers of the entire route) while inspections at the border between Ghana and Burkina-Faso (corridor Tema-Ouagadougou) are taking a long time: around four hours in Burkina Faso and seven hours in Ghana (West Africa Trade Hub, 2010).

Trade barriers are difficult to measure as they take many forms. This paper aims at identifying the nature of the hurdles to trade in food staples. Specifically, we analyze the impact of road infrastructure and country borders on the regional integration of food staples markets across different towns and countries in West and Central Africa. As most trade goes unrecorded by customs, we focus on relative prices and use a highly detailed database of monthly food prices at the town level. Since the seminal work of Ravallion (1986), most research studies the relationship between prices in spatially distant markets. Here, we use monthly prices on 173 markets located in 14 West African countries and 6 commodities (millet, sorghum, maize, cassava, local rice and imported rice).

Following the seminal paper of Engel and Roger (1996), a large body of literature has investigated the extent to which national borders hinder trade among industrialized countries. Most articles studying the importance of distance and of borders find a significant impact of both on price dispersion. Engel and Rogers (1996) and then Parsley and Wei (2001) find an incredibly high impact of borders on respectively the US-Canada and the US-Japan borders. Broda and Weistein (2008) explain those results by the fact that price indices rather than

[7] CEMAC is made up of six member states: Cameroon, Central African Republic, Chad, Republic of the Congo, Equatorial Guinea and Gabon

actual prices are being used. They argue that using aggregated prices mechanically increase the border effect on prices.

Very few studies examine the impact of borders in developing countries. Brenton *et al.* (2013) and Versailles (2012) find substantial distance and border effects in explaining price dispersion between East African cities. Research by Aker *et al.* (2012) on the Niger-Nigeria border suggests that a common ethnicity is associated with lower price dispersion across countries and that ethnic diversity creates an internal border within Niger.

Araujo and Brunelin (2013)'s work is the first studying the existence of a border effect within a large number of West African countries. Their results suggest that crossing the border in West Africa is costly but that the size of the border effect decreased since 2000. The paper also evidences the positive impact of belonging to an economic union on the trade of grains in West Africa. Our paper extends the work done by Araujo and Brunelin (2013) in three ways. First, we use more accurate data for distance. The road network data have been compiled by the World Bank and they provide a measure of the distance between towns in kilometers instead of relying on great circle distances[8] generated using GIS software. Second, the price dataset has extended with 30 additional markets and three commodities. Third, we estimate the effects of national borders and distance on the dispersion of price levels as well as on price volatility.

Our paper examines the price differences of agricultural products across market pairs located in the same country, as well as market pairs located in different countries. We estimate the impact of borders and road distance between markets on relative prices. After controlling for the distance as well as for market and product specific characteristics, we find that crossing a border increases food prices differences by 6 or 7 percent on average. The estimated average border effect is smaller for countries belonging to the West African Economic and Monetary Union. On average, borders increase price differences between countries within WAEMU by 5 percent, and by 8 to 10 percent when any of the countries sharing a border is not part of the WAEMU. Distance between markets also lead to large deviations from the Law of One Price (LOP); the average distance between towns in our sample (1079 km) increases price differentials by 25 percent. We estimate borders effects specific to the 24 pairs of contiguous countries in our sample. Bilateral borders leading to the largest price increase between countries are Ghana-Togo, Guinea-Senegal, Mali-Mauritania and Mauritania-Senegal.

[8] The great circle distances are computed by using the latitude and longitude of each town in a market-pair.

Countries such as Ghana, Mauritania, Chad and Togo also exhibit high price differentials between national markets that may reflect the role of distance.

Then, we test the robustness of our results by regressing two additional dependent variables, the standard deviation of the relative prices as a measure of price volatility and the half-life of shocks as a measure of shock persistence between markets, on distance, border, and market product fixed effects. Estimates confirm the positive role played by borders and distance in explaining cross-country price volatility and persistence in cross-country price differences. When estimating specific border effects in this cross-section setting, we find that Mauritania-Senegal, Mali-Mauritania and Guinea-Senegal have the largest borders, which is consistent with the panel data estimates. Conversely, the Ghana-Togo border is much smaller when using estimates in cross-section than in the panel data setting. The two estimation techniques evidence the high cost of crossing the Mauritanian, Guinean and Ghanaian borders.

The rest of the paper is organized as follows: section 2 provides the context of our study by discussing some relevant characteristics of the region, including the main zones of grain production, agricultural trade patterns, grains marketing channels and the major constraints to trade. Section 3 presents the methodology. Section 4 describes the data. While section 5 estimates the border effect on relative prices, section 6 describes results of the border effect on the volatility of relative prices. Finally, section 7 concludes.

2.2. Regional trade in food staples in West Africa

Cereals are heavily traded within West Africa. However, the official trade statistics are likely to understate the magnitude of regional trade as significant volumes of regional trade are unrecorded in official statistics considering the informal nature of much of the agricultural trade.

2.2.1. Main crop producing areas

The diversity of ecosystems in West Africa enables the cultivation of a wide variety of crops, which stimulate regional cross-border trade.

The Sahel zone extends from the extreme north of the region bordering the Sahara Desert and is delimited to the south by the semi-arid Sudan Savanna. Given that much of smallholder agriculture is rainfed, the arid zone of the Sahel is used primarily for livestock herding.

The semiarid zone, covering most of Chad, Niger, Mali, Senegal and Mauritania and to a lesser extent Nigeria, northern Cameroon and Burkina Faso, is characterized by low erratic rainfall that is a major limitation for crop production. The crops cultivated in the semiarid areas include millet, sorghum, cowpeas and groundnuts.

Maize and rice are grown primarily in the semihumid zones. Semihumid zones include the coastal countries as well as the southern part of Burkina Faso, Mali, Chad and Senegal. In the semihumid zones, the dominant crops include cassava, maize, pulses, coarse grains, and cash crops such as cotton. In addition to the food crops grown in the sub humid agro-ecosystem, tree crops are grown in humid areas including cocoa, coffee, kola, oil palm and rubber which are the region's primary agricultural exports. Tree crops are integrated with food crops such as roots and tubers.

Nigeria is by far the largest producer of cereals in West Africa. It contributes to 51% of the West African cereals supply over the period 2005-2010, followed by Mali (10%), Niger (8%) and Burkina Faso (7.5%) according to FAO statistics (2013). Nigeria is the Western Africa's leading producer of maize accounting for as much as 54% of total West Africa's maize production, followed by Ghana (10.6%) and Cameroon (10.3%). West Africa's maize imports from the rest of the world are relatively low, accounting for only 2.5% of total cereals imports of the region.

Rice imports, on the other hand, account for almost 50% of total West Africa's grains imports. West Africa has become a significant player in world rice markets because of its significant share of world rice imports, which stands now at almost 19% (FAOSTAT, 2013). Africa's emergence as a big rice importer is explained by the fact that West Africa's rice production has not been able to match growth in demand. Nigeria, Côte d'Ivoire and Senegal are the main West African importers of rice representing respectively 6, 2.8 and 2.3 percent of the world rice imports (FAOSTAT, 2013). Nigeria, Guinea and Mali are the main producers of paddy rice in the region.

Millet and sorghum are primarily produced within the Sudano-Sahelian belt. Nigeria contributes respectively to 47% and 62% of the regional production of millet and sorghum, followed by Niger, Burkina Faso and Mali.

2.2.2. Main cross-border regional trade flows

The regional cereal market is structured around two types of commodities: i) the locally grown grains – mainly millet, sorghum and maize - that flow internally from food surplus production zones to deficit consumption zones; ii) the cereals imported from the rest of the world – mostly rice coming from Asia and South America - that ensure food security by supplying the whole region even during bad years.

The region can be divided between at least four trade zones. Cross border trade is intense in the East basin with Nigeria being the main producer and consumer of cereals in the region. Locally grown grains such as maize and millet are regularly exported from Nigeria to Niger to balance the Nigerien deficit in domestic supply. In exceptional circumstances, when production is low and when prices in Nigeria are much higher than in Niger, part of Nigerien production of millet and sorghum can be sold in Nigeria, despite insufficient domestic supply. Maize flows from Nigeria to Niger take place all year round, but reaches its peak at the beginning of the hunger season. Maize coming from Burkina Faso and Mali is exported to Niger as well.

Central zone is primarily a maize trading zone where Côte d'Ivoire and Burkina Faso account for a large share of the regional flows (Josserand, 2013). Most of the maize from Côte d'Ivoire goes to Mali, although it may be ultimately destined for Burkina Faso, Mauritania, or even Senegal. Maize is also exported to the south, towards the densely populated coastal zone.

Benin emerged as a major transit point for goods destined for Nigeria. Re-export trade in Benin consists in importing goods from all across the world and then export them to neighboring countries especially Nigeria. A major portion of imported rice is now being routed through Benin, driven by differences in official trade policies between the two countries. Benin's re-export market is based on skirting the Nigerian protectionist policy and avoiding high import taxes.

The Sahelian band is characterized by flows of millet and sorghum between Mali, Mauritania, Burkina Faso, Nigeria, and Niger in response to the differences between crop calendars in each of these countries and to inter-annual changes in production levels.

Finally, the Western zone which includes Mauritania, Senegal, western Mali, Sierra Leone, Guinea, Liberia and the Gambia, is characterized by important flows of rice. Almost all the rice traded across borders is of imported rice, both through formal transit shipments from the main ports and through informal trade (USAID, 2009). Most imported rice is consumed in the coastal regions in urban areas. Most of the local rice, on the other hand, remains within the country of production due to high transport costs and customs formalities. Informal exports of local rice are mostly from surplus areas located close to borders. For instance, local rice from the Senegal River Valley is occasionally exported to Mauritania, when rice prices are higher on the other side of the border.

2.2.3. Grains marketing channels

Local grown grains and imported cereals use different marketing channels. Rice is the only commodity in our analysis that is widely imported from the rest of the world. Rice importers order large quantities of rice from traders, which arrive in bulk or in bags at the port. The frequency of such shipments is approximately once every 3 months at the port of Dakar (Hamilton, 2010). Bulk or bagged rice is usually moved from the port to warehouses, where wholesalers buy rice in smaller quantities, and generally transport it using their own trucks. When the shipment is intended to be sold abroad, the rice is directly loaded into trucks

Local grown cereals are moved from the farm to the consumer using different marketing channels. Local cereals can first be found in rural retail markets where farmers, traders and consumers come together for commercial purposes: supplying, selling and buying goods. Rural markets may serve as assembly markets as well; assembly markets are places where farmer meet with middlemen and traders to sell their products. They may be occasional markets, such as weekly markets called lumo in Senegal, Gambia and Guinea (CILSS *et al.*, 2010). Rural markets are supplied either by farmers or collectors. During harvests periods, the main role of these markets is to collect cereals and other cash crops and to sell imported commodities. During the lean season, they serve primarily to supply household in grains. However, the markets located in grain surplus areas continue to supply both wholesale markets and rural markets located in food deficit zone, even during the hunger season. Short cross-borders flows of local cereals can be observed between rural assembly markets located near borders.

Wholesale markets are the link between rural assembly markets and urban retail markets. Some assembly markets are specialized in a particular commodity such as the market of Richard Toll (Saint Louis in Senegal) with local rice (CILSS *et al.,* 2010). A few wholesale markets take advantage of the fact that they are located near a border. Cross border markets such as Malainville (Benin), Diaobé (Sénégal), Illela and Jibyia (Nigeria) constitute major regional trade hub for cereals.

Urban retail markets are usually supplied by wholesale markets. They gather retailers and wholesaler and provide a wide variety of commodities all year round.

2.2.4. Major constraints to trade

Poor road conditions are among the main trade constraints in Western and Central Africa. Regional trade in food staples is generally carried out by bulk transportation on roads in trucks. Locally grown grains are collected by traders who transport them over greater distances to regional markets. Transportation costs can significantly influence grain prices and threaten food access of poor households. Road conditions remain deplorable in the region, with a proportion of paved roads of only 13% (UNECA *et al.*, 2010). Road conditions get worse during the rainy season that coincides with the lean season when stocks are depleted and prices reach their peaks. For instance, it takes 32 hours to go from Conakry to Nzérékoré (Guinea) in the rainy season compared to 24 hours in dry season (CILSS *et al.*, 2010).

Rural areas deserve special attention as transport prices are disproportionately high on rural roads compared to national road (World Bank, 2009). A World Bank report (2009) studying the performance on grain markets in Eastern Africa concludes that "*transport prices per ton-km from farm-gate to primary markets are three to five times larger than those from secondary to wholesale markets located in the countries capitals*".

In addition to costs induces by transport infrastructure, traders face delays at various stages including border crossings, road-checkpoint controls by police and delays at customs. Customs inefficiencies hinder the integration of West African countries. These inefficiencies include excessive documentation requirements, outdated procedures, insufficient automated systems, a lack of transparency in customs activities and a lack of cooperation among customs and other governmental agencies.

Along with poor quality of infrastructure and delays and inefficiencies at border posts, major policy constraints still persist. Despite the elimination of tariffs within the region there are still many barriers to trade which hamper intraregional trade flows, such as seasonal trade bans, which are common throughout West Africa. Some countries continue to implement export bans especially when pre-harvest estimates suggest a lower crop than the year prior. For instance, in December 2011, the Burkina Faso Ministry of Agriculture, required that all "irregular" exports of cereals were prohibited, without defining what constituted irregular exports (RPCA, 2012). Trade policy restrictions can increase food price volatility and informal cross-border trade (World Bank, 2012). For instance, traders can be tempted to transfers grains from truck to bicycle and back on to trucks to avoid border controls.

Trade barriers can take many forms and the following econometric analysis is an attempt to disentangle the contribution of inter-town distances and the contribution of border barriers on food price differences.

2.3. Empirical strategy

2.3.1. The Law of One Price

The absolute version of the Law of One Price (LOP) states that prices of identical commodities should be the same across efficient markets, once converted into the same currency:

$$P_{ik,t} = E_{ji,t} P^{d}_{jk,t} = P_{jk,t} \qquad (1)$$

where $P_{ik,t}$ is the price of good *k* in market *i* at time *t* expressed in *i*'s currency; $E_{ji,t}$ is the exchange rate of *j*'s currency per unit of *i*'s currency; $P^{d}_{jk,t}$ is the price of good *k* in market *j* at time *t* expressed in *j*'s currency and $P_{jk,t}$ is the price of good *k* in market *j* at time *t* expressed in *i*'s currency.

The existence of transaction costs is an obvious reason for the failure of the Law of One Price. Transactions costs include transport costs, as well as information costs, contracting costs, costs paid to the intermediary, etc. Transactions costs can be split between transports costs that increase with distance and additional fixed costs. When markets are not located in the same countries, transactions costs include additional costs associated with trade barriers at the border.

In the presence of transaction costs, prices are not equal and spatial arbitrage should equalize supply and demand at different markets until price differences are reduced to the level of transaction costs: $|P_{ik,t} - P_{jk,t}| \leq T_{ijk}$, where T_{ijk} are transaction costs of trading between market *i* and market *j* for the good *k*.

The price of good *k* in market *i* ($P_{ik,t}$) plus transaction costs have to be as large as the price of the same good *k* in market *j*. The rule of spatial arbitrage states that $- T_{ijk} \leq P_{ik,t} - P_{jk,t} \leq T_{ijk}$. As long as the price difference between market *i* and *j* lies between the interval $[- T_{ijk}, T_{ijk}]$, there will be no arbitrage. Arbitrage occurs only when the price differential exceeds the transaction costs between markets.

It is rarely possible to compare prices of identical goods on both sides of a border. Most of the time, researchers measure deviation from the LOP by comparing goods of similar quality. By doing so, we can hardly assess whether the observed deviations in the LOP come from the presence of a border or from the comparison of goods that are non-identical (Broda and Weistein, 2008). To deal with this issue, we can estimate the relative version of the LOP (RLOP) that examines if price movements in market *i* and market *j* are the same over time.

The RLOP analyses the changes in prices over time rather than their level:

$$\Delta p_{ik,t} = \Delta e_{ji,t} + \Delta p^{d}_{jk,t} \qquad (2)$$

where lower case letters denotes the logs of upper case variables, that is $p_{ik,t} = \ln(P_{ik,t})$ and the Δ's refer to relative changes over time. The RLOP holds if price changes in market *i* and market *j* are the same over time.

2.3.2. Estimation of the border effect on relative prices

There are two ways of measuring the range of price dispersion. One can either measure price dispersion by the magnitude of the time-series fluctuations in relative prices or by the price differentials between two markets for a given time period. Most research following Engel and Roger (1996) uses the standard deviation of changes in relative prices as a measure of price dispersion. However, time-series volatility fails to reveal price differences if prices in two markets change in the same proportion over time (Baba, 2007). In that case, relative prices deviate from parity in a stable manner implying that the relative LOP holds but absolute LOP does not. Hence, we use monthly relative prices to measure deviations from absolute LOP.

We use the log of relative prices and its first difference as variables of interest. In the first case, we assess the impact of trade impediments on deviation from absolute LOP while in the second case we assess the determinants behind deviations from the relative version of the LOP, or RLOP. The log of relative prices of good *k* between market *i* and market *j* is defined by:

$$q_{ijk,t} = \ln(P_{ik,t}/P_{jk,t}) \qquad (3)$$

If q is equal to zero, this means that the LOP hypothesis holds perfectly. When calculating relative prices, we can equally choose market *i* or *j* as the denominator. In order to avoid having two different values for each pair of markets, we use the absolute value of relative prices.

Our empirical model is the following:

$$Y_{ijk,t} = \beta_0 + \beta_1 \ln(Dist_{ij}) + \beta_2 Border_{ij} + N_{ij,t} + \theta_{kt} + \theta_{mk} + v_{ijk,t} \qquad (4)$$

With $Y_{ijk,t}$ is either the log of the relatives prices in absolute value, $|q_{ijk,t}|$, or the first difference of the log of the relative prices in the first difference, $|\Delta q_{ijk,t}|$.

$Dist_{ij}$ is the road distance between market *i* and market *j*; $Border_{ij}$ is a dummy variable equal to one when market *i* and market *j* are separated by a border and 0 otherwise; $N_{ij,t}$ measure the monthly nominal exchange rate variations[9]. $N_{ij,t}$ is equal to 0 when two towns of a market-pair share the same currency ; θ_{kt} are the month-commodities dummy interactions controlling for month-products specific variations; θ_{mk} are the market-commodities dummy interactions controlling for market-products specific characteristics.

β_1 and β_2 are expected to be positive. β_2 provides an estimate of the effect borders exert on relative prices in absolute and relative terms. To evaluate the size of the border effect, we express β_2 in terms of its distance equivalent, which is the distance between two cities in the same country that will lead to price dispersions similar to towns separated by an international border. The distance-equivalent of the estimated border effects is calculated as $\exp(\beta_2/\ \beta_1)$. This measure is unitless but is usually expressed in the same unit that the distance variable (here in kilometers). β_2 can also be expressed as the increase in price differentials associated with the border. The impact of crossing a border on relative prices is calculated as: $\exp(\beta_2)-1$

Engel and Roger (2001) showed that most of the border effects come from local currency pricing with fluctuating nominal exchange rates. Local currency pricing refers to exporting firms setting prices in the currency of the consumer. Several authors, such as Feenstra and Kendall (1997) have shown that prices are rigid in the currency of the consumer. If producers selling abroad set their prices in foreign currency, exchange rate changes do not modify consumer prices leading to a zero pass-through of exchange rate changes. Although most countries in our sample adhere to a monetary union, five out of the fourteen countries included in our sample do not have CFA francs as a common currency. Hence, we include a measure of monthly nominal exchange rate variations in our regressions.

2.3.3. Estimation of the border effect on the volatility and persistence in relative prices

There is a large body of literature showing that relative prices of similar goods are more volatile and also more persistent across borders than within the same country (Engel and Roger, 1996; Parsley et Wei, 1996). Following Engel and Rogers (1996), several authors use the standard deviation of changes in relative prices as the dependent variable. By doing so, they keep only the cross-sectional variation in the volatility of the relative prices across markets and commodities. We follow their approach by first calculating indicators measuring

[9] All prices are denominated in US dollars. $N_{ij,t} = \ln((E_{i\$,t}/\ E_{i\$,t-1})/\ (E_{j\$,t}/\ E_{j\$,t-1}))$ where $E_{i\$,t}$ is the exchange rate of *i*'s currency per unit of US\$ and $E_{j\$,t}$ is the exchange rate of j's currency per unit of US\$.

the degree of market integration and then testing the border effect in a cross-sectional regression.

First, we estimate the border effect on price volatility by using the standard deviation of relative prices. We denote the standard deviation of relative prices as $\sigma(q_{ijk})$ with $q_{ijk,t} = \ln(P_{ik,t} / \ln P_{jk,t})$.. Following Gorodnichenko and Tesar (2005), we make the hypothesis that $q_{ijk,t}$ is uniformly distributed in the interval [- T_{ijk}, T_{ijk}] suggesting that the standard deviation of $q_{ijk,t}$ is a linear function of the transactions cost.

Secondly, we calculate a measure of shock persistence between markets to take into account the fact that shocks in one market may not be instantaneously transmitted to other markets due to high transport costs and poor communication networks that prevent agents from adjusting prices instantaneously. The measure of shock persistence between relative prices is the half-life of shocks. Under the hypothesis that prices follow an AR(1) process, we estimate:

$$\Delta q_{ijk,t} = \lambda q_{ijk,t-1} + \sum_{s=1}^{12} \alpha_s M_s + \varepsilon_t \tag{5}$$

The variables M are the monthly dummies introduced to control for seasonal variation. The parameter of interest is λ that denotes the speed of convergence by which deviations from equilibrium are eliminated. Convergence implies a negative λ. This speed of convergence is often expressed in terms of the ''half-life'' of deviations, the period of time required for one-half of the deviation to be eliminated. The half-life of shocks is given by $\ln(0.5)/\ln(1+\lambda)$.

Then we estimate the following regression to compare the differences in price dispersion between markets in opposite side of a border as compared to markets within the same country:

$$Y_{ijk} = \beta_0 + \beta_1 \ln(Dist_{ij}) + \beta_2 Border_{ij} + N_{ij} + \theta_{mk} + \mu_{ijk} \tag{6}$$

where Y_{ijk} is either the standard deviation of relative prices, $\sigma(q_{ijk})$ or h_{ijk}, the half-life of shocks; $Dist_{ij}$ is the road distance between market *i* and market *j*; $Border_{ij}$ is a dummy variable equal to one when market *i* and market *j* are separated by a border and 0 otherwise; N_{ij} is the standard deviation of nominal exchange rate changes between location *i* and *j*; θ_{mk} are the market-commodities dummy interactions controlling for market-products specific characteristics. Note that all regressions are cross-sectional.

We expect β_2 to be positive and significant, even after controlling for distance. As explained earlier, we expressed β_2 in distance equivalent.

2.4. Data

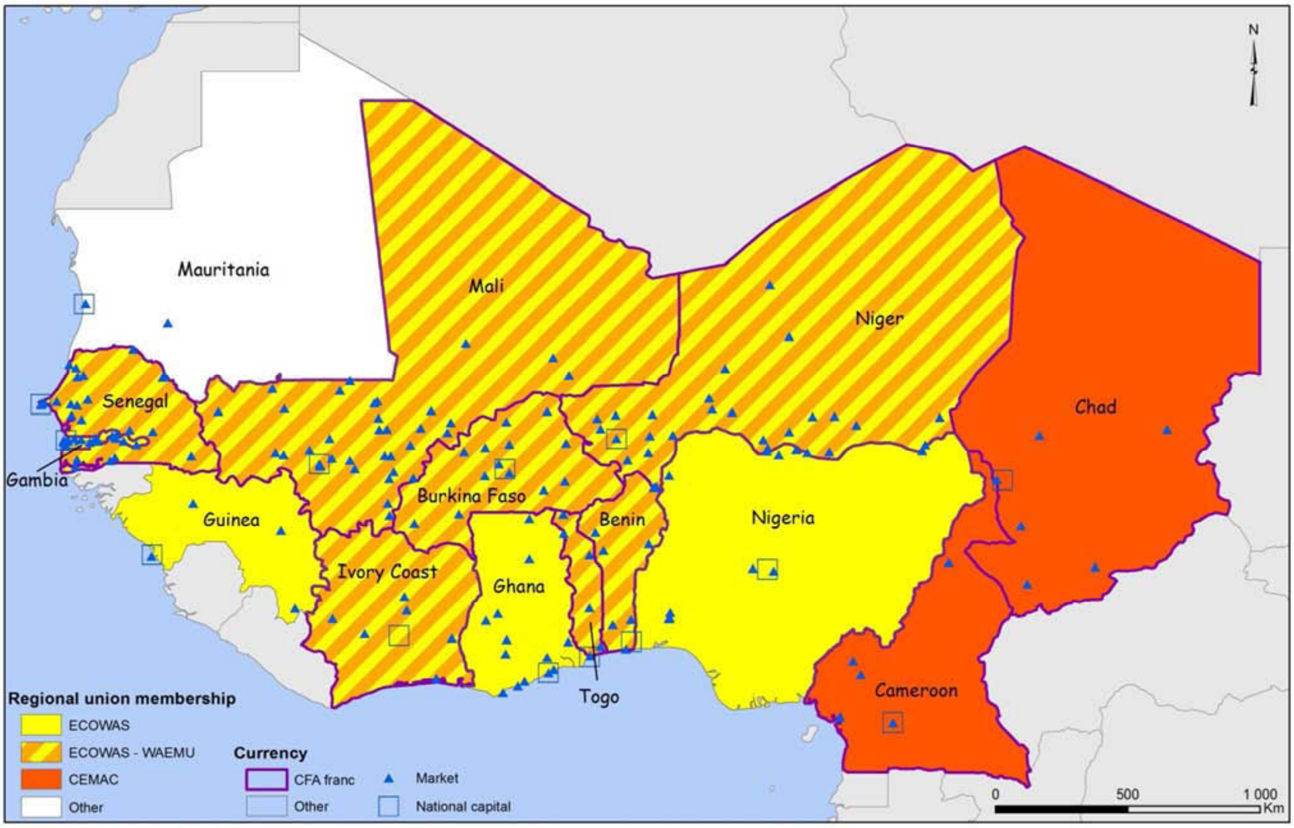
This article combines two datasets. The first includes the length in kilometers of the shortest road between any pairs of markets in our sample. These data have been compiled by the World Bank using detailed information on the road networks in West and Central Africa.

The second dataset includes retail food prices on a monthly basis for 173 markets located in 14 West and Central African countries. The monthly data cover the period January 2007 to January 2013 for 6 commodities (millet, sorghum, maize, cassava, local rice and imported rice). Data has been collected by the World Food Program[10], FAO[11] and Fews Net, but most of the data have been initially collected by national market information systems set in place in each country. Our dataset includes retail prices for every country except Ghana for which retail prices were not available. All prices have been converted in US$ per kilogram, using monthly exchange rates compiled by the IMF's International Finance Statistics (IFS).

The choice of commodities was constrained by data availability. Yet, commodities in our sample make up for a large share of food consumed in these countries, except in Mauritania[12], as shown in Table B2 in appendix. Our analysis mainly focuses on cereals and cassava[13], which represent on average 50% of dietary energy supply in our sample. Moreover cereals are storable and are heavily traded within West Africa.

[10] See VAM Food and Commodity Prices Data Store : http://foodprices.vam.wfp.org/Default.aspx
[11] See Giews Food price Data and Analysis Tool : http://www.fao.org/giews/pricetool/
[12] Mauritania is the only country in our sample where wheat makes up a significant part of the diet.
[13] As raw cassava roots are highly perishable, cassava is usually traded in some processed form, generally gari or chips/flour. Our price data labeled as cassava refers to gari that is the most commonly traded cassava product. Gari is a granulated and toasted cereal-like cassava food product.

Map 2.1: Markets studied and Economic and Monetary Union membership



Seven out of the fourteen countries included in our sample are both members of ECOWAS and WAEMU – Benin, Burkina Faso, Cote d'Ivoire, Mali, Niger, Senegal and Togo – and two countries are members of the CEMAC, namely Cameroon and Chad (Map 2.1). Only five countries do not have CFA francs as a common currency: The Gambia, Ghana, Guinea, Mauritania and Nigeria. Among these five countries, Mauritania, which did not join WAEMU, withdrew from ECOWAS in 2000. By including countries not belonging to ECOWAS or to WAEMU, we can estimate the effect of regional blocs on food market integration. Indeed, larger border effects are expected between countries that either do not share the same currency or that are not members of the same economic union.

Figures 2.1 and 2.2 compare the average price dispersion between markets located in a same country (within-country price dispersion) and markets located in opposite sides of a border (cross-country price dispersion). Clearly, international markets pairs have larger price dispersion that intra-national markets pairs for every commodity except local rice[14], suggesting the existence of greater transaction costs between towns located in different countries than those located within the same country. Transactions costs may be due to higher

[14] Figure not shown but available on request.

distance between markets located in different countries than markets within countries or to the cost associated with crossing borders.

Figure 2.1: Average relatives prices in logarithm, millet, 2007.01-2013.01

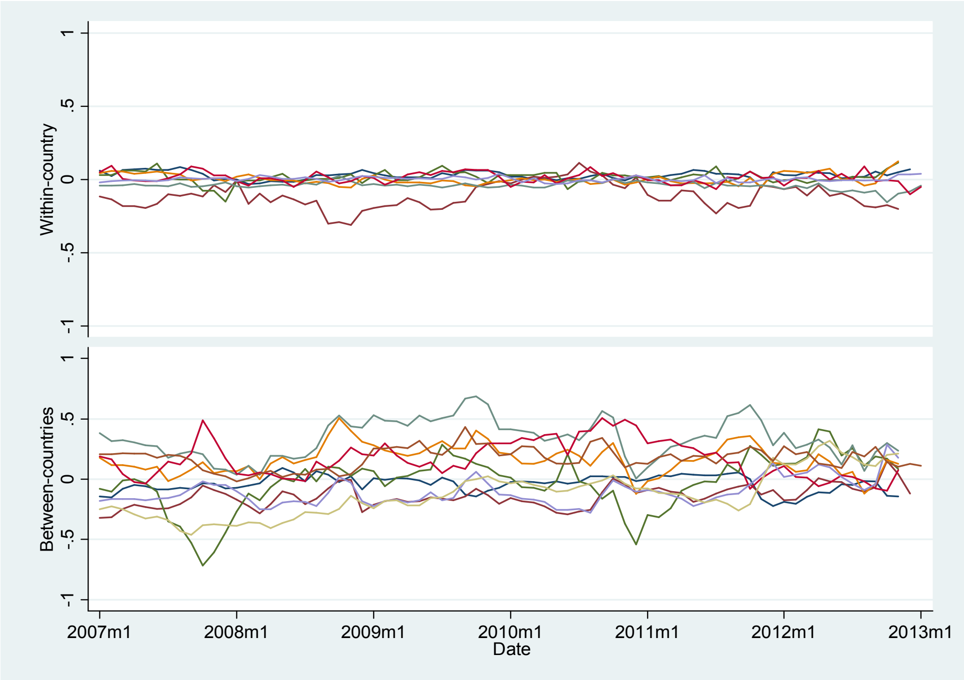


Figure 2.2: Average relatives prices in logarithm, maize, 2007.01-2013.01

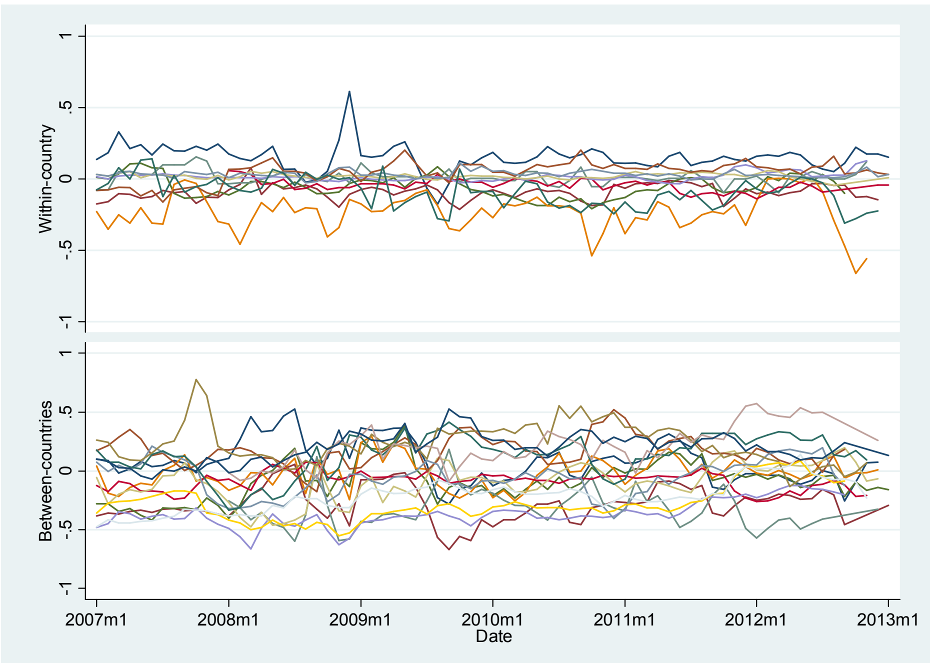


Table B3 in appendix presents descriptive statistics of the log relative prices and of the first difference of the log relative prices. A zero value of the log relative prices (or of the first difference of the log relative prices) indicates that the LOP (RLOP) holds perfectly.

The table confirms that the price differentials between markets is on average lower within countries than between countries; within-country relative prices are 17%[15] higher than the LOP benchmark whereas between-country relative prices are 31% higher than the LOP benchmark. However, prices may vary substantially even within a country; the average within-country price differentials range from 9 percent for Gambia to 45 percent for Ghana. Average price differentials of all commodities hide important variations between commodities. Deviations in the relative prices are smaller for rice than other commodities especially cassava. The low price differentials among rice markets may reflect lower transactions costs of moving imported rice from the ports to consumption centers compared to locally grown crops. Conversely cassava presents large price dispersion within and between countries suggesting that cassava is mainly consumed near to the production areas.

When we look at deviations from the RLOP, we notice a smaller discrepancy between within-country market pairs and markets pairs from different countries. Indeed, within and between country price changes are respectively 7 and 9 percent higher than the RLOP benchmark. Notice that commodities included in our analysis vary country by country, as shown in Table B1 in appendix.

2.5. Estimation of the border effect on relative prices

2.5.1. Estimation of the average border effect

As series often exhibit trending behaviour or non-stationarity in the mean, we first conduct unit root tests good-by-good by pooling all relative prices series. We use panel unit root tests by Levin, Lin and Chu (2002) and by Breitung (2000). The null hypothesis is that all groups have a common unit root. As shown by test results in Table B7 in appendix, the null-hypothesis of a common unit-root is rejected, suggesting that our variables are stationary. When estimating an equation like equation (4), the time-varying dependent variables and nominal exchange rate series should be of similar orders of integration. In order to avoid spurious estimates, we check that our nominal exchange rate series are stationary. The hypothesis that the nominal exchange rate series are stationary is tested using the augmented Dickey-Fuller (ADF) test. ADF tests reject the null-hypothesis of a unit root for all the

[15] (=exp(0.16)-1) (Table B3, column 3)

nominal exchange rate series (Table B8 in appendix). We can conclude that both the dependent variables and the nominal exchange rates are I(0).

Table 2.1: Average border effect

	|ln(Pikt/Pjkt)|	|ln(Pikt/Pjkt)|	|Δ ln(Pikt/Pjkt)|	|Δ ln(Pikt/Pjkt)|
	(1)	(2)	(3)	(4)
Border dummy	0.065***	0.057***	0.008***	0.006***
	(0.004)	(0.004)	(0.000)	(0.000)
Log(distance)	0.032***	0.034***	0.003***	0.004***
	(0.002)	(0.002)	(0.000)	(0.000)
Nominal exchange rate variations		0.871***		0.273***
		(0.057)		(0.014)
Distance equivalent of the border (kms)	7	5	16	5
Price increase by distance (average dist = 1079) (%)	25	27	3	3
Price increase by the border (%)	7	6	1	1
Observations	595,598	586,845	573,896	573,707
R-squared	0.406	0.408	0.171	0.172

All regressions include market-product dummies and month-product dummies. Robust standard errors in parentheses are clustered by market-pairs.

Table 2.1 reports estimates of the average border effect when estimating equation (4). In the first two regressions, the dependent variable is the absolute value of the log of relative prices whereas in the last two regressions, the dependent variable is the first difference of relative prices in absolute value. Specifications (2) and (4) include a measure of monthly nominal exchange rate changes to measure their impact on the relative prices.

According to our estimates, distance and borders affect positively price differentials between markets (Table 2.1, columns 1 and 2). The border dummy coefficient reflects the average effect on prices of crossing a border across countries and commodities; crossing a border induces on average an increase of about 7 percent in relative prices for market pairs located in different countries (Table 2.1, column 1). The average distance between international market pairs in the sample is 1079 kilometers: on average, the distance is associated with an increase of 25 percent[16] in price differentials for markets located on opposite side of a border. The coefficient of the nominal exchange rate variations is positive and significant (Table 2.1, columns 2 and 4). As expected, controlling for monthly fluctuations of the nominal exchange rate decreases the border coefficient suggesting that a substantial part of the border effect comes from variations in nominal exchange rates. However, even after controlling for nominal exchange rate changes, the border dummies remain positive and significant.

[16] (=exp(0.032*ln(1079))-1) (Table 2.1, column 1)

Similar results are found when the explained variable is the first difference of relative prices, although with smaller coefficients (Table 2.1, columns 3 and 4). On average, distance between international market pairs increases the monthly variation of relative prices by 3% while the fact that the markets are separated by a border leads to an increase of 1%.

In terms of distance equivalent, the specifications in column (2) and in column (4) display similar results: once controlling for nominal exchange rate changes, crossing the border is equivalent to traveling 5 kilometers between markets located in the same country.

Our dataset covers 7 countries members of WAEMU and 7 countries not belonging to the union (Map 2.1). Estimates in Table 2.2 assess the effect of regional integration agreements by distinguishing between countries member of WAEMU and countries that are not. As shown in Table 2.2, the impact of crossing a border is smaller between countries belonging to WAEMU. The border effects, when at least one of the countries is not member of the union, decrease once controlling for nominal exchange rate variations (Table 2.2, columns 2 and 4). However, the coefficients remain positive and significant suggesting that countries within WAEMU benefit from being member of the union beyond the fact that they share a common currency. The smaller border coefficient for WAEMU members may reflect the positive effect of trade policies harmonization.

Table 2.2: The effects of regional integration agreements

	|ln(Pikt/Pjkt)|	|ln(Pikt/Pjkt)|	|Δ ln(Pikt/Pjkt)|	|Δ ln(Pikt/Pjkt)|
	(1)	(2)	(3)	(4)
Border dummy within WAEMU members	0.049*** (0.004)	0.049*** (0.004)	0.004*** (0.000)	0.004*** (0.000)
Border dummy when at least one country is not member of WEAMU	0.093*** (0.006)	0.079*** (0.006)	0.016*** (0.001)	0.011*** (0.001)
Log(distance)	0.036*** (0.002)	0.036*** (0.002)	0.004*** (0.000)	0.004*** (0.000)
Nominal exchange rate variations		0.632*** (0.043)		0.214*** (0.015)
Distance equivalent of the border within WAEMU (kms)	4	4	3	2
Distance equivalent of the border outside WAEMU (kms)	13	9	59	16
Price increase by the border within WAEMU (%)	5	5	0.4	0.4
Price increase by the border outside WEAMU (%)	10	8	2	1
Observations	595,598	586,845	573,896	573,707
R-squared	0.408	0.409	0.172	0.173

All regressions include market-product dummies and month-product dummies. Robust standard errors in parentheses are clustered by market-pairs.

As pooling all observations may hide differences across commodities, we estimate equation (4) for each commodity. Estimates in Table 2.3 show that crossing a border has a similar impact on relative prices of millet, sorghum and local rice. In contrast, borders lead to higher price differentials for imported rice (+13%) and cassava (+23%). As distance appears as a bigger trade impediment for cassava compared to the other commodities, when expressed in distance equivalent, the border effect is large only for imported rice (658km). A possible explanation is that imported rice is less subject to informal cross-border trade than other staple foods such as millet and sorghum. An alternative explanation is that rice is more subject to official and unofficial trade restrictions.

Table 2.3: Average border effect by commodities

	Dependent variable: Log of the relative prices					
	Millet	Sorghum	Maize	Cassava	Local rice	Imported rice
Border dummy	0.02***	0.027***	0.078***	0.206***	0.023***	0.122***
	(0.005)	(0.006)	(0.007)	(0.033)	(0.007)	(0.005)
Log(distance)	0.032***	0.038***	0.04***	0.128***	0.015***	0.019***
	(0.003)	(0.004)	(0.004)	(0.031)	(0.005)	(0.002)
Distance equivalent of the border (kms)	2	2	7	5	5	658
Price increase by the border (%)	2	3	8	23	2	13
Price increase by distance (%)	25	31	32	119	11	14
Observations	132,169	176,237	128,785	12,165	34,746	92,489
R-squared	0.291	0.394	0.318	0.466	0.422	0.429

All regressions include monthly nominal exchange rate variations, market-product dummies and month-product dummies. Robust standard errors in parentheses are clustered by market-pairs.

2.5.2. Estimation of bilateral border effects

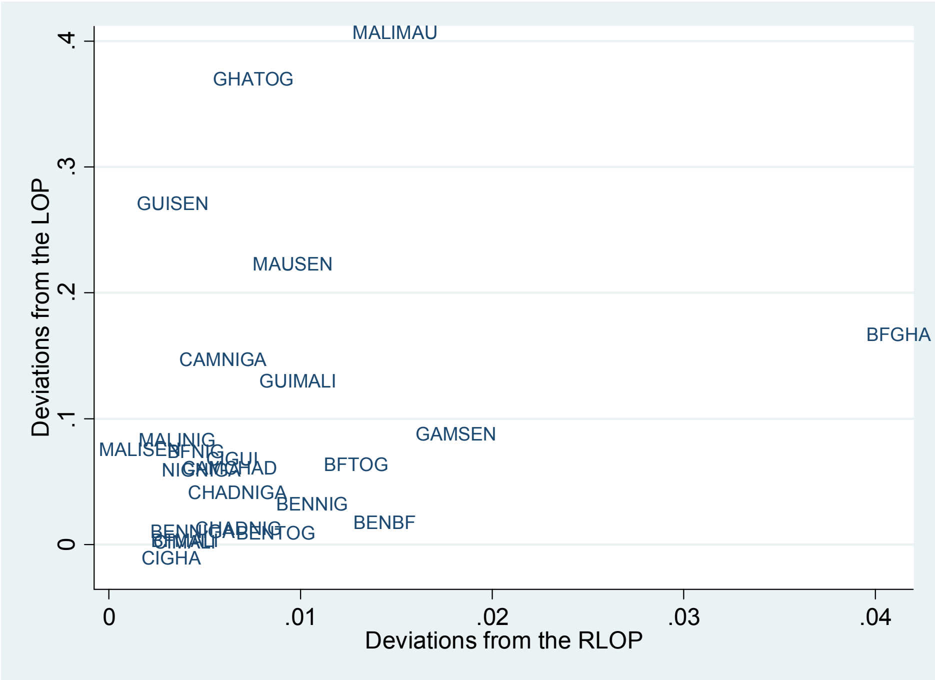
Table B4 in appendix measures the importance of each bilateral border in our sample by including 24 border dummies (e.g. Benin-Niger, Senegal-Mauritania, etc.). The first part of the table uses relative prices as dependent variable whereas the second part considers the first difference of relative prices as dependent variable.

In the first part of the table, 18 out of 24 border coefficients are positive and significant. The largest are Ghana-Togo, Guinea-Senegal, Mali-Mauritania and Mauritania-Senegal. For instance, the borders Ghana-Togo and Mali-Mauritania lead respectively to an increase of 43 and 48 percent in relative prices of markets located on both sides of the border.

Every border coefficients are positive and significant when the first difference of relative prices is the dependent variable. Country-pairs such as Burkina Faso-Ghana, Gambia-Senegal and Mauritania-Mali show the largest deviations from the RLOP.

In both cases, the country-pairs with the greatest border coefficients are the pairs including either a country that is not member of ECOWAS, WAEMU or of the CFA Francs zone.

Figure 2.3: Bilateral border coefficients in regressions studying deviations from the LOP and deviations from the RLOP



The Y-axis presents the bilateral border coefficients of Table B4, column 1 while the X-axis presents the coefficients of Table B4, column 4.

Figure 2.3 confronts border coefficients estimated in the regressions with the log of relative prices as dependent variable and the ones with monthly variation of relative prices as explained variable. A large proportion of country-pairs showing small deviations from the LOP also present small deviations from the RLOP. It suggests that both approaches provide similar results. However, several country-pairs do not have similar correlations between both estimations. Indeed, country-pairs including Mali-Mauritania, Ghana-Togo, Guinea-Senegal and Mauritania-Senegal show much larger deviations from the LOP than from the RLOP suggesting that those countries have very different prices but the monthly price variation on each side of the border is quite similar.

2.5.3. Estimation of lower and upper bounds of bilateral border effects

Until now, we have compared relative prices between markets in opposite side of a border to the average within-country relative prices. As pointed out by Gorodnichenko and Tesar (2009), our border estimates may be biased by the heterogeneity in relative prices across countries. When the distribution of relative prices in each country at both sides of a border is very different, estimated coefficients may reflect what the authors call the country heterogeneity effect. For example, in the context of the US-Canada border, they found that the US-Canada border effect is much bigger when including a dummy for US city pairs (and not the dummy for Canadian city pairs) than when including a dummy for Canadian town-pairs (and removing the US city-pairs dummy). This difference is explained by a relatively lower variation of Canadian prices than US prices. Thus, when within-country price distributions are different, it is only possible to estimate a lower and an upper bound for the border effect by omitting alternatively the dummy of one of the countries, which becomes the benchmark for the border coefficient. When the dummy for Canadian city pairs is omitted, the between-country price dispersion is compared with the low price dispersion of Canadian cities, and then the border effect is overestimated.

To deal with this country heterogeneity effect, we follow Gorodnichenko and Tesar (2009) and control for within countries heterogeneity by introducing dummies for market pairs located in the same country. We estimate lower and upper bounds for bilateral border coefficients by omitting alternatively a country dummy. The omitted country dummy will serve as benchmark. We estimate 14 regressions that provide us with two border coefficients for each country-pair: the lower bound and the upper bound estimates of the border coefficient.

To understand how bounds are calculated, take as example the estimation of the Burkina Faso-Ghana border. As shown in figure 2.4 below, Burkina Faso has a smaller dispersion of relative prices than Ghana so comparing the relative prices between Burkina and Ghana to the relative prices inside Burkina Faso gives us a high border coefficient (the upper bound). By contrast, if we compare the Burkina-Ghana relative prices to the within country relatives prices in Ghana, we obtain the lower bound of the border estimate.

Figure 2.4: Distance adjusted within-country relative prices

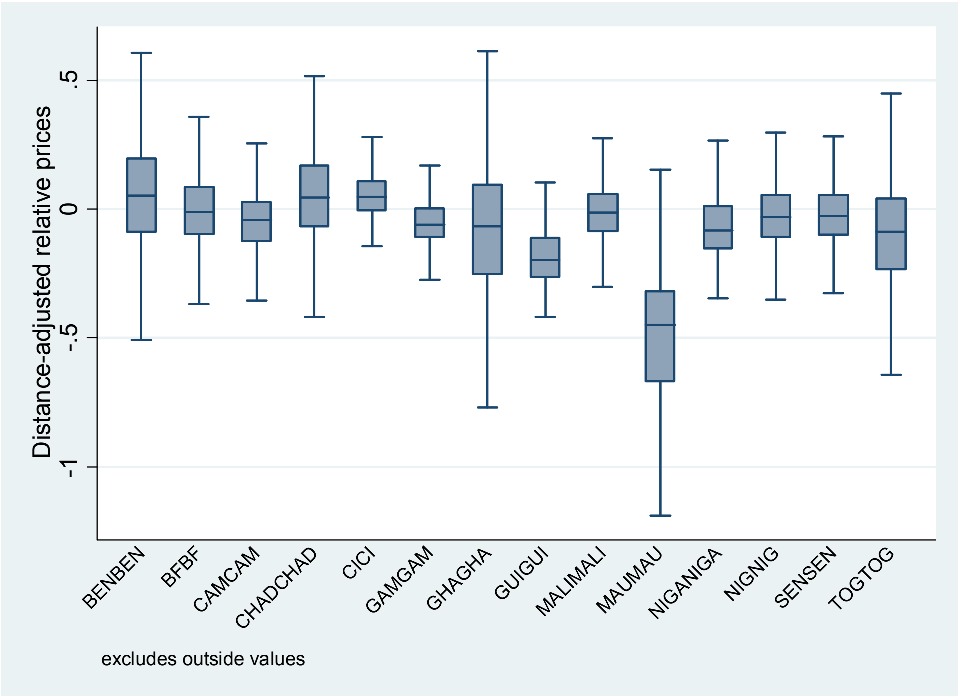


Figure 2.4 displays residuals of the regression of the log of relative prices on log distance between markets. The regression includes market-product dummies and month-product dummies. The bottom and top of the boxes are the 25th and the 75th percentiles of the y-variable, and the band inside the boxes is the median. The ends of the whiskers represent the lower and the upper adjacent value. Adjacent values are calculated utilizing the interquartile range (IQR). The upper adjacent value is the largest data value that is less than or equal to the third quartile plus 1.5 x IQR and the lower adjacent value is the smallest data value that is greater than or equal to the first quartile minus 1.5 x IQR.

Table 2.4: Estimated coefficients of the five largest bilateral borders - regressions explaining relative price dispersion

Average estimation			**Lower Bound**				**Upper bound**			
	(1)	Price increase (%)		(2)	Price increase (%)	Omitted dummy		(3)	Price increase (%)	Omitted dummy
Log(distance)	0.029*** (0.002)		Log(distance)	0.03*** (0.002)			Log(distance)	0.03*** (0.002)		
Exchange rate variations	0.489*** (0.030)		Exchange rate variations	0.544*** (0.032)			Exchange rate variations	0.544*** (0.032)		
BF-GHA	0.154*** (0.029)	17	BF-GHA	0.131*** (0.036)	14	GHA	BF-GHA	0.169*** (0.029)	18	BF
MAU-SEN	0.21*** (0.059)	23	CAM-NIGA	0.131*** (0.017)	14	NIGA	GUI-SEN	0.282*** (0.038)	33	GUI
GUI-SEN	0.258*** (0.024)	29	GUI-SEN	0.23*** (0.033)	26	SEN	MAU-SEN	0.327*** (0.028)	39	SEN
GHA-TOG	0.357*** (0.023)	43	MALI-MAU	0.334*** (0.094)	40	MAU	GHA-TOG	0.355*** (0.022)	43	TOG
MALI-MAU	0.394*** (0.057)	48	GHA-TOG	0.347*** (0.029)	41	GHA	MALI-MAU	0.524*** (0.027)	69	MALI

All regressions include monthly nominal exchange rate variations, market-product dummies and month-product dummies. Robust standard errors in parentheses are clustered by market-pairs.

For the sake of brevity, Tables 2.4 and 2.5 report only the five largest of the 24 bilateral border dummies. (The whole results are presented in Tables B5 and B6 in appendix). Each table is divided in three parts: the first part displays again the average bilateral border effects presented in Table B4; the second and the third parts report the lower and the upper bounds of the border effects.

The largest estimated bilateral borders vary with the estimated specification. In column 1 (Table 2.4), the benchmark is the average within-country relative prices whereas in columns 2 and 3, the benchmark is the omitted country dummy. Large differences between within-countries relative prices lead to imprecise estimates as observed for the Mauritania-Senegal and Mauritania-Mali borders (Table B5). As a consequence, the largest estimate of the border effect depends on whether we consider the lower or the upper bound.

If we take a conservative approach (omitting the country with the largest intra-country relatives prices), the largest bilateral border is the Ghana-Togo border (Table 2.4, column 2). If we consider the upper bound, the largest border is Mali-Mauritania (Table 2.4, column 3). Apart from differences in the size of the coefficients, four out of the five largest bilateral border dummies remain unchanged in any of the three different specifications presented in Table 2.4. The borders Burkina-Ghana, Guinea-Senegal, Ghana-Togo and Mali-Mauritania are the borders leading to the largest deviations from the LOP.

Table 2.5: Estimated coefficients of the five largest bilateral borders - regressions explaining monthly variations in relative prices

Average estimation			**Lower Bound**				**Upper bound**			
	(1)	Price increase (%)		(2)	Price increase (%)	Omitted dummy		(3)	Price increase (%)	Omitted dummy
Log(distance)	0.004*** (0.000)		Log(distance)	0.004*** (0.000)			Log(distance)	0.004*** (0.000)		
Exchange rate variations	0.196*** (0.016)		Exchange rate variations	0.201*** (0.016)			Exchange rate variations	0.201*** (0.016)		
BF-TOG	0.013*** (0.002)	1.3	CHAD-NIGA	0.004 (0.004)	0.4	CHAD	GAM-SEN	0.03*** (0.001)	3.1	SEN
BEN-BF	0.014*** (0.002)	1.5	GAM-SEN	0.005*** (0.002)	0.5	GAM	BEN-TOG	0.035*** (0.002)	3.5	BEN
MALI-MAU	0.015*** (0.001)	1.5	BEN-NIG	0.007*** (0.003)	0.7	BEN	MALI-MAU	0.039*** (0.003)	3.9	MALI
GAM-SEN	0.018*** (0.001)	1.8	BEN-BF	0.008*** (0.003)	0.8	BEN	BF-TOG	0.045*** (0.002)	4.6	BF
BF-GHA	0.041*** (0.002)	4.2	BF-GHA	0.027*** (0.003)	2.7	GHA	BF-GHA	0.055*** (0.003)	5.7	BF

All regressions include monthly nominal exchange rate variations, market-product dummies and month-product dummies. Robust standard errors in parentheses are clustered by market-pairs.

We observe larger differences in estimated border coefficients between lower and upper bounds when the dependent variable is the first difference of relative prices. Out of the five largest bilateral borders, only two are consistent throughout the three specifications (Table 2.5). The borders between Gambia-Senegal and Ghana-Burkina Faso are the borders leading to the largest deviations from the RLOP.

2.6. Estimation of the border effect on the volatility and persistence in relative prices

We examine the robustness of our results by using successively the standard deviation of the relative prices and the half-life of shocks as dependent variables. By using those indicators, we examine the effect of road distance and borders on the relative prices volatility and on the price convergence between markets located in different countries. The half-life indicates the time required for a divergence from LOP to dissipate by one half.

Table B9 in appendix summarizes descriptive statistics. The average volatility and persistence is lower for within-country market pairs than between-country market pairs suggesting the existence of large transaction costs when crossing borders. Imported rice is the commodity with the lowest volatility within and between countries but differences between prices of imported rice are the most persistent. Indeed, the average estimated half-lives of imported rice prices are 2.9 months within-country and 4.6 months between countries. This high degree of persistence of price differentials between market pairs in the case of imported rice may reflect imperfect or asymmetric price transmission from international rice market to domestic markets in West Africa (Brunelin, 2013).

Table 2.6: Average border effect

	Standard deviation of relative prices		Half-life of shocks	
Border dummy	0.026***	0.019***	0.681***	0.661***
	(0.00)	(0.00)	(0.06)	(0.07)
Log(distance)	0.013***	0.015***	0.466***	0.471***
	(0.00)	(0.00)	(0.03)	(0.04)
Standard deviation of the nominal exchange rate changes		0.766***		2.308
		(0.07)		(3.38)
Distance equivalent of the border (kms)	7	4	4	4
Observations	9,337	9,337	9,337	9,337
R-squared	0.841	0.846	0.517	0.517

All regressions include market-product dummies. Robust standard errors in parentheses are clustered by market-pairs.

Table 2.6 reports the estimations of the average border effect. We compare the price volatility (persistence) of cross-country market pairs to the average within-country volatility (persistence). Both the distance and the border variables are positive and significant. We find similar distance equivalent of the border (four kilometers) on price volatility and on price persistence when we control for the variability of the nominal exchange rate.

When we study the border effect by commodity (Table 2.7), we find similar results for all commodities except imported rice. Crossing a border has a greater effect on the price volatility of imported rice compared to the other commodities, which is consistent with our previous estimates. Indeed crossing the border is equivalent to 26 kilometers of distance between markets in the case of imported rice whereas the distance equivalent of the border is of 3 kilometers for the other commodities.

Table 2.7: Average border effect by commodities - Dependent variable: Standard deviation of relative prices

	Millet	Sorghum	Maize	Local rice	Imported rice
Border dummy	0.023***	0.018***	0.02***	0.006***	0.022***
	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)
Log(distance)	0.02***	0.016***	0.018***	0.007***	0.007***
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)
Distance equivalent of the border (kms)	3	3	3	3	26
Observations	1,945	2,855	2,249	620	1,465
R-squared	0.743	0.798	0.751	0.915	0.862

All regressions include the standard deviation of the nominal exchange rate changes and market dummies.
Robust standard errors in parentheses are clustered by market-pairs.

When we estimate specific bilateral borders (Table B10 in appendix), Mauritania-Senegal, Mali-Mauritania and Guinea-Senegal have the largest estimated borders when the price volatility is the dependent variable. Mauritania-Senegal, Mali-Senegal and Guinea-Senegal are the pairs showing the greatest persistence of shocks compared to the average within-country persistence.

The estimation of lower and upper bounds (Table B11 in appendix) confirm the bad ranking of the country-pairs mentioned above[17]. Conversely, the cost associated with crossing the border seems low for the following country-pairs: Benin-Nigeria, Burkina Faso-Niger and Burkina Faso-Mali, confirming the good ranking of few countries located in the Sahel region of West Africa (Araujo and Brunelin, 2013). In addition, border coefficients of country pairs such as Benin-Nigeria, Burkina Faso-Niger, and Cote d'Ivoire-Mali are measured accurately

[17] For the sake of brevity we do not present the results with the half-lives as dependent variable.

as the within country price volatility of those pairs are quite similar. On the other hand, we observe large discrepancies in the lower and upper bounds estimations of the pairs Burkina Faso-Togo and Mali-Mauritania.

2.7. Conclusion

Our research based on monthly retail price data over the 2007-2012 sample period strongly indicates that borders matter in regional integration of food markets in West and Central Africa. On average, crossing a border is responsible for an increase of 7% in relative prices. However this average border effect hides large discrepancies by bilateral borders.

Benin, Niger, Nigeria, Cote d'Ivoire, and Burkina Faso have the lowest estimated borders, and thus are found to be the most integrated reflecting the intense cross-border trade of grains between those countries. On the other hand, borders estimates are large for Mauritania, Ghana and Guinea as trading partners. Price dispersion may be large even within countries reflecting the poor degree of internal market integration. Countries such as Ghana, Mauritania, Chad and Togo show high price differentials between national markets that may reflect the important role played by road distance.

Belonging to an economic union and sharing the same currency appear as major determinants of market integration; countries not members of WAEMU or ECOWAS have larger borders. Each of the country-pairs showing the greatest discrepancies from the LOP - Ghana-Togo, Guinea-Senegal and Mali-Mauritania - includes a country that is either not member of ECOWAS or of WAEMU.

We observe differences between commodities as well. Borders do not lead to large increase in relative prices for millet, sorghum, maize and local rice. On the other hand, borders appear as a large impediment to trade of imported rice. This may reflect the fact that imported rice is less subject to informal cross-border trade than locally grown crops or the fact that imported rice is more subject to trade restrictions at the border.

Our analysis shows that road distance is not the only factor explaining deviations from the Law of One Price in West Africa. Borders, especially between countries that are not members of the same economic union, matter. Efforts should be made to deepen regional integration and to apply rules when countries are already members of an economic union. Borders appear as a large trade impediment in the case of imported rice. As rice is a commodity of strategic significance across West Africa, efforts should be made to reduce transactions costs at the border.

The 2008 food crisis demonstrated the inability of governments to take concerted actions in response to the price increase. The decisions to impose sudden export restrictions or to engage in panic buying created substantial uncertainty in the markets. Price deviations and price instability are exacerbated by the lack of accurate information on the supply and demand situation. Efforts should be made by governments to cooperate and take concerted actions in order to increase transparency.

Finally, our analysis underlines the importance of providing adequate hard infrastructure such as rural roads and rural telecommunications in order to reduce the role played by distance. Improving storage facilities and post-harvest processing facilities would also reduce the importance of distance between markets by increasing the tradability of food items. The lack of cereal processing facilities in rural areas decreases the market acceptability of certain food goods and then increase the role played by distance.

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Appendix B:

Figure B1: Distance adjusted within-country changes in relative prices

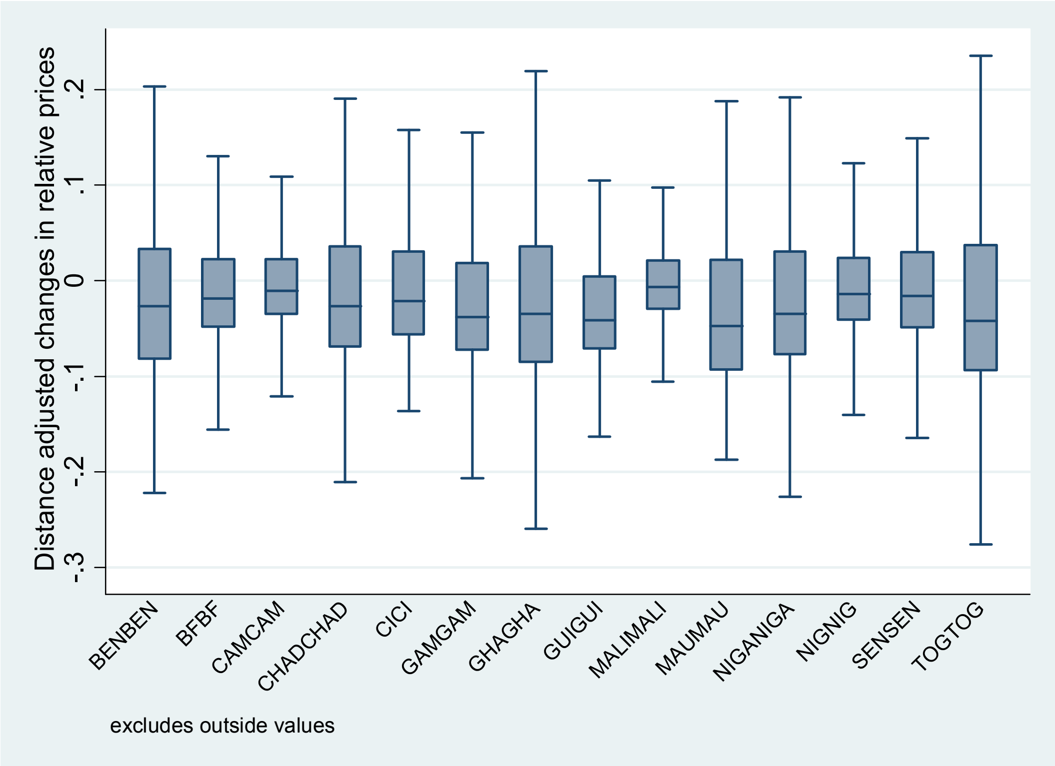


Figure B1 presents residuals of the regression of variations in the relative prices on log distance between markets. The regression includes market-product dummies and month-product dummies. The bottom and top of the boxes are the 25th and the 75th percentiles of the y-variable, and the band inside the boxes is the median. The ends of the whiskers represent the lower and the upper adjacent value. Adjacent values are calculated utilizing the interquartile range (IQR). The upper adjacent value is the largest data value that is less than or equal to the third quartile plus 1.5 x IQR and the lower adjacent value is the smallest data value that is greater than or equal to the first quartile minus 1.5 x IQR.

Table B1: Countries and markets included in the sample

	Millet	Sorghum	Maize	Cassava	Local rice	Imported rice
Benin	0	3	6	6	0	4
Burkina Faso	12	11	6	0	0	0
Cameroon	0	0	5	0	0	5
Chad	5	4	3	0	0	2
Cote d’Ivoire	0	0	0	0	6	4
Gambia	8	7	7	0	2	15
Ghana	0	0	7	12	10	0
Guinea	0	0	0	0	4	0
Mali	10	24	18	0	18	16
Mauritania	0	4	0	0	0	0
Niger	23	21	18	0	4	24
Nigeria	6	7	7	0	2	0
Senegal	22	17	20	0	2	9
Togo	0	5	6	6	0	6
Number of markets	**87**	**103**	**103**	**24**	**48**	**85**
Number of countries	**7**	**10**	**11**	**3**	**8**	**9**

Table B2: Food Consumption Pattern of Main Food Items - Share in total Dietary Energy Consumption (%)

	Millet	Sorghum	Maize	Cassava	Rice	Total
Benin	1	6	21	16	11	55
Burkina Faso	22	27	15	N/A	6	70
Cameroon	1	9	14	12	9	45
Chad	15	18	5	5	4	47
Cote d’Ivoire	N/A	N/A	7	12	17	36
Gambia	21	5	3	N/A	14	43
Ghana	2	3	13	23	8	49
Guinea	N/A	N/A	3	12	36	51
Mali	20	14	10	N/A	20	64
Mauritania	N/A	4	N/A	N/A	11	15
Niger	41	12	2	1	9	65
Nigeria	11	13	7	9	9	49
Senegal	8	4	9	2	31	54
Togo	2	7	24	15	11	59
Mean	13	10	10	11	14	50

This table includes the contribution in percent of the main food items in the total dietary energy consumption in 14 West African countries. Those data are coming from the Statistic division of FAO and have been calculated on the period 2003-2005.

Table B3: Descriptive statistics

	Average road distance in kms	|Ln(Pikt/Pjkt)|				|ΔLn(Pikt/Pjkt)|			
		Obs	**Mean**	**Std**	**Max**	**Obs**	**Mean**	**Std**	**Max**
WITHIN - COUNTRY									
BEN-BEN	382	2437	0.28	0.23	1.26	2324	0.1	0.12	0.94
BF-BF	319	10389	0.17	0.14	2.65	10201	0.08	0.12	2.46
CAM-CAM	466	1449	0.17	0.13	0.72	1428	0.05	0.06	0.44
CHAD-CHAD	536	1420	0.3	0.23	1.13	1400	0.11	0.1	0.9
CI-CI	319	1375	0.1	0.09	0.52	1326	0.08	0.08	0.55
GAM-GAM	158	11360	0.09	0.12	1.32	10764	0.07	0.12	1.34
GHA-GHA	301	7524	0.37	0.3	2.08	7260	0.13	0.15	1.51
GUI-GUI	544	352	0.14	0.11	0.52	332	0.08	0.08	0.41
MALI-MALI	490	46096	0.15	0.14	1.04	44646	0.05	0.05	0.65
MAU-MAU	653	276	0.32	0.2	0.92	270	0.1	0.1	0.58
NIGA-NIGA	544	4039	0.16	0.14	1.26	3935	0.1	0.1	0.82
NIG-NIG	574	57357	0.16	0.14	0.98	54627	0.07	0.07	0.72
SEN-SEN	270	39774	0.15	0.13	0.98	38360	0.08	0.08	0.7
TOGO-TOGO	335	3945	0.27	0.24	1.63	3885	0.14	0.17	1.88
Millet		45093	0.18	0.14	1.32	43932	0.08	0.08	0.89
Sorghum		46988	0.2	0.16	2.65	45144	0.08	0.1	2.46
Maize		39273	0.17	0.15	1.3	37597	0.08	0.09	1.34
Cassava		5863	0.41	0.32	2.08	5671	0.14	0.17	1.51
Local rice		13529	0.12	0.12	1.15	12934	0.06	0.07	0.91
Imported rice		37047	0.08	0.08	0.82	35480	0.04	0.06	1.18
Average values	430	187793	0.16	0.16	2.65	180758	0.07	0.09	2.46
BETWEEN -COUNTRY									
BEN-BF	795	4459	0.35	0.3	3.2	4318	0.11	0.13	2.34
BEN-NIG	958	15888	0.26	0.24	1.48	14892	0.09	0.1	0.83
BEN-NIGA	638	4098	0.29	0.25	1.3	3953	0.12	0.12	0.88
BEN-TOG	376	7305	0.27	0.23	1.85	7066	0.12	0.14	1.71
BF-GHA	825	2296	0.38	0.24	1.18	2219	0.13	0.13	0.95
BF-MALI	717	32596	0.19	0.16	2.66	31806	0.07	0.11	2.37
BF-NIG	1090	41965	0.26	0.19	2.94	40726	0.09	0.11	2.69
BF-TOG	660	6465	0.3	0.27	2.92	6359	0.14	0.19	2.72
CAM-CHAD	1169	1725	0.26	0.18	1.33	1700	0.08	0.09	0.74
CAM-NIGA	1087	2315	0.35	0.23	1.17	2260	0.1	0.09	0.77
CHAD-NIG	1427	19832	0.25	0.2	1.4	19253	0.1	0.1	0.78
CHAD-NIGA	1383	5503	0.29	0.24	1.35	5389	0.12	0.11	0.89
CI-GHA	607	3140	0.19	0.15	0.93	2960	0.1	0.1	0.87
CIGUI	905	1416	0.22	0.14	0.71	1328	0.09	0.08	0.46
CI-MALI	907	10271	0.11	0.09	0.55	9772	0.06	0.07	0.48
GAM-SEN	333	37167	0.23	0.18	1.81	35496	0.11	0.12	1.11
GHA-TOG	492	6384	0.74	0.51	2.47	6156	0.15	0.16	1.68
GUI-MALI	1003	4147	0.26	0.15	0.79	3882	0.08	0.07	0.51
GUI-SEN	1075	416	0.42	0.17	0.89	392	0.08	0.08	0.48
MALI-MAU	991	4315	0.72	0.4	2.23	4134	0.11	0.11	0.85
MALI-NIG	1608	93235	0.26	0.18	1.14	90125	0.07	0.07	0.81
MALI-SEN	1260	72576	0.26	0.2	1.47	69945	0.07	0.07	0.78
MAU-SEN	634	3274	0.52	0.33	1.77	3138	0.11	0.11	0.92
NIG-NIGA	693	27017	0.23	0.16	1.13	25869	0.1	0.1	0.82
Millet		89073	0.24	0.19	1.67	86742	0.09	0.09	1
Sorghum		131742	0.28	0.24	3.2	126973	0.09	0.11	2.72
Maize		101757	0.29	0.21	1.81	97694	0.09	0.1	1.11
Cassava	.	6426	0.73	0.51	2.47	6204	0.15	0.15	1.68
Local rice		21918	0.18	0.14	0.93	20667	0.07	0.08	0.87
Imported rice		56889	0.2	0.13	0.82	54858	0.05	0.06	0.92
Average values	1079	407805	0.27	0.22	3.2	393138	0.09	0.1	2.72

Table B4: Bilateral border effects on relative prices and on variations in relative prices

	|ln(Pikt/Pjkt)|	Distance equivalent (kms)	Price increase (%)	|Δ ln(Pikt/Pjkt)|	Distance equivalent (kms)	Price increase (%)
Log(distance)	0.029*** (0.002)			0.004*** (0.000)		
Exchange rate variations	0.489*** (0.030)			0.196*** (0.016)		
BEN-BF	0.005 (0.022)	0	0	0.014*** (0.002)	36	1
BEN-NIG	0.019 (0.013)	0	0	0.011*** (0.001)	14	1
BEN-NIGA	-0.003 (0.017)	0	0	0.004*** (0.002)	3	0
BEN-TOG	-0.004 (0.018)	0	0	0.009*** (0.002)	9	1
BF-GHA	0.154*** (0.029)	222	17	0.041*** (0.002)	28979	4
BF-MALI	-0.01 (0.009)	0	0	0.004*** (0.001)	3	0
BF-NIG	0.061*** (0.007)	9	6	0.005*** (0.001)	3	0
BF-TOG	0.05*** (0.015)	6	5	0.013*** (0.002)	25	1
CAM-CHAD	0.048*** (0.018)	5	5	0.006*** (0.002)	5	1
CAM-NIGA	0.134*** (0.019)	110	14	0.006*** (0.002)	4	1
CHAD-NIG	0 (0.012)	0	0	0.007*** (0.002)	5	1
CHAD-NIGA	0.029* (0.016)	3	3	0.007*** (0.002)	5	1
CI-GHA	-0.024*** (0.008)	0	-2	0.003* (0.002)	2	0
CI-GUI	0.055*** (0.019)	7	6	0.006*** (0.002)	5	1
CI-MALI	-0.011** (0.004)	1	-1	0.004*** (0.001)	3	0
GAM-SEN	0.075*** (0.006)	14	8	0.018*** (0.001)	91	2
GHA-TOG	0.357*** (0.023)	275493	43	0.008*** (0.002)	7	1
GUI-MALI	0.117*** (0.017)	61	12	0.01*** (0.002)	12	1
GUI-SEN	0.258*** (0.024)	8541	29	0.003 (0.002)	0	0
MALI-MAU	0.394*** (0.057)	1009092	48	0.015*** (0.001)	41	2
MALI-NIG	0.07*** (0.005)	12	7	0.004*** (0.000)	2	0
MALI-SEN	0.063*** (0.006)	9	6	0.002*** (0.000)	1	0
MAU-SEN	0.21*** (0.059)	1585	23	0.01*** (0.002)	11	1
NIG-NIGA	0.046*** (0.006)	5	5	0.005*** (0.001)	3	0
Observations	586,845			573,707		
R-squared	0.432			0.173		

All regressions include market-product dummies and month-product dummies. Robust standard errors in parentheses are clustered by market-pairs.

Table B5: Upper and lower bounds of the border effect on relative prices

	Average estimation		Lower Bound			Upper bound		
	|ln(Pikt/Pjkt)|	Price increase (%)	|ln(Pikt/Pjkt)|	Price increase (%)	Omitted dummy	|ln(Pikt/Pjkt)|	Price increase (%)	Omitted dummy
Log(distance)	0.029*** (0.002)		0.03*** (0.002)			0.03*** (0.002)		
Exchange rate variations	0.489*** (0.030)		0.544*** (0.032)			0.544*** (0.032)		
BEN-BF	0.005 (0.022)	0	-0.010 (0.027)	0	BEN	0.015 (0.023)	0	BF
BEN-NIG	0.019 (0.013)	0	-0.016 (0.021)	0	BEN	0.039*** (0.011)	4	NIG
BEN-NIGA	-0.003 (0.017)	0	-0.039* (0.023)	-4	BEN	0.027 (0.018)	0	NIGA
BEN-TOG	-0.004 (0.018)	0	-0.004 (0.023)	0	BEN	-0.01 (0.018)	0	TOG
BF-GHA	0.154*** (0.029)	17	0.131*** (0.036)	14	GHA	0.169*** (0.029)	18	BF
BF-MALI	-0.01 (0.009)	0	-0.03** (0.013)	-3	BF	0.008 (0.009)	0	MALI
BF-NIG	0.061*** (0.007)	6	0.046*** (0.012)	5	BF	0.075*** (0.007)	8	NIG
BF-TOG	0.05*** (0.015)	5	0.032* (0.017)	3	TOG	0.063*** (0.018)	6	BF
CAM-CHAD	0.048*** (0.018)	5	-0.008 (0.022)	0	CHAD	0.123*** (0.021)	13	CAM
CAM-NIGA	0.134*** (0.019)	14	0.131*** (0.017)	14	NIGA	0.139*** (0.025)	15	CAM
CHAD-NIG	0.00 (0.012)	0	-0.054*** (0.020)	-5	CHAD	0.057*** (0.008)	6	NIG
CHAD-NIGA	0.029* (0.016)	3	-0.037* (0.022)	-4	CHAD	0.086*** (0.015)	9	NIGA
CI-GHA	-0.024*** (0.008)	-2	-0.077*** (0.014)	-7	GHA	0.023* (0.013)	2	CI
CI-GUI	0.055*** (0.019)	6	0.045*** (0.013)	5	CI	0.058** (0.024)	6	GUI
CI-MALI	-0.011** (0.004)	-1	-0.023*** (0.008)	-2	MALI	0.000 (0.010)	0	CI
GAM-SEN	0.075*** (0.006)	8	0.065*** (0.006)	7	SEN	0.078*** (0.008)	8	GAM
GHA-TOG	0.357*** (0.023)	43	0.347*** (0.029)	41	GHA	0.355*** (0.022)	43	TOG
GUI-MALI	0.117*** (0.017)	12	0.097*** (0.014)	10	MALI	0.132*** (0.025)	14	GUI
GUI-SEN	0.258*** (0.024)	29	0.23*** (0.033)	26	SEN	0.282*** (0.038)	33	GUI
MALI-MAU	0.394*** (0.057)	48	0.334*** (0.094)	40	MAU	0.524*** (0.027)	69	MALI
MALI-NIG	0.07*** (0.005)	7	0.064*** (0.006)	7	NIG	0.073*** (0.006)	8	MALI
MALI-SEN	0.063*** (0.006)	6	0.053*** (0.007)	5	SEN	0.069*** (0.007)	7	MALI
MAU-SEN	0.21*** (0.059)	23	0.154 (0.095)	0	MAU	0.327*** (0.028)	39	SEN
NIG-NIGA	0.046*** (0.006)	5	0.039*** (0.006)	4	NIG	0.05*** (0.011)	5	NIGA

All regressions include market-product dummies and month-product dummies. Robust standard errors in parentheses are clustered by market-pairs.

Table B6: Upper and lower bounds of the border effect on variations in relative prices

	Average estimation		Lower Bound			Upper bound		
	|Δ ln(Pikt/Pjkt)|	Price increase (%)	|Δ ln(Pikt/Pjkt)|	Price increase (%)	Omitted dummy	|Δ ln(Pikt/Pjkt)|	Price increase (%)	Omitted dummy
Log(distance)	0.004***		0.004***			0.004***		
	(0.000)		(0.000)			(0.000)		
Exchange rate variations	0.196***		0.201***			0.201***		
	(0.016)		(0.016)			(0.016)		
BEN-BF	0.014***	1.5	0.008***	0.8	BEN	0.021***	2.1	BF
	(0.002)		(0.003)			(0.002)		
BEN-NIG	0.011***	1.1	0.007***	0.7	BEN	0.012***	1.2	NIG
	(0.001)		(0.003)			(0.002)		
BEN-NIGA	0.004**	0.4	-0.004	-0.4	NIGA	0.012***	1.2	BEN
	(0.002)		(0.003)			(0.003)		
BEN-TOG	0.009***	0.9	-0.018***	-1.8	TOG	0.035***	3.5	BEN
	(0.002)		(0.003)			(0.002)		
BF-GHA	0.041***	4.2	0.027***	2.7	GHA	0.055***	5.7	BF
	(0.002)		(0.003)			(0.003)		
BF-MALI	0.004***	0.4	-0.004***	-0.4	BF	0.012***	1.2	MALI
	(0.001)		(0.001)			(0.001)		
BF-NIG	0.005***	0.5	0.001	0.1	NIG	0.008***	0.8	BF
	(0.001)		(0.001)			(0.001)		
BF-TOG	0.013***	1.3	-0.021***	-2.0	TOG	0.045***	4.6	BF
	(0.002)		(0.003)			(0.002)		
CAM-CHAD	0.006***	0.6	-0.015***	-1.5	CHAD	0.025***	2.5	CAM
	(0.002)		(0.004)			(0.002)		
CAM-NIGA	0.006***	0.6	-0.012***	-1.2	NIGA	0.022***	2.2	CAM
	(0.002)		(0.003)			(0.002)		
CHAD-NIG	0.007***	0.7	-0.007**	-0.7	CHAD	0.02***	2.0	NIG
	(0.002)		(0.003)			(0.001)		
CHAD-NIGA	0.007***	0.7	0.004	0.4	CHAD	0.01***	1.0	NIGA
	(0.002)		(0.004)			(0.003)		
CI-GHA	0.003*	0.3	0.000	0.0	CI	0.007***	0.7	GHA
	(0.002)		(0.003)			(0.002)		
CI-GUI	0.006***	0.6	-0.008***	-0.8	CI	0.021***	2.2	GUI
	(0.002)		(0.003)			(0.004)		
CI-MALI	0.004***	0.4	-0.022***	-2.2	CI	0.03***	3.0	MALI
	(0.001)		(0.002)			(0.002)		
GAM-SEN	0.018***	1.8	0.005***	0.5	GAM	0.03***	3.1	SEN
	(0.001)		(0.002)			(0.001)		
GHA-TOG	0.008***	0.8	-0.012***	-1.2	TOG	0.025***	2.5	GHA
	(0.002)		(0.003)			(0.002)		
GUI-MALI	0.01***	1.0	-0.002	-0.2	GUI	0.021***	2.1	MALI
	(0.002)		(0.005)			(0.003)		
GUI-SEN	0.003	0.3	0.002	0.2	SEN	0.004	0.4	GUI
	(0.002)		(0.005)			(0.006)		
MALI-MAU	0.015***	1.5	(0.004)	-0.4	MAU	0.039***	3.9	MALI
	(0.001)		(0.005)			(0.003)		
MALI-NIG	0.004***	0.4	-0.008***	-0.8	NIG	0.015***	1.5	MALI
	0.000		(0.001)			(0.001)		
MALI-SEN	0.002***	0.2	-0.011***	-1.1	SEN	0.014***	1.5	MALI
	0.000		(0.001)			(0.001)		
MAU-SEN	0.01***	1.0	0.003	0.3	MAU	0.02***	2.0	SEN
	(0.002)		(0.006)			(0.004)		
NIG-NIGA	0.005***	0.5	-0.006**	-0.6	NIGA	0.015***	1.5	NIG
	(0.001)		(0.002)			(0.001)		

All regressions include market-product dummies and month-product dummies. Robust standard errors in parentheses are clustered by market-pairs.

Table B7: Panel unit root tests on relative prices

Commodities	Method	Statistic	Prob.	Cross-sections	Obs
Millet	Levin, Lin & Chu	-111.88	0.00	1997	130162
	Breitung t-stat	-73.60	0.00	1997	128165
Sorghum	Levin, Lin & Chu	-110.55	0.00	2879	170877
	Breitung t-stat	-70.02	0.00	2879	167998
Maize	Levin, Lin & Chu	-110.31	0.00	2250	134203
	Breitung t-stat	-66.18	0.00	2250	131953
Cassava	Levin, Lin & Chu	-30.04	0.00	205	11846
	Breitung t-stat	-14.08	0.00	205	11641
Local rice	Levin, Lin & Chu	-46.73	0.00	620	33257
	Breitung t-stat	-29.46	0.00	620	32637
Imported rice	Levin, Lin & Chu	-60.35	0.00	1480	89764
	Breitung t-stat	-45.94	0.00	1480	88284

H0: Common unit root. We include a constant and a trend in the tests. The choice of lag order was based on Schwartz criteria.

Table B8: ADF unit root tests on nominal exchange rate variations

		Model	ADF	Prob
CFA/Nigerian Naira	Level	[2]	-5.30	0.00
CFA/Guinean Franc	Level	[3]	-5.59	0.00
CFA/Ghanaian Cedi	Level	[2]	-8.55	0.00
CFA/ Mauritanian Ouguiya	Level	[2]	-5.30	0.00
CFA/ Gambian Dalasi	Level	[2]	-5.43	0.00

[1]: Model without constant nor determinist trend, critical value = -1.95 ; [2]: Model with constant without determinist trend, critical value = -2.89 ; [3]: Model with constant and determinist trend, critical value = -3.45. The choice of lag order was based on Schwartz criteria.

Table B9: Descriptive statistics

WITHIN-COUNTRY	**Average road distance (kms)**	Standard deviation of relative prices				Half-live of shocks			
		Obs	**Mean**	**Std**	**Max**	**Obs**	**Mean**	**Std**	**Max**
BEN-BEN	382	39	0.19	0.06	0.34	39	2.7	1.9	8.7
BF-BF	328	135	0.14	0.05	0.31	135	2.1	1.2	6.1
CAM-CAM	466	21	0.13	0.07	0.24	20	2.6	1.4	6.3
CHAD-CHAD	536	20	0.19	0.05	0.29	20	2.4	1.1	4.7
CI-CI	319	21	0.12	0.02	0.17	21	1.6	1.1	4.5
GAM-GAM	158	170	0.11	0.07	0.31	170	0.8	0.5	2.5
GHA-GHA	301	132	0.24	0.11	0.63	132	2.4	2.3	14.6
GUI-GUI	544	6	0.11	0.02	0.14	6	1.6	0.9	3.4
MALI-MALI	490	746	0.10	0.04	0.25	746	2.8	2.5	19.2
MAU-MAU	653	6	0.17	0.03	0.20	6	1.7	0.8	3.3
NIGA-NIGA	544	58	0.17	0.05	0.28	58	1.9	1.4	6.6
NIG-NIG	570	895	0.12	0.05	0.28	895	2.4	1.8	19.3
SEN-SEN	270	593	0.12	0.03	0.20	593	1.4	0.7	5.5
TOG-TOG	335	54	0.25	0.08	0.41	54	2.1	1.9	11.5
Millet		646	0.12	0.03	0.26	646	1.7	1.1	7.9
Sorghum		739	0.14	0.05	0.41	739	2.2	1.6	14.4
Maize		617	0.14	0.05	0.30	617	1.9	1.2	7.6
Cassava		97	0.29	0.11	0.63	97	2.8	2.8	14.6
Local rice		228	0.10	0.06	0.30	228	1.9	1.0	6.0
Imported rice		569	0.07	0.03	0.31	569	2.9	3.0	19.3
Average values	429	2896	0.13	0.06	0.63	2896	2.2	1.9	19.3

BETWEEN - COUNTRY	**Average road distance (kms)**	Standard deviation of relative prices				Half-live of shocks			
		Obs	**Mean**	**Std**	**Max**	**Obs**	**Mean**	**Std**	**Max**
BEN-BF	795	69	0.22	0.05	0.36	69	2.8	1.2	6.0
BEN-NIG	962	264	0.18	0.07	0.31	264	3.1	1.9	12.3
BEN-NIGA	638	63	0.22	0.05	0.34	63	2.0	1.3	6.0
BEN-TOG	376	111	0.22	0.07	0.35	111	2.1	1.3	6.9
BF-GHA	825	42	0.20	0.03	0.27	42	1.4	0.9	4.9
BF-MALI	719	488	0.14	0.05	0.35	488	2.3	1.3	8.3
BF-NIG	1090	614	0.16	0.04	0.38	614	2.5	1.5	14.1
BF-TOG	660	91	0.27	0.06	0.41	91	2.5	1.4	5.8
CAM-CHAD	1169	25	0.17	0.07	0.27	25	2.2	1.3	6.7
CAM-NIGA	1087	35	0.27	0.03	0.34	35	5.0	2.0	9.1
CHAD-NIG	1422	301	0.18	0.05	0.30	301	2.4	1.3	7.6
CHAD-NIGA	1383	79	0.22	0.04	0.28	79	2.6	1.0	5.5
CI-GHA	607	60	0.17	0.04	0.26	60	2.0	0.9	4.6
CI-GUI	905	24	0.17	0.02	0.22	24	2.5	1.0	3.9
CI-MALI	907	172	0.11	0.02	0.16	172	2.1	1.6	10.6
GAM-SEN	333	574	0.20	0.04	0.33	574	2.7	2.1	19.5
GHA-TOG	492	112	0.29	0.08	0.58	112	2.9	2.8	19.4
GUI-MALI	1003	72	0.14	0.02	0.20	72	3.6	2.2	9.0
GUI-SEN	1075	8	0.15	0.02	0.20	8	3.2	1.5	5.2
MALI-MAU	991	94	0.22	0.07	0.37	94	3.9	2.4	17.3
MALI-NIG	1617	1500	0.14	0.05	0.29	1500	3.7	2.6	19.3
MALI-SEN	1260	1161	0.17	0.04	0.29	1161	4.8	3.1	19.8
MAU-SEN	634	65	0.23	0.04	0.30	65	3.8	1.9	11.0
NIG-NIGA	693	417	0.18	0.05	0.31	417	2.2	1.5	8.5
Millet		1299	0.16	0.04	0.31	1299	3.2	2.8	19.8
Sorghum		2116	0.18	0.05	0.41	2116	3.0	2.2	19.3
Maize		1632	0.19	0.05	0.35	1632	3.0	1.9	17.9
Cassava		106	0.29	0.08	0.58	106	3.0	2.9	19.4
Local rice		392	0.13	0.04	0.26	392	2.4	1.5	9.0
Imported rice		896	0.12	0.04	0.26	896	4.6	3.0	19.5
Average values	1082	6441	0.17	0.06	0.58	6441	3.2	2.4	19.8

Table B10: Bilateral border effects

	Standard deviation of real exchange rate		Half-life of price deviations	
	Coeff.	Dist. equivalent (kms)	Coeff.	Dist. equivalent (kms)
Log(distance)	0.012*** (0.001)		0.296*** (0.036)	
BEN-BF	0.026*** (0.005)	9	0.106 (0.180)	0
BEN-NIG	0.022*** (0.004)	6	-0.034 (0.179)	0
BEN-NIGA	0.012* (0.007)	3	-0.506** (0.222)	0
BEN-TOG	0.007 (0.005)	0	-0.422** (0.187)	0
BF-GHA	0.034*** (0.005)	17	-1.074*** (0.167)	0
BF-MALI	0.000 (0.002)	0	-0.398*** (0.084)	0
BF-NIG	0.011*** (0.002)	3	0.129* (0.072)	2
BF-TOG	0.047*** (0.004)	53	0.421*** (0.126)	4
CAM-CHAD	0.015** (0.007)	4	0.405 (0.274)	0
CAM-NIGA	0.061*** (0.009)	167	1.822*** (0.336)	471
CHAD-NIG	0.012* (0.006)	3	0.020 (0.197)	0
CHAD-NIGA	0.029*** (0.008)	12	0.301 (0.218)	0
CI-GHA	0.007* (0.004)	2	-0.347** (0.163)	0
CI-GUI	0.042*** (0.005)	35	0.492 (0.403)	0
CI-MALI	0.006** (0.002)	2	-0.346*** (0.130)	0
GAM-SEN	0.063*** (0.002)	194	1.58*** (0.130)	208
GHA-TOG	0.027*** (0.006)	9	0.231 (0.246)	0
GUI-MALI	0.045*** (0.004)	44	1.624*** (0.290)	241
GUI-SEN	0.068*** (0.006)	298	2.988*** (0.343)	24212
MALI-MAU	0.065*** (0.008)	236	1.506*** (0.315)	162
MALI-NIG	0.017*** (0.001)	4	0.504*** (0.091)	5
MALI-SEN	0.043*** (0.001)	37	2.235*** (0.103)	1902
MAU-SEN	0.078*** (0.009)	702	2.4*** (0.279)	3321
NIG-NIGA	0.018*** (0.004)	5	0.132 (0.109)	0
Observations	9,337		9,337	
R-squared	0.865		0.56	

All regressions include market-product dummies. Robust standard errors in parentheses are clustered by market-pairs.

Table B11: Upper and lower bounds. Dependent variable: standard deviation of relative prices

	Average estimation		**Lower bound**			**Upper bound**		
	Coeff.	Dist. equivalent (kms)	Coeff.	Dist. equivalent (kms)	Ommitted dummy	Coeff.	Dist. equivalent (kms)	Ommitted dummy
Log(distance)	0.012*** (0.001)		0.012*** (0.001)			0.012*** (0.001)		
BEN-BF	0.026*** (0.005)	9	0.003 (0.006)	0	BEN	0.048*** (0.004)	53	BF
BEN-NIG	0.022*** (0.004)	6	-0.018*** (0.006)	0	BEN	0.047*** (0.003)	49	NIG
BEN-NIGA	0.012* (0.007)	3	0.004 (0.007)	0	BEN	0.02** (0.009)	5	NIGA
BEN-TOG	0.007 (0.005)	0	-0.028*** (0.006)	0	TOG	0.037*** (0.006)	21	BEN
BF-GHA	0.034*** (0.005)	17	-0.013** (0.006)	0	GHA	0.082*** (0.005)	842	BF
BF-MALI	0.000 (0.002)	0	-0.025*** (0.003)	0	BF	0.026*** (0.002)	8	MALI
BF-NIG	0.011*** (0.002)	3	0.00 (0.003)	0	BF	0.021*** (0.001)	6	NIG
BF-TOG	0.047*** (0.004)	53	-0.008 (0.005)	0	TOGO	0.102*** (0.004)	4581	BF
CAM-CHAD	0.015** (0.007)	4	-0.029** (0.014)	0	CHAD	0.029*** (0.009)	11	CAM
CAM-NIGA	0.061*** (0.009)	167	0.035*** (0.011)	18	NIGA	0.082*** (0.010)	842	CAM
CHAD-NIG	0.012* (0.006)	3	-0.024** (0.012)	0	CHAD	0.037*** (0.002)	21	NIG
CHAD-NIGA	0.029*** (0.008)	12	0.025** (0.012)	8	CHAD	0.037*** (0.008)	21	NIGA
CI-GHA	0.007* (0.004)	2	-0.048*** (0.004)	0	GHA	0.061*** (0.005)	150	CI
CI-GUI	0.042*** (0.005)	35	0.032*** (0.006)	14	CI	0.053*** (0.009)	80	GUI
CI-MALI	0.006** (0.002)	2	-0.013*** (0.004)	0	CI	0.023*** (0.001)	6	MALI
GAM-SEN	0.063*** (0.002)	194	0.051*** (0.004)	68	GAM	0.074*** (0.002)	468	SEN
GHA-TOG	0.027*** (0.006)	9	0.017** (0.007)	4	TOGO	0.033*** (0.006)	15	GHA
GUI-MALI	0.045*** (0.004)	44	0.038*** (0.008)	23	GUI	0.052*** (0.003)	74	MALI
GUI-SEN	0.068*** (0.006)	298	0.059*** (0.008)	132	SEN	0.076*** (0.010)	539	GUI
MALI-MAU	0.065*** (0.008)	236	0.027** (0.011)	9	MAU	0.104*** (0.006)	5405	MALI
MALI-NIG	0.017*** (0.001)	4	0.001 (0.001)	0	NIG	0.031*** (0.002)	13	MALI
MALI-SEN	0.043*** (0.001)	37	0.027*** (0.002)	9	SEN	0.058*** (0.002)	122	MALI
MAU-SEN	0.078*** (0.009)	702	0.056*** (0.010)	99	MAU	0.102*** (0.004)	4581	SEN
NIG-NIGA	0.018*** (0.004)	5	-0.007 (0.007)	0	NIGA	0.042*** (0.002)	31	NIG

All regressions include market-product dummies. Robust standard errors in parentheses are clustered by market-pairs. Dependent variable: Standard deviation of relative prices

Chapter 3

Alert at Maradi: Preventing Food Crises by Using Price Signals[†]

[†] This chapter has been published under the reference: Araujo, C., Araujo-Bonjean, C., & Brunelin, S. (2012). Alert at Maradi: Preventing Food Crises by using Price Signals. World Development, 40(9), 1882-1894. The indicators defined in this chapter are currently being used by the World Food Program to detect abnormally high food prices.

3.1. Introduction

Countries located in the Sahel region of Africa are repeatedly confronted by episodes of rapid increase in grain prices resulting in food crises, sometimes acute, as in Niger in 2005. This crisis highlighted the weaknesses of the early warning system which failed to anticipate the crisis, and under-estimated its extent. In Niger, as in the other countries of the Sahel region, the food crisis prevention systems remain primarily oriented towards the detection of food production deficits. In these countries, food insecurity is above all the consequence of insufficient food production, which results from adverse weather conditions. As a consequence, the present early warning systems focus on monitoring the conditions of food crops and estimating food availability.

However, in spite of the significant resources used at the national and international level to assess future food availability (e.g. yearly agricultural surveys, monitoring of the crop season, weather forecasting models and agro-climatic models based on satellite data, etc), the exercise remains difficult, politically sensitive, and prone to controversy. For example, marketing year 2004/05, initially considered as one of the best years ever known in the Sahel, finally proved to be a deficit year (Egg *and al.*, 2006). Also regional dialogue within the framework of the food crisis prevention network in Sahel and West Africa regularly exhibits large inconsistencies between the forecasts established by bordering countries.

Furthermore, production forecasts provided in the Cereal Balance Sheet, which also integrates stocks and trade estimates are generally published in late October after the beginning of the harvest. These figures are then adjusted between January and March when yield data collected through the agricultural survey become available. As a consequence, production forecasts do not really provide early information about the state of future food availability. Assessing the level of stocks and trade flows constitutes another major difficulty when estimating food availability. Grain storage is handled by private agents who are reluctant to give such strategic information, while grain trade with neighboring countries usually takes place in the informal sector and is mostly unregistered. As a consequence the information on production forecasts, initial stocks and trade provided in the Cereal Balance Sheet, is generally considered to be of poor quality.

Paradoxically, little attention is paid to the information conveyed by market prices. In some countries such as Niger, occasional vulnerability analyses aimed at identifying the populations at risk, and targeting interventions, are conducted when production forecasts are alarming. In these analyses, food price information is considered as an indicator of the ability of the households to ensure access to markets to compensate for food deficit.

But the information provided by market prices could also be used to forecast future crises. Indeed, if markets are efficient, prices at any given time fully reflect all available information not only on current food availability but also on agents' expectations about future scarcity (see for instance Ravallion, 1985; Deaton and Laroque, 1992). Price changes are driven by the arrival of new information in the market, and any new information on future market conditions is immediately reflected in prices. Thus, it is expected that prices reflect the available information on the future harvest very early in the crop season. Of course, if markets are not efficient due to agents' irrational behaviour, or informational failures, market prices may not reflect the actual state of food availability. In that case the information provided by market prices will not be exploitable by an early warning system.

In this paper, it is argued that the information provided by market prices can usefully complement existing early warning systems which tend to privilege biophysical models. The objective is to use price data to consolidate food security forecasts, and build indicators to alert policymakers as to when a future crisis can be expected. In other words, the aim of this research is to exploit the statistical properties of grain price data to detect the warning signs of a looming crisis, early in the crop marketing year.

The analysis focuses on three countries – Mali, Niger and Burkina Faso – and a local crop – millet – which plays an essential role in the diets of Sahelian populations. Price data come from the national *Systèmes d'Information sur les Marchés* of each country. The paper is organized in the following manner. Section two stresses the important role of millet in food security and sets out the main characteristics of the sample markets. Section three is devoted to identifying the markets that play a leading role in influencing prices at the national and regional level. Section four presents an analysis of millet price dynamics aimed at identifying the price crises during the sample period, and characterizing the price behaviour during the period preceding a crisis. Section five is dedicated to the identification of warning indicators. These indicators are based on the difference between the current price and its long run value measured at the beginning of the harvest season. The relevance of these indicators is tested in section six. The final section presents conclusions.

3.2. Context and sample description

Burkina Faso, Mali and Niger belong to the same regional integration area (ECOWAS) and to a common monetary union (UEMOA). These countries share many other common characteristics that call for a regional approach to food crisis prevention. We first stress the role of millet in food security, and then present the markets under study and the data set.

3.2.1. The critical role of millet in food security

The Sahel is one of the poorest regions of the world and millet is the main grain crop. Nigeria is the largest producer, with 54% of West African millet production. Niger is the second producing country with 21% of West African production, ahead of Mali and Burkina Faso (Table 3.1). Northern Nigeria and South Niger belong to the same production basin, which is the largest in West Africa, while Burkina Faso and Mali belong to the second production basin of the region (Soulé and Gansari, 2010).

Table 3.1: Millet production and supply

	Burkina Faso	Mali	Niger
Millet production in 2008 (tons)	1 255 190	1 413 910	3 489 390
Millet production in % of West Africa production (2008)	8	8	21
Millet production in % of total cereal production (2008)	29	29	72
Millet supply (kg/capita/year) in 2007	70.3	65.8	137.8
Total food supply (kcal/capita/day) (2007)	2677	2614	2376
Millet supply in % total food supply (2007)	21	21	39

Source: FAOSTAT. Millet supply = Production + Imports + ΔStocks – Exports – Seed – other utilizations

Burkina Faso, Mali and Niger are closely tied through millet trade flows. Niger is structurally an importer of millet. Its main source of imports is Nigeria, but imports from Burkina Faso and Mali have been expanding during the last decade. While millet is the subject of intensive cross-border trade in West Africa it is not traded internationally. As a consequence millet price variations in the sub-region mainly reflect changes in local supply conditions, demand being less volatile.

The millet growing season varies from year to year according to the start of the rains, but generally begins in April and ends in October. Usually, sowing takes place from May to August. Harvest starts in October and lasts until December. Part of millet production is sold at harvest by farmers to meet their financial needs. The other part, intended for family consumption and seed production, is stored on the farm until the next season or beyond;

indeed millet can be stored without damage for more than a year. The wholesalers hold grain stocks for generally short periods, not more than two or three months (Aker, 2010). The public authorities also manage food stocks that are built up at the beginning of the year (February-March), and which are intended to be sold on the market in the following months.

Millet prices are characterized by large seasonal fluctuations especially in Niger, due to the seasonal pattern of the production cycle. Prices are lowest during the harvest and post-harvest period (October to February). Then they gradually rise to reach their maximum level at the end of the lean season (May to August in Niger; June to October in Mali and Burkina Faso) which precedes the new harvest and during which farmers' stocks are depleted.

Millet and sorghum are the staple diet, especially in rural areas. According to the latest available data, millet supply represents more than 20% of total food supply in Mali and Burkina Faso, and almost 40% in Niger (Table 3.1). In that context, a millet price increase may have dramatic consequences on food security by directly affecting the entitlement set of poor people (Sen, 1981).

Sharp rises in grain prices generally follow a crop failure due to bad weather conditions. Indeed, rain fed farming is the dominant production system and is highly vulnerable to climatic shocks, especially to drought. It should be stressed that the price increase does not necessarily reflect the severity of the food deficit. As shown by Sen (1981) the food price increase may be exacerbated by market failures – excessive hoarding or inadequate spatial arbitrage – so that a modest decline in food availability may generate large price variations.

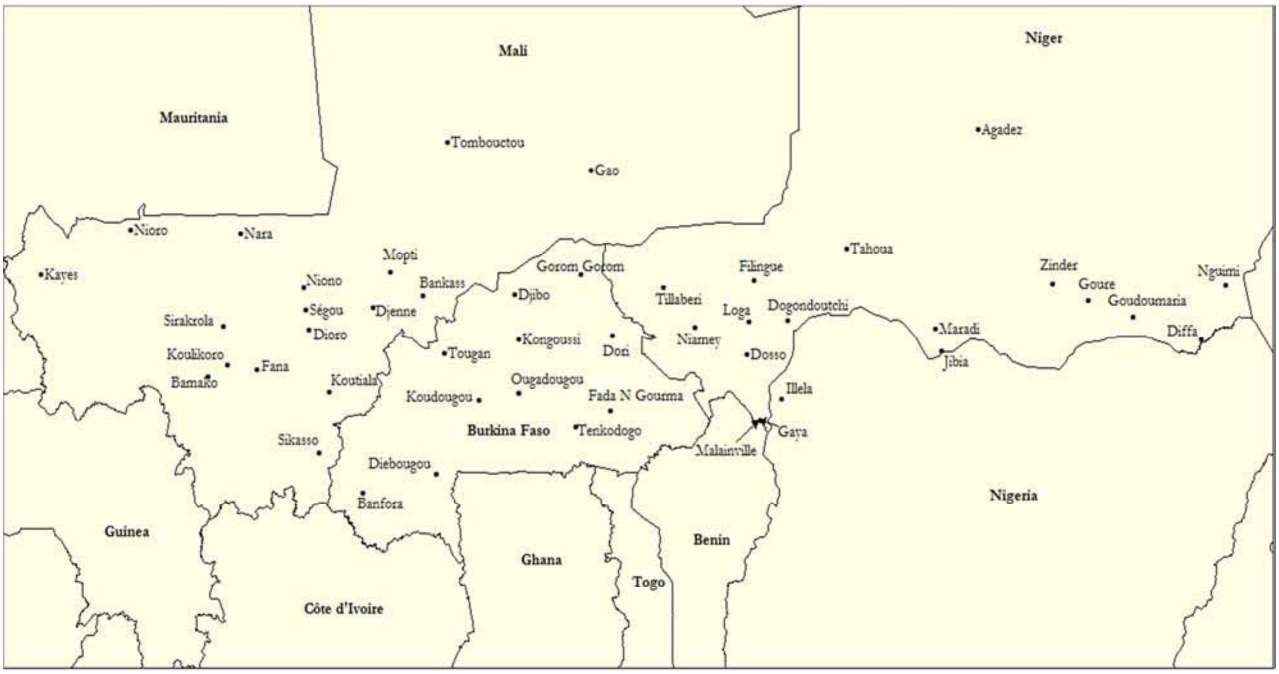
The impact of a food price increase on food security is biggest when the exogenous shock also affects other sources of entitlement, such as wages, assets and transfers (Ravallion, 1997; O'Grada, 2007). This is typically the case during drought periods in Mali, Niger and Burkina Faso. The millet price is positively correlated with other local grain prices, and negatively correlated with the price of livestock, an asset which is typically held as a buffer stock in this region. As a consequence, the possibilities for substitution in consumption are limited, while livestock sales do not compensate for losses in income. More generally, the literature shows that insurance mechanisms against income shocks are weak, and only allow for partial consumption smoothing in African developing countries (see for instance, Kazianga and Udry, 2006).

3.2.2. The sample markets

Burkina Faso, Mali and Niger share a harmonized system for collecting price information on grain markets. In each country a market information system (MIS) was started in the early 90s. The implementation of these devices was part of the measures accompanying the liberalization of the agricultural sector within the framework of structural adjustment programs. The aim was to increase market efficiency after the withdrawal of the State from the production and marketing of agricultural products.

MISs collect market prices for major agricultural products (but also livestock) and disseminate this information to producers, consumers and traders through the media. They have now accumulated a large amount of information and can trace the evolution of food prices in a wide geographical area and for a wide range of commodities.

Map 3.1: Millet markets studied



Source: the authors

We selected a sample of 44 millet markets from the markets covered by the MISs: l5 markets in Niger, 12 in Burkina Faso, and 17 in Mali (see Table C1 in the appendix). Market selection was based on the quality of available information: markets for which too much data is missing were dropped. As can be seen in table D1 and map 3.1, the selected sample includes a variety of markets that differ according to their location: remote area, border proximity, production area or urban area. The observation period starts in January 1990 in Niger, January 1992 in Burkina Faso and February 1993 in Mali.[18]

3.3. The leading markets

The main objective of this part of the analysis is to identify markets whose prices can help in forecasting the future value of prices in other domestic and regional markets. These "leading markets" are identified using Granger causality tests that are conducted in a multivariate vector autoregressive (VAR) framework.

3.3.1. The VAR model

The main advantage of the VAR model is that it takes into account the fact that prices are determined simultaneously on a set of markets, as well as the dynamic nature of price adjustments. Each price is considered as endogenous and is expressed as a function of the lagged values of all of the endogenous variables in the system. The estimated model is given by:

$$\boldsymbol{P}_t = \gamma + \sum_{i=1}^{p} A_i P_{t-i} + \xi_t \qquad (1)$$

$\boldsymbol{P}_t$ is a k vector of real prices, A_i is a matrix of coefficients to be estimated and ξ_t is a vector of innovations that may be contemporaneously correlated but are uncorrelated with their own lagged values and uncorrelated with all of the right-hand side variables.

$E(\xi_t) = 0$; $E(\xi_t \xi_t') = \boldsymbol{\Sigma}$ (an $m \times m$ positive semi definite matrix) ; $E(\xi_t \xi_{t'}') = 0$ for all $t \neq t'$. $t = 1, \ldots, T$. T = 201 for Burkina Faso, T = 226 for Niger and T = 191 for Mali.

The lag order p is selected using the Schwarz information criterion. Prices are deflated by the domestic consumer price index (base 2000 = 100).

3.3.2. The Granger causality test

The Granger causality tests indicate whether there is a statistically significant relationship between current prices on market i and lagged prices on market j. They consist of standard F-test, equation by equation, for the joint hypothesis of nullity of some of the coefficients of the

[18] The MIS of Niger also covers five markets located in northern Nigeria and one market in northern Benin. Unfortunately the observation period is quite short for these markets (2000-2008) so they cannot be incorporated in the following econometric analysis despite their importance in regional trade.

VAR system. In the null hypothesis (P_j does not cause P_i), the coefficients of the lagged prices in market *j* in the P_i equation, are null.

The Granger causality tests do not reveal the structural nature of the relationship between prices (the parameters are not readily interpretable), and do not provide information about the causal factors that lead to dynamic adjustments between prices. According to the Granger approach, P_i is said to be Granger caused by P_j if P_j helps in the prediction of P_i. The Granger causality test does not by itself indicate causality, but identifies precedence between two variables and measures the information content of lagged variables. This test can therefore be used to identify markets whose prices can help in forecasting future prices in other markets.

We consider as leading markets, those markets that *Granger cause* a large number of other markets, but are themselves *Granger caused* by only a few markets. In other words, lagged prices in leading markets play a significant role in influencing current prices in other markets and can help to predict the latter. In addition, prices in leading markets are weakly exogenous (i.e. they do not depend on the lagged prices of the other markets in the sample).

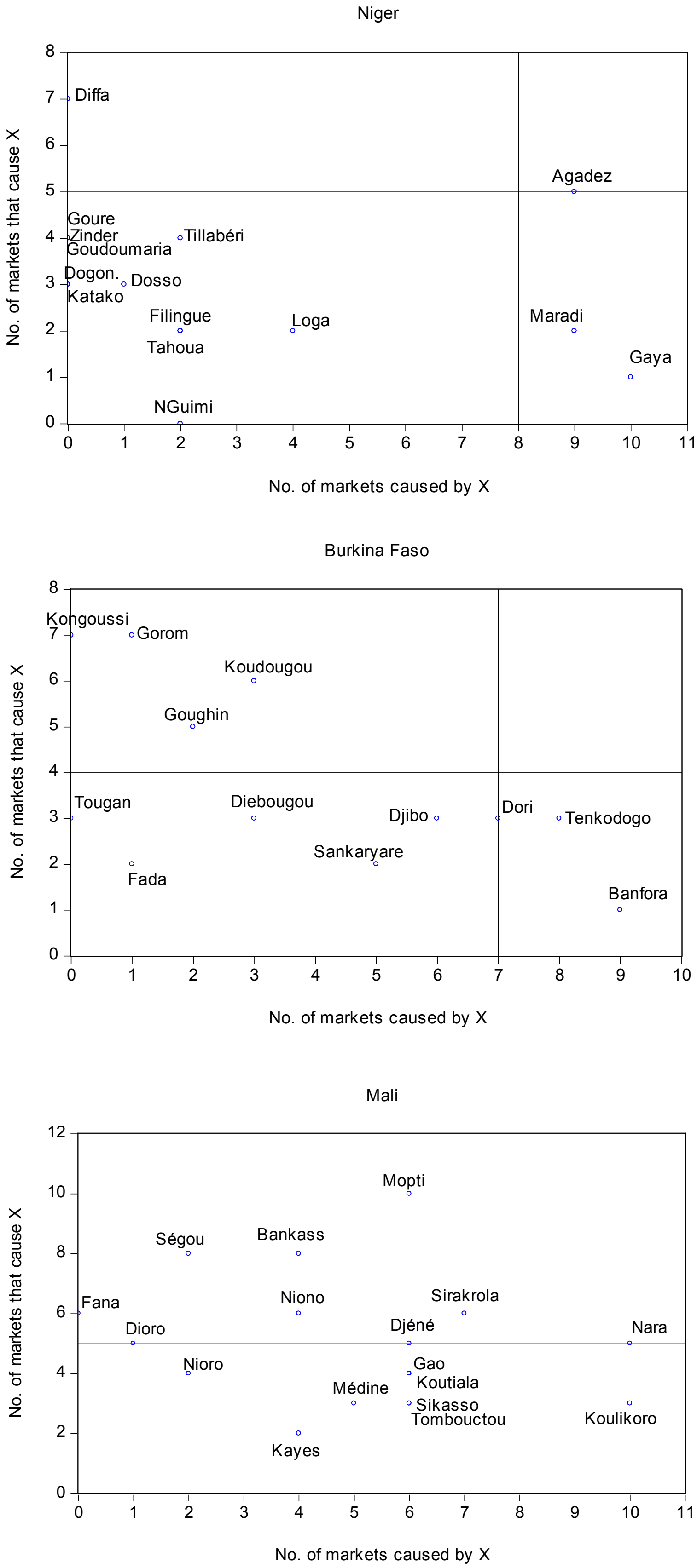
The Granger causality tests are first performed using a VAR model specific to each country, incorporating all the markets of that country. This approach allows identification of the leading markets in each country. Secondly, causality tests are performed on a regional VAR model limited to 25 markets of the sub-region.[19]

3.3.3. Results

To identify the leading markets, markets are ranked according to two criteria: the number of markets that are *Granger caused* by each market, and the number of markets that each market *Granger causes*. We consider as a leading market at the domestic level, a market that *causes* more than half of the sample markets (i.e. at least seven markets in Burkina Faso, nine markets in Mali, and eight markets in Niger). It appears that these markets are also caused by a small number of markets (less than 30%). As can be seen in figure 3.1, these criteria are highly discriminating. Only a few markets are classified as “leading markets” (Table 3.2): Gaya and Maradi in Niger; Dori, Tenkodogo and Banfora in Burkina Faso; Nara and Koulikoro in Mali. Nara and Dori are on the limit for consideration as leading markets; they could have been considered as non leading markets. Indeed, the subsequent analysis shows that the pertinence of alert indicators based on Nara prices is doubtful.

[19] The regional sample includes: 8 markets in Niger, 7 in Burkina Faso, and 10 in Mali.

Figure 3.1: Granger causality test results



These results are not surprising for Maradi and Gaya. Maradi is one of the most important markets of Southern Niger, the main producing region. Gaya is located on the border with Benin and is one of the main gateways for grain imports. In Mali, Koulikoro is an important wholesale market located in the same region as Nara. In Burkina Faso, Dori is an important wholesale market for millet in the Sahel region, and is close to the border with Niger. Banfora is located at the intersection of major roads, close to the borders of both Mali and Ivory Coast, and is also close to Bobo Dioulasso the second city in Burkina Faso. Tenkodogo is located in a major production area.

Table 3.2: Leading markets

		Number of markets that are Granger caused by market X		Number of markets that Granger cause market X	
	Market X	National level[a]	Regional level[b]	National level[a]	Regional level[b]
Niger	Gaya	10	3	1	3
	Maradi	9	8	2	3
Burkina Faso	Banfora	9	7	1	3
	Dori	7	9	3	2
	Tenkodogo	8	9	3	2
Mali	Koulikoro	10	3	3	5
	Nara	10	0	5	4

[a]: results from the VAR model estimated on a market sample restricted to domestic markets.
[b]: results from the VAR model estimated on the regional market sample (25 markets). Only markets belonging to foreign countries are accounted for in these calculations.

At the regional level, the analysis confirms the leading role of Maradi: prices in this market *Granger cause* those of 8 markets in Burkina Faso and Mali (Table 3.2). The leading role of Maradi probably reflects the influence of Nigeria on millet prices within the whole sub region. The markets of Dori and Tenkodogo also confirm their leading market status at the regional level. In contrast, Gaya (Niger), Nara (Mali) and Banfora (Burkina Faso) which appeared to be leading markets at the national level, do not play a significant role at the regional level.

In summary, the causality tests highlight the important role of a small number of markets at the national and regional level, namely: Maradi, Dori and Tenkodogo, and to a lesser extent, Gaya, Nara and Koulikoro. Priority should be given to the monitoring of these markets whose lagged prices can help to predict the prices of other markets, in the framework of an early warning system.

3.4. Price crisis characteristics

The approach consists of firstly identifying price crises, and then characterizing the price behaviour during periods that precede crises.

3.4.1. Identifying price crises

The stationarity tests (Table C1 in the Appendix) reject the presence of a unit root, and lead to the consideration of all the price series as trend stationary. The price trend (2) is estimated for each market's price over the whole period. The seasonal dummies $M_{s,}$ catch the monthly price fluctuations related to the production cycle, and the trend $T,$ captures long term movements (e.g. related to population growth):

$$P_t = aT_t + \sum_{s=1}^{12} b_s M_{st} + \zeta_t \qquad (2)$$

with:

P_t the current millet price at time t and ζ_t an *iid* random variable with: $\zeta_t \sim N(0, \sigma_\zeta^2)$.

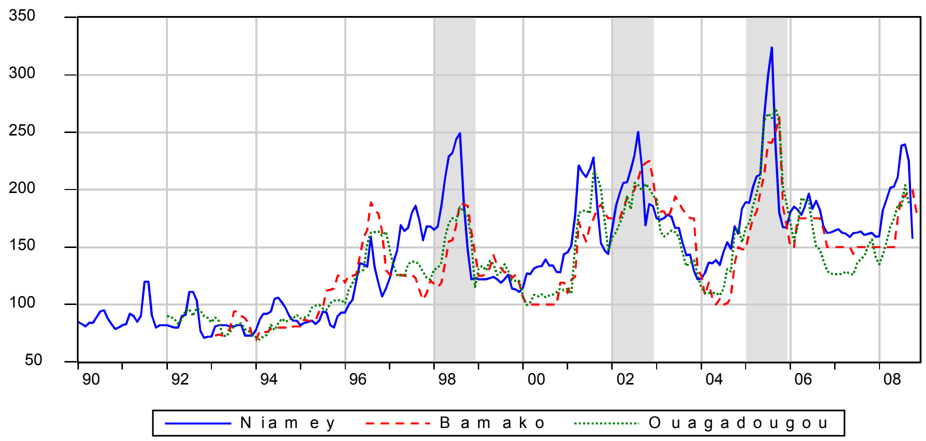
The coefficient's stability is tested using the Quandt-Andrews breakpoint test[20] for 158 possible breakpoint dates in the period 1990-2008 in Niger, 131 for Mali and 139 for Burkina Faso[21]. The tests fail to reject the null hypothesis of no structural breaks.

In the following we consider that there is a crisis at time t on the market under consideration if the spread between the observed price, P_t, and its trend value, $\hat{P}_t$, is greater than one standard deviation, i.e. if:

$$I_t = P_t - \hat{P}_t \geq \sigma_I \qquad (3)$$

[20] Test for one or more unknown structural breakpoints in the sample.
[21] According to a 15% trimming procedure that excludes the first and last 7.5% of the observations.

Figure 3.2: Millet prices in the capital cities (Fcfa/kg)



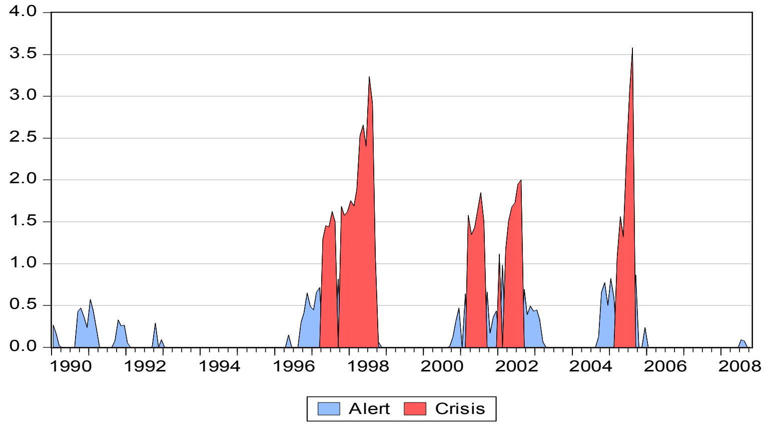
Gray: crises common to the three countries
Source: MIS's and authors' calculations

According to our definition of crisis, Burkina Faso, Mali and Niger experienced three common price crises in 1998, 2002 and 2005 (Figure 3.2). In addition to these shared major crises the three countries were affected by crises of smaller magnitude: 1997 in Niger, 1996 in Mali and Burkina Faso, 2001 in Niger and Burkina Faso, 2003 in Mali. Most of these price crises resulted from a drop in production, but the correlation between price and supply shocks is fairly weak (Araujo and Brunelin, 2010). In 2008, a few episodes of short-term crises were recorded, limited to a small number of millet markets in Niger and Burkina Faso. These crises were of lesser importance, and 2008 cannot be considered as a crisis year in the millet markets.

3.4.2. Dating price crises

A deeper analysis shows that crises break out during the lean period and are preceded by a period of high prices that can be regarded as an alert phase. This phenomenon is most obvious in Niger where crises erupt in April, and end in September. They are preceded by a period running from September/October to March during which prices are above their trend value. For example in Maradi, millet prices were above their trend value from September 1996 to March 1997, and the crisis broke out in April 1998 (Figure 3.3). At Gaya, prices were above their trend value from September 1996 to January 1997, and the crisis broke out in January 1997.

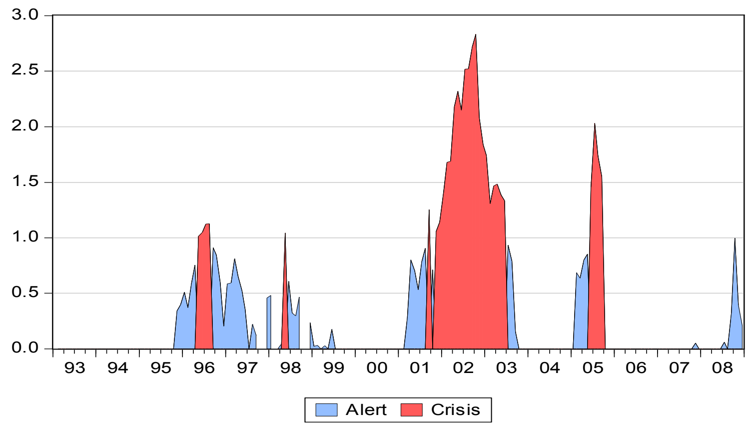
Figure 3.3: Maradi (Niger). Alert and crisis phases over the period 01/1990 to 10/2008



Crisis phase: $I_t/\sigma_I \geq 1$; alert phase: $I_t/\sigma_I > 0$

In Mali, crises occur later in the year, erupting in May/June and ending in October/November. This lag follows the harvest calendar that starts later in Mali. These crises are preceded by a period of high prices running from October to May. Thus, for example, the 1996 crisis that broke out in May/June on the 17 markets of the sample was preceded by a period running from October 1995 to April 1996 during which prices in almost all the markets were above their trend value (see Figure 3.4 as an illustration). The 1999 crisis was preceded in all markets, except Koulikoro, by a phase of high prices that began in December 1998. The 2002 crisis, the most severe, was preceded by particularly high prices starting in September 2001. In contrast, the 2002 crisis started very early in the year, in October or November for most markets.

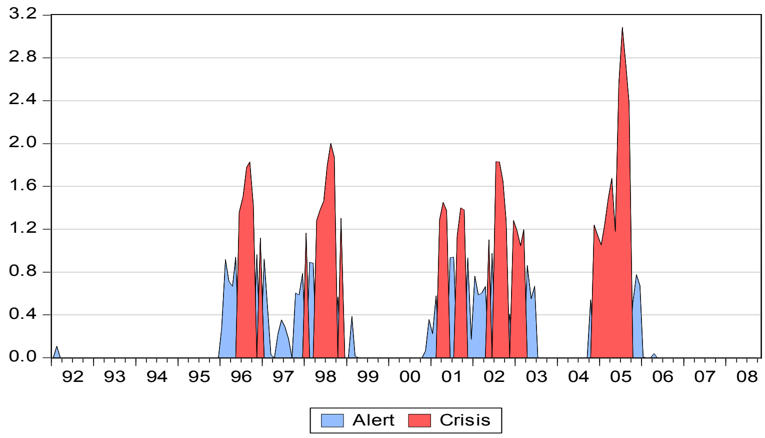
Figure 3.4: Nara (Mali). Alert and crisis phases over the period 02/1993 to 12/2008



Crisis phase: $I_t/\sigma_I \geq 1$; alert phase: $I_t/\sigma_I > 0$

In Burkina Faso, as in Mali, crises occur generally in May or June, and are preceded by positive shocks, but of lower magnitude, from November or December. For instance, the 1996 crisis was preceded by a period of high prices starting from November 1995 in Banfora, and Tenkodogo, and from January 1996 in Dori (Figure 3.5).

Figure 3.5: Dori (Burkina Faso). Alert and crisis phases over the period 01/1992 to 10/2008



Crisis phase: $I_t / \sigma_I \geq 1$; alert phase: $I_t / \sigma_I > 0$

In short, over the period studied, crises break out at the beginning of the lean season, and reach their climax at the end of the lean season. They are usually preceded by a warning phase, characterized by prices higher than their trend value during the harvest period.

3.5. Warning indicators

The above observations lead to the proposition of warning indicators based on the gap between prices and their trend value during the harvest and post-harvest period. Different indicators are proposed, whose relevance is tested using nonlinear panel models.

These indicators aim at capturing as soon as possible the price movements which herald a price crisis. Special attention is paid to the markets previously identified as leading markets. Three types of indicators are proposed being designed to capture the intensity and the spatial extent of the price distortions during the alert phase.

First, for each leading market (l), we define a binary warning indicator (A_{lr}) equal to 1 if the market registers a positive shock during the month r of the harvest period that runs from October to March:

$$A_{lr} = 1 \text{ if } I_{lr} = P_{lr} - \hat{P}_{lr} > 0 \text{ ; } = 0 \text{ otherwise} \quad (4)$$

Second, vigilance should increase with the magnitude of the price disequilibrium that is captured by an indicator of the intensity of the alert (AI_{lr}):

$$AI_{lr} = I_{lr} / \sigma_I \qquad (5)$$

This indicator is calculated for each leading market (*l*) and each month (*r*) of the alert period.

Third, the alert should go up if many markets are simultaneously on alert. An indicator of the spatial extent of the alert (AE_{nr}) is therefore given by the number of markets on alert during the month *r* in the country *n*:

$$AE_{nr} = \sum_{i=1}^{m} A_{ir} \text{ ; } \qquad m = \text{number of markets in country } n. \qquad (6)$$

Four limitations of these warning indicators must be underlined. First, while most of the price crises are preceded by an alert phase, not all phases of alert lead to a crisis. Thus, in 1990, 1991 and 2003 in Niger, prices were above their trend value over the period September to December, but the bubble burst in March or April of the next year (Figure 3.3). In general, after an alert phase, it is observed that either the crisis occurs, or the bubble bursts in March or April. In the latter case, the alert can be lifted by the end of April.

Second, the alert phase can sometimes be short, and so the crisis not anticipated. This is the case for Niger in 2001 - the crisis occurred suddenly in Gaya and N'Guigmi in April 2001, without being preceded by an alert phase. In this case, however, the alert could have been given in September at Maradi. In Burkina Faso also, the 2001 crisis broke out suddenly in March/April 2001 without a generalized warning phase. We note however, that Dori, identified as a leading market in the above analysis, had been on alert since November 2001.

Third, after a crisis prices return to the normal level, but the process may take time so that predicting prices for the following year can be difficult. Prices tend to return slowly to their trend value after a crisis, so that the alert holds, sometimes unnecessarily, until May/June of the next year. This is the case, for example, in Mali after the 1996 crisis (Figure 3.4). Malian prices in all the markets of the sample were above their trend value until spring 1997, inferring that the warning indicators would have been activated until April/May 1997.

Finally, some markets, such as Kayes and N'Guimi, exhibit atypical behaviour. In Kayes, crises tend to erupt a few months later (July/August) than in other Malian markets, and prices revert more slowly to their long-run equilibrium. This phenomenon can be explained by the relative isolation of these two markets, and delays in price shocks transmission.

3.6. Predictive power of early warning indicators

The predictive power of the early warning indicators defined above is tested econometrically using three types of nonlinear panel models: a probit model, a count data model, and a Tobit model[22]. Each model allows for time specific random effects.[23] The sample set consists of the three countries and a 19 year period of annual observations (1990 – 2008).

1. The first model (probit) seeks to explain the likelihood of a price crisis in country *n* at year *t*. The outcome, y_{nt}, is a binary variable that takes 1 if the country is in crisis at year *t*, and 0 otherwise. We consider that the country *n* is in crisis at year *t* if the mean crisis indicator, E(I), calculated on the sample of the *m* markets of the country during the lean period (*S*) of year *t*, is greater than one (Table 3.3). Let: $\begin{cases} y_{nt} = 1 & \text{(with probability } p) \\ y_{nt} = 0 & \text{(with probability } 1-p) \end{cases}$

A regression model is created by parametrizing the probability *p* to depend on a regressor vector of warning indicator (*x*), a parameter vector β and time-specific effects. The conditional probability is given by:

$$\Pr\left[y_{nt} = 1 \middle| x_{nt}, \beta, \alpha_t\right] = \Pr\left[y^*_{nt} > 0\right] = \Pr\left[x'_{nt}\beta + u_{nt} > 0\right] \text{ with, } u_{nt} = \alpha_t + \varepsilon_{nt}$$

y^*: latent variable. *n* denotes the *n*-th country, *t* the *t*-th time period; α_t captures the time-specific unobserved effects assumed to be constant over individuals, $\alpha_t \sim iid(0, \sigma^2_\alpha)$; $\varepsilon_{nt,}$ is an idiosyncratic error satisfying the usual assumptions: $\varepsilon_{nt} \sim iid(0, \sigma^2_\varepsilon)$, $E(x_{nt}, \varepsilon_{nt}) = 0$ and $Cov(\varepsilon_{nt}, \varepsilon_{n't'}) = V(\varepsilon_{nt}) = 1$, if $n = n'$ and $t = t'$, or 0 otherwise. The unobservable time-specific effects are correlated neither with errors nor each explanatory variable.

The proportion of the total variance contributed by the time-level variance component is given by: $\rho = \frac{\sigma^2_\alpha}{\sigma^2_\alpha + 1}$. When ρ is zero, the time-level variance component is unimportant and the panel estimator is not different from the pooled estimator.

[22] See Cameron and Trivedi (2005) and Wooldridge (2010) for a review of these models.

[23] A qualitative response model with fixed effects is confronted by the incidental parameters problem. In a fixed effects model the specific effects may be correlated with the regressors, generally leading to inconsistent estimation of all parameters (Lancaster, 2000).

2. The second estimated model is a count data model that seeks to explain the extent of the crisis. The dependent variable, y_{nt}, is a count of the number of markets across country *n* which experienced at least one episode of crisis during the lean season of the year *t* (Table 3.3).

y_{nt}, takes on non-negative integer values, including zero: {0, 1, 2, …}.

The basic Poisson probability specification is: $\text{Prob}(y \mid x) = f(y \mid x) = \frac{e^{-\lambda}\lambda^{y}}{y\,!}$, where *y*! is *y* factorial ; $\lambda \equiv E(y|x) = V(y|x)$.

Following Hausman *et al.* (1984), we consider the random effects panel Poisson specification where the Poisson parameter is specified as: $\tilde{\lambda}_{nt} = \lambda_{nt}\alpha_t = e^{x'_{nt}\beta + \mu_t}$, $\tilde{\lambda}_{nt} > 0$; $\alpha_t = e^{\mu_t}$ are the time-specific effects (unobserved); x_{nt} is a vector of warning indicators. It is assumed that α_t is distributed as a gamma random variable: $\alpha_t \sim \Gamma(\eta,\eta)$, with $E(\alpha_t) = 1, V(\alpha_t) = \delta$. Note that when δ is zero the panel estimator is not different from the pooled estimator.

Table 3.3: Price crises in millet markets

	Country in crisis[a]			No. of markets affected by a crisis[b]			Crisis intensity[c]		
	Burkina Faso	Niger	Mali	Burkina Faso	Niger	Mali	Burkina Faso	Niger	Mali
1990	-	0	-	-	0	-	-	0	-
1991	-	0	-	-	1	-	-	0	-
1992	0	0		0	0	-	0	0	-
1993	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0
1996	1	0	1	11	1	17	2	0.1	4
1997	0	1	0	2	14	0	0.1	1.5	0
1998	1	1	1	12	15	15	3.3	3.9	2.6
1999	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	1	0	0	0	0
2001	1	1	0	11	14	6	1.6	1.8	0.5
2002	1	1	1	12	15	17	1.7	1.8	4.4
2003	0	0	0	0	0	13	0	0	0.9
2004	0	0	0	0	0	0	0	0	0
2005	1	1	1	12	15	17	4.3	3	4.6
2006	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0
2008	0	0	0	3	3	0	0.3	0.1	0

[a] Variable equal to one if the mean crisis indicator, E(I), calculated on the sample of the *m* markets of the country in question during the lean period (*S*) of year *t* is greater than one; = 0 otherwise, with :

$$E(I)=\frac{1}{m}\frac{1}{S}\sum_{i=1}^{m}\sum_{s=1}^{S}\frac{I_{is}}{\sigma_I} \text{ and } I_{is} = P_{is}-\hat{P}_{is}$$

[b] Number of markets that have experienced at least one episode of crisis during the lean season.
[c] Intensity of the crisis = E(I) if E(I) > 0; =0 otherwise
Number of markets in the sample: Burkina Faso 12; Niger 15; Mali 17.
Lean season in Mali and Burkina Faso: June to October. Lean season in Niger: May to August.

3. The third model to be estimated is a limited dependent variable model (standard censored Tobit) that seeks to explain the intensity of the crisis (Table 3.3) where $y_{nt} \in [0 ; +\infty[$

The censored regression Tobit model expresses the observed response, y_{nt}, in terms of an underlying latent variable $y_{nt}^* = x_{nt}'\beta + u_{nt}$

$$\text{with } \begin{cases} y_{nt} = y_{nt}^* & if \;\; y_{nt}^* > 0 \\ y_{nt} = 0 & otherwise \end{cases} \; ; t = 1990, \ldots, T \, ; n = 1, \ldots, N .$$

x_{nt} is a vector of warning indicators; β is a vector of parameters to be estimated; u_{nt} is a random variable, $u_{nt} = \alpha_t + \varepsilon_{nt}$, defined as above.

The independent variables in the probit, Tobit and count models are the warning indicators defined above: a binary warning indicator for each leading market (A_{lr}), an indicator of the alert intensity for each leading market (AI_{lr}), and the number of markets on alert (AE_{nr}).

The test strategy consists in successively introducing the monthly warning indicators into the regressions, starting with the earliest indicator (October) and ending with the last one (March). The testing procedure stops when the alert indicator enters significantly in the regression. This procedure allows both for testing the adequacy of warning indicators, and identifying those which detect a looming crisis earliest.

Table 3.4 gives the marginal effects of the exogenous variables derived from the probit model. The share of the specific component (ρ) is quite high and significant, which means that the panel estimation is more relevant than the pooling estimation (see the likelihood ratio test).

The warning indicator for Maradi is significant from November; its marginal effect on the probability of crisis is 56% (Table 3.4, column 1). According to these results, if the millet price in Maradi is above its trend value during November, the likelihood of a widespread crisis arising six to seven months later is 56%. The probability of crisis also increases by, respectively, 33%, 50% and 34%, if the markets of Gaya, Dori, and Tenkodogo are on alert in November. However, an alert at Nara cannot be considered as a significant harbinger of a crisis until December.

The marginal effect of an alert in Maradi during the month of November is high, both in absolute terms, and relative to the marginal effect of an alert in any of the other leading markets considered. These results confirm the importance of monitoring price movements in Maradi.

The variable "number of markets on alert" is also significant from November (Table 3.4, columns 6-10). The marginal effect of the number of markets on alert in November on the probability of crisis is 7%, and this effect increases over time - it increases to 10% in December, 11% in January, 13% in February, and 17% in March.

Table 3.4: Probit model - Marginal effects. Dependent variable = 1 if the country is in crisis; = 0 otherwise

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Alert at leading market	Maradi November (Niger)	0.558										
		[0.043]										
	Gaya November (Niger)		0.326									
			[0.077]									
	Dori November (Mali)			0.500								
				[0.043]								
	Tenkodogo Nov. (Burkina Faso)				0.340							
					[0.061]							
	Nara December (Mali)					0.498						
						[0.118]						
Number of markets on alert	November						0.067					
							[0.097]					
	December							0.104				
								[0.020]				
	January								0.106			
									[0.012]			
	February									0.128		
										[0.007]		
	March										0.172	
											[0.042]	
AI	Maradi November											0.736
												[0.060]
Log-likelihood		- 17.476	-19.446	- 17.677	- 18.439	- 18.479	- 19.340	- 17.474	- 17.505	- 15.382	- 12.885	- 15.954
ρ		0.80	0.89	0.85	0.87	0.88	0.90	0.89	0.89	0.86	0.80	0.78
LR (ρ = 0)		8.43	13.73	11.68	13.42	13.87	13.93	12.32	12.89	9.75	5.47	7.42
		[0.002]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.001]	[0.010]	[0.003]
Number of observations		51	51	48	48	45	49	49	52	52	52	51

Intercept not reported. AI: intensity of the alert on the leading market.

P-values are in brackets. Approximation method of the log-likelihood: adaptive Gauss-Hermite quadrature (Naylor – Smith, 1982).

The alert intensity, which is measured as the price deviation from its trend value relative to its standard deviation, appears to be a good indicator of the occurrence of a crisis. This indicator is more relevant than the scope of the alert, which is caught by the number of markets on alert. Indeed, the marginal effect of the alert intensity at Maradi on the probability of crisis is as high as 74% for the month of November (Table 3.4). In other words, the higher the price increases in Maradi at the beginning of the season relatively to its trend value, the greater the likelihood of a widespread crisis.

Table 3.5: Probit model - Goodness-of-fit

	Alert at the leading market:					Number of markets on alert in:					Alert intensity
	Maradi Nov	Gaya Nov.	Dori Nov.	Tenkodogo Nov.	Nara Dec.	Nov	Dec.	Jan.	Feb	Mar.	at Maradi Nov
1. % of observations correctly predicted	0.78	0.71	0.71	0.65	0.69	0.71	0.71	0.73	0.73	0.92	0.76
2. % of crises correctly predicted	0.86	0.71	0.86	0.86	0.64	0.07	0.29	0.21	0.36	0.93	0.50
3. % of false alarms in total alarms	0.43	0.52	0.50	0.56	0.50	0.50	0.50	0.50	0.50	0.19	0.42
4. % prob. of crisis given no alarm	0.07	0.13	0.08	0.10	0.19	0.28	0.24	0.24	0.21	0.03	0.18

Cut-off probability of 30 %
1. (correct prediction of no crisis + correct prediction of crises) / total observations; 2. Correct prediction of crises / all true crises; 3. False alarms / total alarms; 4. Missing alarms / all predicted non-crises

Any early warning system (EWS) is confronted by two drawbacks: the number of false alarms (Type 2 errors), and the number of missing alarms (Type 1 errors). Table 3.5 presents some indicators of the predictive quality of the probit model based on the percentage of Type 1 and Type 2 errors, using a cut-off probability equal to 0.3[24]. Choosing a low cut-off means considering that missing a crisis is more costly than a false alarm (i.e. an alarm not followed by a crisis). Given the potential cost of a food crisis this assumption seems reasonable, even if the cost of preventive measures should not be ignored in case of a false alarm. Table 3.5 highlights once again the higher performance of an EWS based on Maradi price signals. This model correctly predicts 86% of price crises, with a probability of crisis given no alarm of only 7%, but at the expense of a 43% rate of false alarms.

The results from the count data model (Table 3.6) confirm the previous ones. They show that the warning indicator for Maradi significantly explains, from November onwards, the extent

[24] The cut-off is the threshold probability above which the predicted probability is interpreted as a signal of a coming crisis. The lower (higher) the threshold, the more (less) signals the model will send at the expense of raising the number of false alarms (missing crisis) (see for instance Berg and Patillo, 1999).

of the crisis to come, although only at the 10% significance level in November. The same applies for Dori's warning indicator from December onwards. Specifically, the incidence rate ratio (IRR)[25] shows that when Maradi (Dori) goes on alert in November (December) the predicted number of markets in crisis increases by a factor of 6.725 (6.786). An alert in Gaya in February is a significant predictor of an impending and generalized crisis. We note that an alert in Nara or Tenkodogo does not significantly predict the extent of the future crisis.

Table 3.6: Estimation results for the count data model: Incidence rate ratio.

Dependent variable: Number of markets that have experienced at least one episode of crisis during the lean season

Alert at leading market		Obs	Number of markets on alert		Obs	Alert intensity in Maradi		Obs
Maradi November	6.725 [0.083]	51	November	n.s.	49	November	n.s.	51
Nara	n.s.	45	December	1.068 [0.030]	49	December	13.214 [0.086]	51
Dori December	6.786 [0.071]	48	January	1.091 [0.043]	52	January	4.807 [0.023]	52
Tenkodogo	n.s.	48	February	1.130 [0.001]	52	February	11.593 [0.027]	52
Gaya February	3.187 [0.082]	52	March	1.173 [0.002]	52	March	5.493 [0.056]	52

Cluster-robust standard errors obtained from a cluster bootstrap with 1000 replications. *P-values* are in brackets. n.s.: non significant.
Approximation of the log-likelihood by adaptive Gauss-Hermite quadrature (Naylor – Smith, 1982).

The number of markets on alert (Table 3.6) enters significantly in the Poisson regression model, but its ability to predict the extent of the crisis is fairly low, with an IRR close to one in November. However the IRR for the number of markets on alert in March is slightly higher - the expected number of markets in crisis increases by 17% when one more market is on alert during March.

The intensity of the alert at Maradi is significant from December, and can be considered as a good predictor of the extent of the crisis (Table 3.6). The number of markets affected by the crisis increases sharply - by a factor of 13.2 - when the price shock in Maradi at the beginning of the season increases by one standard deviation. Lastly, for all regressions, the LR test confirms that the panel estimator is more relevant than the pooling estimator.

The results from the Tobit model (Table 3.7) corroborate these results. The warning indicator for Maradi in November is positively related to the intensity of the coming crisis. The same applies for the Gaya warning indicator in November, as well as Dori and Tenkodogo in

[25] The incidence rate ratio is given by e^{β}. It measures the variation in the dependant variable for a one unit change in the independent variable, x_{nt}, with all other variables held constant.

December. The marginal effects show that when Maradi goes on alert in November, the crisis intensity rises by 2.8. The marginal effect of Dori’s warning indicator (November) and Tenkodogo (December) is of the same order of magnitude; it is lower for Gaya (November).

Table 3.7: Estimation results for the Tobit model: Marginal effects.

Dependent variable: Crisis intensity

	Independent variables	Marginal effect		Log likelihood	Sample size
Alert at leading market	Maradi November (Niger)	2.812 [0.004]	0.72	- 52.87	51
	Gaya November (Niger)	1.792 [0.056]	0.78	- 55.18	51
	Dori December (Mali)	2.792 [0.008]	0.74	- 50.88	48
	Tenkodogo December (Burkina Faso)	3.151 [0.007]	0.74	- 50.45	48
Number of markets on alert	November	0.117 [0.030]	0.81	- 54.47	49
	December	0.170 [0.001]	0.82	- 52.06	49
	January	0.192 [0.000]	0.85	- 51.43	52
	February	0.214 [0.000]	0.85	- 48.10	52
	March	0.253 [0.000]	0.79	- 44.49	52
Alert intensity	Maradi November	3.096 [0.001]	0.68	- 52.05	51
	Maradi December	2.906 [0.003]	0.71	- 53.03	51
	Maradi January	2.812 [0.000]	0.64	- 51.80	52
	Maradi February	3.169 [0.000]	0.63	- 51.10	52

P-values are in brackets.
Approximation of the log-likelihood by adaptive Gauss-Hermite quadrature (Naylor – Smith, 1982).

As in the probit model case, the marginal effect of the number of markets on alert increases with time (Table 3.7). Finally, the intensity of the alert at Maradi at the beginning of the season (November) significantly explains the intensity of the future price crises. However, the marginal effect of this variable on the intensity of the crisis is not higher than the effect of the binary warning indicator.

In summary, the results show that the three types of warning indicators identified above are relevant, as they significantly explain the scope and the intensity of future price crises. It is of most importance to monitor millet price movements in Maradi during the harvest period. Indeed, the probability of a widespread crisis breaking out six or seven months later sharply increases when prices in Maradi are above their trend value in November. The results also show that monitoring all markets during the harvest period does not add significant extra information. Nevertheless, it may be useful to monitor the markets of Dori, Gaya and Tenkogogo in addition to Maradi. If these markets are also on alert during the last months of the year, the probability of crisis increases significantly.

3.7. Conclusion

Whatever the explanatory factors of the price crisis, our analysis shows that it is possible to anticipate crises from the observation of past price movements. The crises that erupt usually during April or May, may in fact be anticipated as early as November by monitoring the price movements in some key markets – most importantly Maradi, but also Dori, and to a lesser extent Gaya and Tenkodogo.

Therefore the warning indicators defined in this paper should usefully complement the early warning systems currently focused on crop monitoring. They have the advantage of being based on objective information, which is easy to collect, and quick to collate. These indicators could be calculated in each country and integrated into the national early warning system. The high inter-country correlation of price crises should encourage the construction of a regional warning system, incorporating indicators from all the three countries. Irregularities detected early, at the beginning of the harvest, on the border markets of Nigeria and Benin must lead to alerts for not only the authorities of Niger, but also of Burkina Faso and Mali.

Of course, our calculations face a number of limitations. The main one is the quality of the estimated price trend value. We used a very simple form for the trend equation. The advantage of this specification is ease of calculation and updating of indicators, on the other hand, the goodness of fit may be poor. The introduction of the consumer price index instead of the trend variable generally improves the accuracy of the estimates. However, the consumer price index is published with a delay of several months, so an early warning system based on this index would be ineffective.

With hindsight, the adequacy of the warning indicators, based on the deviation of prices from their trend value seems to be good. However it is difficult to assess the ability of these indicators to prevent crises in advance. Out-of-sample simulations were made for the period 2000-2008 which were satisfactory. They show, however, the need to periodically update the price trend. In that regard, we suggest a conservative approach that consists in updating the trend estimates only if the predicted trend values are lower than previous forecasts. This method, which tends to underestimate the trend value, is expected to lead to better detection of coming crises, although at the expense of an increase in the number of false alarms.

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Appendix C:

Table C1: Market characteristics and unit root tests

Region	Market	Type of market	Millet production in the region: % of total	Min price	Max price	Mean price	No Obs	ADF P.value	KPSS LM-Stat
Niger		**Sample period: January 1990 – October 2008**							
Agadez	Agadez	bulk	0.04	52	337	134	226	0.00	0.12
Diffa	Diffa	bulk	1.6	41	328	138	221	0.00	0.09
Diffa	Goudoumaria	consumption		45	371	131	215	0.02	0.08
Diffa	Nguimi	consumption		55	333	148	218	0.01	0.06
Dosso	Dogondoutchi	collect	18.6	48	270	114	217	0.00	0.08
Dosso	Dosso	bulk		58	329	139	226	0.00	0.11
Dosso	Gaya	cross-border		42	315	124	226	0.00	0.10
Dosso	Loga	consumption		50	279	123	216	0.00	0.07
Maradi	Maradi	bulk	21.2	39	261	104	226	0.00	0.12
Tahoua	Tahoua	bulk	18.4	54	369	144	226	0.00	0.11
Tillaberi	Filingue	collect	20.9	51	326	129	210	0.00	0.09
Tillaberi	Tillaberi	collect		58	306	145	226	0.00	0.11
Zinder	Goure	consumption	18.4	52	319	118	226	0.00	0.08
Zinder	Zinder	bulk		40	312	109	226	0.00	0.12
Niamey	Katako	consumption	0.3	71	324	141	226	0.00	0.09
Burkina Faso		**Sample period: January 1992–September 2008**							
Cascades	Banfora	retail	0.9	51	267	129	201	0.01	0.16
Centre est	Tenkodogo	retail	8.5	42	228	113	201	0.03	0.10
Centre nord	Kongoussi	retail	7.9	52	229	114	201	0.00	0.17
Centre ouest	Koudougou	retail	0.1	51	260	117	201	0.00	0.13
Est	Fada N'Gourma	retail	10.5	40	241	106	197	0.01	0.10
Mouhoun	Tougan	retail	18	33	220	105	194	0.01	0.12
Sahel	Djibo	retail	0.1	58	243	120	201	0.01	0.16
Sahel	Dori	retail		56	299	142	201	0.12	0.13
Sahel	Gorom-Gorom	retail		60	263	141	201	0.01	0.17
Sud Ouest	Diébougou	retail	5.4	36	265	120	201	0.02	0.14
Ouagadougou	Gounghin	consumption		69	236	126	201	0.04	0.08
Ouagadougou	Sankaryaré	consumption		70	271	137	201	0.05	0.10
Mali		**Sample period: February 1993 – December 2008**							
Kayes	Kayes	consumption	14	89	325	186	189	0.05	0.18
Kayes	Nioro			52	305	152	186	0.16	0.11
Koulikoro	Fana	production	16	45	227	112	185	0.02	0.09
Koulikoro	Koulikoro Gare	wholesale		55	249	127	190	0.01	0.10
Koulikoro	Nara			51	240	128	187	0.05	0.10
Sikasso	Sirakrola	production	18.2	34	212	100	188	0.00	0.13
Sikasso	Koutiala	bulk		46	218	118	188	0.02	0.15
Sikasso	Sikasso Centre	bulk		64	246	136	190	0.00	0.14
Segou	Dioro	production	17.1	35	205	89	192	0.02	0.07
Segou	Niono	bulk		46	228	111	192	0.01	0.06
Segou	Ségou centre	bulk		44	225	109	192	0.02	0.08
Mopti	Bankass	production	15.1	41	183	98	190	0.01	0.11
Mopti	Djenne	production		38	203	102	188	0.02	0.08
Mopti	Mopti Gangal	bulk		55	230	129	190	0.02	0.08
Tombouctou	Tombouctou	consumption	4.9	77	248	154	184	0.09	0.09
Gao	Gao	consumption	4	72	232	139	190	0.03	0.06
Bamako	Médine	consumption	10.3	69	263	142	191	0.05	0.09

Source: MISs and authors' calculations.

Chapter 4

Impact of climate related shocks on child's health in Burkina Faso[†]

[†] This chapter is a version of a paper co-authored with Catherine Araujo-Bonjean and Catherine Simonet.
We would like to thank the World Food Program for providing us the household database. We gratefully acknowledge FAO and the Meteorological Office of Burkina Faso for providing the rainfall data.

4.1. Introduction

Burkina Faso is a low income and a landlocked country located in the Sahel part of West Africa. Agriculture is the major source of growth, accounting for about a third of GDP growth. About 70% of the poor live in rural areas. They depend on rainfed agriculture for subsistence and face large income fluctuations originating from climate variability. In the absence of formal insurance households can hardly protect themselves against weather related income shocks. As evidenced by a large literature, risk mitigating strategies, self-insurance and informal risk sharing mechanisms set up by low-income farmers only afford a partial protection against income risk (Deaton, 1992; Morduch, 1995; Townsend, 1995).

Uninsured risk may have dramatic consequences on household welfare in the short and long run. Households experiencing an adverse shock may be forced to reduce their consumption, including health and schooling expenditures, as well as investment in their farm. In the most severe cases, agricultural households are forced to sell productive assets such as cattle to compensate for an income loss. By reducing the productive capacity of the household, a temporary income shock may have a persistent impact on future income (Rosenzweig and Binswanger, 1993; Rosenzweig and Wolpin, 1993; Morduch 1995, 1999). Therefore, uninsured risk is widely considered as a cause of chronic poverty (Dercon and Christiaenen, 2011; Jalan and Ravallion, 2001; Dercon, 2004; Lokshin and Ravallion, 2000).

The empirical literature has paid particular attention to the consequences of transitory income shocks on investment in human capital when insurance and credit markets are imperfect. Foster (1995) showed that fluctuations in the growth pattern for children exposed to the severe flood of 1988 in rural Bangladesh, reflect variation in access to credit. Jacoby and Skoufias (1997) explored the links between the structure of financial markets in rural India and child school attendance. According to their results, schooling can be considered as part of the self-insurance strategy of poor households in particular in villages with less developed financial markets. Households adjust child school attendance to unanticipated income changes originating from rainfall deviation from long-run mean. A related and growing literature exploits naturally random events such as severe droughts, pandemics or violent conflicts, to highlight the sensitivity of human capital formation in childhood to extreme events (see for instance Jensen, 2000; Hoddinott and Kinsey, 2001; Akresh *et al.*, 2009, 2011)[26].

[26] See also Alderman (2011) for a more complete review of case studies.

Another strand of literature drawing on Barker (1998) has shown that deprivation experienced in infancy and early childhood has long-run consequences on adult future welfare. According to Barker's "foetal origin hypothesis", individuals who have suffered from nutritional deprivation in utero or from stunting and underweight during their first couple of years have poorer performance at school, a lower income level, a lower social status and a lower life expectancy. For instance, Maccini and Yang (2009) working on Indonesia, evidenced a strong relationship between birth year rainfall and adult height and education, suggesting that nutrition in infancy varies with agricultural output and household income. Among the natural experiment literature, Almond (2006), Banerjee *et al*. (2007) and Gorgens *et al*. (2012) examined the long-term effects of an economic shock experienced during early childhood on adult health and education outcomes. They showed that children exposed to a dramatic event during early-life had lower investment in education and health which consequences are measurable many years later on adults' outcome[27].

Most authors agree to recognize that consumption smoothing in developing countries is far from being complete especially among poor households, exposing young children to episodes of undernutrition. But empirical studies diverge as to the critical period of life during which a shock has irreversible effects. This critical period can be the foetal period (Barker, 1998), the first six months of life (Dobbing, 1976), the 6 to 24 months period (Martorell and Habicht, 1986; Martorell *et al*., 1994) or more generally the post weaning period until age 24-36 months (e.g. Alderman *et al*., 2001; Hoddinott and Kinsey, 2001; Alderman *et al*., 2006). As a general rule, nutritionists consider that stunting in the first two years of life cannot be offset later so that the size at three years is a good indicator of the size in adulthood (Martorell, 1995).

Drawing on this literature, the main objective of this paper is to assess the ability of rural households in Burkina Faso to smooth investment in child health over agricultural income fluctuations. Like Maccini and Yang (2009) and Jacoby and Skoufias (1997) we do not focus on the impact of extreme events but we consider the impact of the "ordinary" income fluctuations that are regularly faced by farmers in relation with weather conditions. The effectiveness of risk-coping strategy is tested by estimating the short run impact of weather shocks on the nutritional status of children aged 0 to 5 years.

The analysis is original in many respects. First, the study covers the whole Burkina Faso. Health data are drawn from a national survey representative at the regional level, conducted in

[27] See Strauss and Thomas (2008) and Alderman (2011) for a detailed review of empirical literature on child health and adult prosperity.

June, 2008. They are combined with rainfall data collected by the meteorological office of Burkina Faso to define rainfall shocks at the child level. Second, a special attention is paid to the shock pattern which is generally not clearly taken into account in the empirical literature. Weather shocks translate into an income and a nutritional shock with a delay that depends on the crop calendar. Thanks to the high precision of the data, we are able to accurately characterize the economic conditions prevailing during the first months of the child's life and to identify the critical period in child early life during which children are more vulnerable to deprivations. Third, the role of livestock as buffer assets is examined by stratifying the sample by livestock holdings. Fourth, the relative impact of weather shocks and other factors according to the severity of malnutrition is examined by using quintile regression model.

Results show the importance of weather conditions in prenatal period on the future nutritional status of the child. The period in utero to twelve months is a critical period during which exposure to nutritional shortfall has long lasting effects. Results evidence the asymmetric impact of positive and negative rainfall shocks: large negative shocks have a bigger impact on the child nutritional status than large positive shocks. Results also show that even wealthy households are not able to preserve the child human capital from external shocks. Last, the analysis indicates that weather insurance mechanisms would help reducing moderate malnutrition but would be ineffective in fighting against acute malnutrition. Acute malnutrition is above all the consequence of the poor education and poor health status of mothers. Results are robust to different specifications of test equations, in particular to the introduction of household effects that control for unobserved socioeconomic factors.

The remainder of the paper is organised as follows. The second part provides information on the relationships between climate and nutrition in Burkina Faso. The third part presents the datasets and provides descriptive statistics for child health and rainfall. Part 4 describes the conceptual and empirical framework. Part 5 exposes the main econometric results and part 6 discusses the results validity. Part 7 concludes.

4.2. The relationships between climate and nutrition in Burkina Faso

In this tropical country, weather conditions are a key determinant of food production and farm income, with lagged impact on health conditions.

4.2.1. Weather shocks and food access

In Burkina Faso, water resources for agriculture depend on weather conditions[28]. The productivity of rainfed agriculture which is the dominant production system depends mainly on the precipitation level. Crop yields are also sensitive to the occurrence of dry spells during the rainy season and a delayed onset of the monsoon. Water storage for irrigation systems and livestock also varies with the annual surface water flow and dam capacity which is rather low.

Beyond the crop output, weather shocks impact the nutritional status of rural households and more specifically of children. Firstly, rainfall has a direct impact on the "production-based entitlement" of households who cultivate food crops (Sen, 1981). A rainfall deficit entails a shortage in food production and food intake of the household's members. In turn, babies whose mothers suffered from malnutrition during pregnancy or lactation period will exhibit poor growth rate and lower weight. Poor nutrition provided during early childhood has also adverse health effects on weaned children.

Secondly, a rainfall shock translates into an income shock which in turns affects the living standards of the household and health conditions. However, the relationship between rainfall and income may be ambiguous. Farmers' income is generally assumed to be positively related to the rainfall level. This is obviously the case for producers of tradable goods which price is given by foreign markets. In Burkina Faso, a negative (positive) rainfall shock will result in a decrease (increase) in production and income of cotton and rice which are respectively the main exported and imported crop.

The correlation between rainfall and income may be weaker for domestic or regionally traded goods such as millet and sorghum, the main staple diet of rural populations. In case of bad weather conditions the price increase may partly compensate for the production loss. However, this offsetting effect should be of little importance when rainfall shocks are spatially limited. Studies have shown that grain markets within the sub-region are spatially integrated (Araujo *et al*., 2012). Trade flows should therefore prevent large local price variations in response to local production shocks. In case of a widespread drought, the vast majority of farmers are expected to become net buyers of food. High domestic prices will then prevent deficit farmers from easy access to food. Access to food will be even more difficult for rural households than for urban dwellers who can more easily access to imported food products.

[28] The exploitation of groundwater is limited and perennial rivers are few (Sally *et al*., 2011).

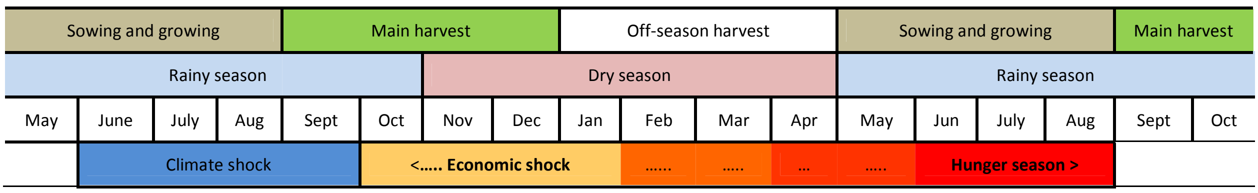
Thus it is expected that a rainfall deficit (surplus) has a negative (positive) impact on households' income which in turn conditions access to food and health care. The weather information being limited, we consider in the following that agricultural outcome depends above all of the cumulated precipitation level recorded during the rainy season.

4.2.2. The shocks calendar

The impact of a climate shock on food availability, income and nutrition occurs with delay and last over several months in relation with the agricultural calendar (Figure 4.1). The inter-tropical climate of Burkina Faso defines two seasons which determine the crop calendar and the agricultural year. The wet season usually runs from May to October and the dry season runs from November to May. The agricultural year starts in September and ends in August. Planting typically takes place from May to July at the beginning of the rainy season. The main harvest occurs from September to December. A second harvest of lesser importance, the "off-season harvest", takes place from January to March (Figure 4.1).

Generally, farmers sell part of their grain at the time of the harvest to meet their financial needs. The rest of the harvest, intended for family consumption and seed production, is stored on the farm until the next harvest or beyond. The amount of grain stored depends on the production level which itself depends on rainfall conditions during the rainy season. Insufficient precipitations result in a poor harvest, low stocks and a food shortage during the months preceding the next harvest which occurs 12 months later. The length of the hunger season[29] varies across years, regions and households according to the importance of stocks and non-agricultural income but generally runs from June to August.

Figure 4.1: The crop calendar



Source: The authors

Therefore, a rainfall shock translates into an income and a nutrition shock with a delay varying from 1 to 12 months. As a consequence, a rainfall shock not only affects children alive during the shock but also children born within the year that follows the shock. In case of a deficit rainy season, children are at risk of under nutrition during the following twelve months. In other words, a rainfall deficit occurring during the rainy season of year *t* will affect

[29] The hunger season is the period that precedes the new harvest, during which farmers' stocks are depleted.

the nutritional status of children alive during the shock period as well as children born in the following crop year, from September *t* to August *t*+1.

4.3. Data

4.3.1. Child heath

Data on children's nutritional status are drawn from the ENIAM survey[30] conducted in June and July 2008. This survey covers the whole country and is representative at the regional level. Most analyses that follow are restricted to children living in rural areas as the impact of rainfall shocks is likely to be felt by households involved in rural activities. The sample includes 12,572 children living in 273 rural municipalities located in the 45 provinces of Burkina Faso.

To assess the health status of children, the height-for-age indicator is preferred to the weight-for-age indicator. The latter mainly reflects short-term scarcities or recent illness episodes experienced by children while the former is a stock variable reflecting current and past health investments (Linnemayr *et al.*, 2008; Martorell and Habicht, 1986). The height-for-age indicator is expressed as z-scores[31] (HAZ).

Table 4.1: Percentage of children aged 0-5 years with height-for-age z-scores below –2 or -3

	HAZ < -2	HAZ < -3
By age group		
0-12 months	18.72	6.42
13-24 months	44.50	19.14
25-36 months	47.29	20.33
37-48 months	44.88	18.90
49-60 months	41.95	17.82
0-60 months	38.60	16.10
By mother education		
None	39.22	16.52
Literate	37.83	14.74
Primary education	32.58	13.31
Secondary education	27.68	9.04
By quartile of wealth index		
< -0.672	38.92	17.38
[-0.672, -0.163[	40.00	17.81
[-0.163, 0.485[	39.34	15.00
≥0.485	36.16	14.21

Source: Authors' calculation based on the ENIAM database.

[30] The household database has been provided by WFP.

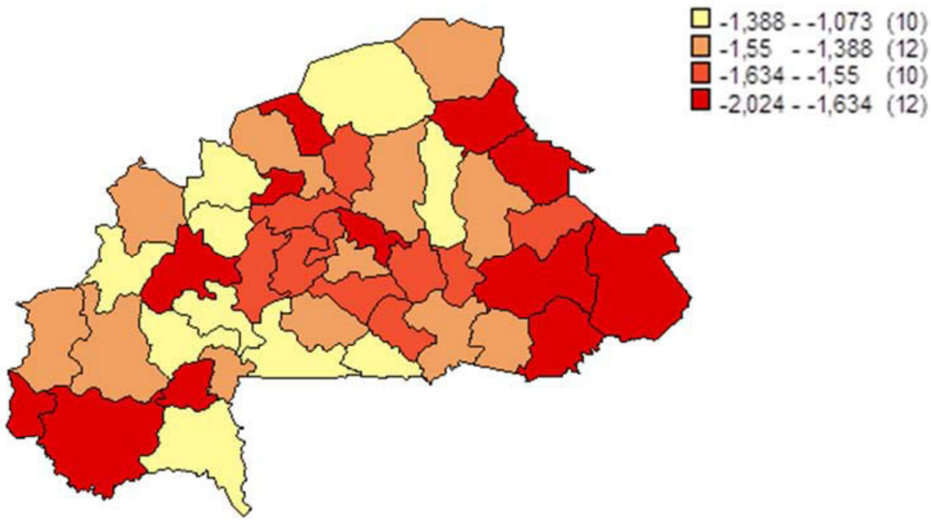
[31] Z-scores are given by the difference between the child's height-for-age and the median height-for-age for the same aged reference population divided by the standard deviation of the reference population. They have been calculated using the ANTHRO 2005 software program and the 2005 World Health Organization reference.

38.6% of children aged 0 to 5 years suffer from moderate malnutrition or stunting (with HAZ below -2) and 16.1% from acute malnutrition (with HAZ below - 3) (Table 4.1). The prevalence of moderate stunting increases rapidly from 18.7% during the first 12 months to about 45% in the second year of life and 47% in the third year. Prevalence of stunting remains at a high level, above 40%, in the two following years. The prevalence of severe stunting follows the same pattern.

Interestingly, the prevalence of malnutrition decreases with the education level of the mother. 39% of children whose mother has no education are moderately stunted and 16.5% are severely stunted. By contrast, only 28% of children whose mother has completed secondary education are moderately stunted and 9% are severely stunted.

A negative relationship between household's wealth and the prevalence of stunting can also be observed. The prevalence of moderate (severe) stunting decreases in the third and fourth wealth quintile, from 40% (18%) to 36% (14%). The wealth index measures the household's living standards. It is based on housing characteristics such as materials used for construction, the type of water access, sanitation facilities and assets ownership[32].

Map 4.1: Average height-for-age z-score by province and quartiles



Source: Authors' calculation based on the ENIAM database.
The number of provinces is in parenthesis.

Contrary to what might be expected, the prevalence of malnutrition is not confined to the dry northern region but exhibits great regional heterogeneity (Map 4.1). Malnutrition appears to be more severe in the East part and the South West part of Burkina Faso which benefit from the most favourable climatic conditions. These regions are also the main producing areas of

[32] The calculation of the wealth index is detailed in the appendix.

cotton, the leading cash crop. Regions with the highest rate of stunting are the Cascades (46.5%) and the East (42.5%) whereas the rate of chronic malnutrition is about 31% in the Centre region.

4.3.2. Rainfall data

Rainfall shocks at the child level are calculated using decadal data originating from 138 weather stations distributed throughout the country and covering the 1995-2008 period. A four-step approach is followed.

First, a decadal rainfall index is calculated for all municipalities. Each municipality is matched to the closest weather station. In case of missing observations, the rainfall data of the second closest station are used. As a consequence, the rainfall index for a given municipality may come from varying weather stations. The average distance between the municipality centroid and the closest informed weather station is 15.6 km[33] (Table 4.2). Only 5% of the municipalities are more than 40 km away from the closest informed weather station.

For 40.5 % of the municipalities, the rainfall indicator has been computed using data from only one station; for 48.5% of the municipalities, data come from two stations and for 10.1% of the municipalities data come from three stations. Only one municipality (Bagré) uses rainfall data originating from 5 different stations[34]. On average, slightly less than two weather stations (1.92) are used to compute the municipality rainfall indicator. Therefore, we can confidently say that the municipality rainfall index mostly reflects the precipitation level measured at the closest weather station.

Table 4.2: Distance between the municipality centroid and reference weather stations (km)

	1st Station	2nd Station	3rd Station	4th Station	5th Station	Mean	Total Min	Max
Mean	14.3	33.4	37.1	37.8	41.39	15.6	0.4	60.1
Max	59.1	96.2	64.1	37.8	41.39	35.2	0.5	96.2
Min	0	1.5	21.9	37.8	41.39	13.4	0	59.8

Second, an annual rainfall index is calculated by municipality as the cumulated rainfall level during the crop growing season that runs from June 1st to September 30th. Map 4.2 shows the mean rainfall index aggregated at the province level calculated over the period 2003-2008[35].

[33] Two municipalities whose distance to the closest informed weather station was greater than 100 km have been dropped from the sample

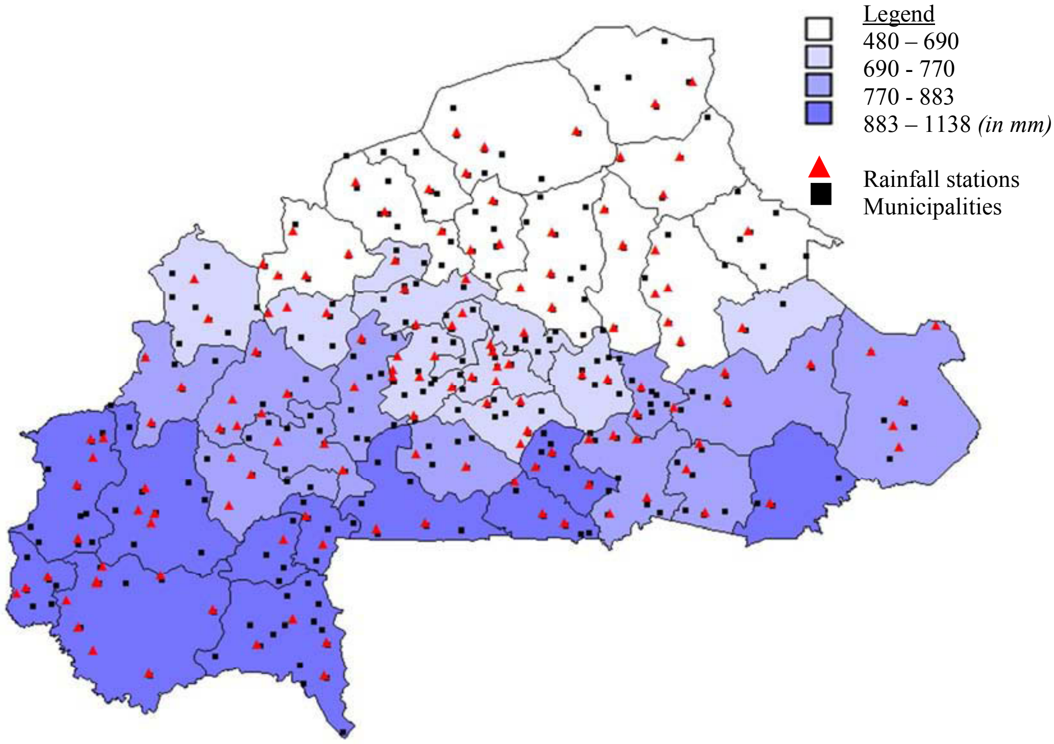
[34] The 4th and 5th stations are respectively 37.8 and 41km away from this municipality. Estimations have been conducted with and without the Bagre municipality which includes only 37 children. Results are not significantly affected.

[35] This period corresponds to the date of birth of the children in the sample.

This map illustrates the important discrepancies in the average rainfall that ranges from 400mm in the North to 1200mm in the south of Comoé. The annual rainfall level is higher in the South West region. The North-East provinces (Oudalan, Seno, Yagha) features a low level and a large variability of precipitations, two phenomena that are common to Sahelian areas.

Third, annual rainfall shocks are calculated as the cumulated rainfall deviation from the norm of the municipality. The norm for year *t* is given by the mean rainfall over the 1995-2008 period excluding year *t*. Shocks are expressed in percentage of the norm[36].

Map 4.2: Mean annual rainfall by province



Source: The authors

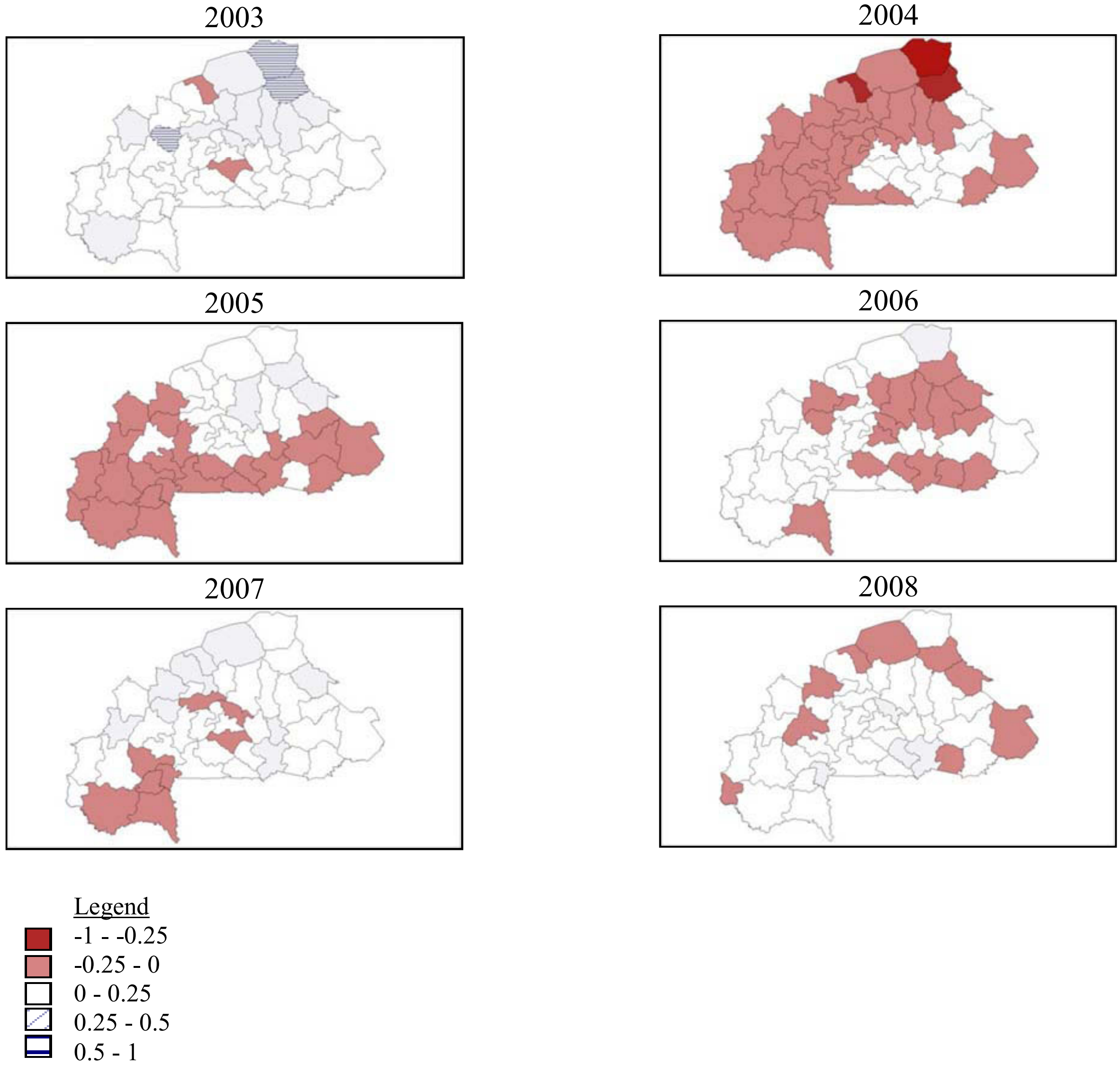
Fourth, a rainfall shock variable is defined at the child level using the date and place of birth of the child. Shocks are calculated at different ages. For instance, the rainfall shock in the prenatal period is given by the rainfall shock registered during the rainy season of year *t* in the municipality of birth of a child born between September *t* and August *t*+1. This variable captures the child's exposure to a nutritional deficiency while in utero and in the months prior to her birth.

Map 4.3 displays the rainfall shocks aggregated at the province level for the birth year of children aged 0 to 5 years in 2008. Blue areas correspond to positive shocks (positive rainfall

[36] Rainfall shock at year *t* is given by: $S_t = \frac{R_t - \bar{R}}{\bar{R}}$ with $\bar{R} = \frac{1}{n-1}\sum_{i=1}^{n} R_i$ for $i \neq t$

deviation over the long term mean), while red areas represent negative shocks. 2003 was a good year in terms of rainfall while 2004 was marked by widespread drought. Except these two years, shocks are fairly well distributed across the territory. On the period, extreme events are infrequent and circumscribed to two regions of the Sahel region in the northern part of the country.

Map 4.3: Rainfall Shocks by province and year[37]



Source: The authors

4.4. Conceptual and empirical framework

According to the life cycle-permanent income hypothesis (LC/PIH) when insurance markets are missing but credit markets are well-functioning, households consumption should not

[37] Data by province are calculated as the average value of the municipality shocks.

respond to short run fluctuations in current income. Consumption adjusts to unexpected changes in permanent income but does not correct for transitory income shocks (Hall, 1978; Deaton, 1992). In the empirical literature detection of excess sensitivity of consumption to current income is generally taken as evidence of liquidity constraints (Zeldes, 1989*)* although it can also be the consequence of precautionary saving behaviour (Caroll and Kimball, 2001).

Considering child health as a kind of durable good the standard result of the LC/PIH can be extended to investment in child health. Assuming that households maximize an inter-temporal expected utility function with instantaneous utility defined over consumption and child health, subject to an inter-temporal budget constraint and a health production function, the child's growth should be unaffected by current income fluctuations in the absence of credit market imperfections (Foster, 1995; Hoddinott and Kinsey, 2001).

Considering that the height-for-age indicator keeps the record of past investments in child health, we assess the ability of households to smooth out income fluctuations resulting from rainfall shocks by estimating a reduced form of a health demand equation given by:

$$H_{jc} = \gamma T_{jc} + \beta X_{jc} + \alpha_c + \varepsilon_{jc} \qquad (1)$$

H_{jc} is the height-for-age z-score for the *j*th child in the *c*th sample cluster.

T_{jc} is the rainfall shock variable. We consider successively rainfall shocks in the prenatal period (T_0), in the first year (T_1) and in the second year of the child life (T_2). Children are aged [in utero – 12 months], [2 to 24 months] and [14 to 36 months] during the economic shock that follows respectively, a rainfall shock in the prenatal period, in the first year and in the second year of life.

γ measures the impact of rainfall shocks on the nutritional status of the birth cohort [September, 1st Year *t* - August, 31th Year *t*+1].

X is a vector of child, mother and household characteristics. Child characteristics include year of birth, month of birth, sex and being a twin. Maternal characteristics include age, education and mother's body mass index. Household characteristics include the household size, a household wealth index, the age and education level of the head of household.

α_c are the cluster-specific effects. ε_{jc} is an idiosyncratic stochastic term.

One of the main issues in estimating (1) relates to potential measurement error in the rainfall shock variable. Rainfall is measured at the weather station closest to the municipality's centroid and may not fit perfectly with the rainfall actually experimented by each household in the municipality. Assuming that the measurement error is uncorrelated with the true unobserved value of shocks, we correct for the resulting attenuation bias by instrumenting the rainfall shock variable. Following Maccini and Yang (2009) we consider as potential instruments the rainfall shock measured at the second to fifth closest weather station.

Another difficult issue with survey data is the choice of the clustering unit. We consider that the appropriate clustering unit is the municipality and test the robustness of results considering alternatively the household as the clustering unit.

Equation (1) is estimated using the within estimator for fixed effects and the GLS estimator for random effects. The standard F test for fixed effects, the Breusch Pagan test for cluster-specific random effects and the Hausman test for correlated random effects are implemented to select the best fit model.

4.5. Econometric results

4.5.1. Impact of rainfall shocks in early life

We first estimate the impact of a rainfall shock occurring in the prenatal period. The results of the first stage regression are reported in Table D3 in the appendix. The instrumental variables are positively correlated with the rainfall measured at the nearest station. The F-statistic for the test of joint significance of the rainfall variables is 126, suggesting that the instruments are jointly strong. The over-identifying restrictions are not rejected suggesting that the instruments are not correlated with the error term.

Table 4.3 reports the estimation results of the health demand equation for the municipality fixed effect model. They evidence a positive impact of rainfall shocks in the rainy season preceding the child birth on her nutritional status. The height-for-age z-score of children under five increases by 0.333 when rainfall in the prenatal period is one percent higher than normal. These children are in utero to 12 months old during the economic shock that follows the rainfall shock.

Table 4.3: IV regression results with Municipality Fixed Effects

Dependent variable :	Height for age z-score
Rainfall shock in prenatal period	0.333***
	(0.129)
Sex (1 = male)	-0.256***
	(0.027)
Twin (1 = twin)	-0.559***
	(0.126)
Mother's age	0.046***
	(0.013)
Mother's age²	-0.001***
	(0.000)
Body Mass Index of the mother	0.037***
	(0.006)
Mother literacy	0.085
	(0.057)
Mother primary education	0.158**
	(0.070)
Mother secondary/higher education	0.231*
	(0.137)
Age of the household head	0.001
	(0.001)
Household head literacy	0.031
	(0.055)
Household head primary education	0.002
	(0.054)
Household head secondary/higher education	0.208**
	(0.096)
Household head other education	-0.089
	(0.095)
Household size	-0.004
	(0.003)
Wealth index	0.039**
	(0.019)
Year of birth dummies	Yes
Month of birth dummies	Yes
Observations	12,572
Adjusted R²	0.147

Cluster robust standard errors in parentheses. * indicates significance at 10% level; ** at 5% level and *** significant at 1% level of confidence. List of exogenous instruments: rainfall shock in prenatal period measured at the second to fifth closest weather station.

Results also give several interesting insights on the determinants of malnutrition. Consistent with other studies conducted in Africa (e.g. Wamani *et al.*, 2007; Marcoux, 2002; Svedberg, 1990), boys have worse nutritional status than girls and twins have worse nutritional status than only children. As expected, the relationship between the child nutritional status and her mother's age is nonlinear: the nutritional status of the child improves with the age of the mother until she is 46 years old. Above that age, the risk of malnutrition increases. The Body Mass Index (BMI) of the mother which offers a simple measure of short-run health is a significant determinant of children's nutritional status. Finally, the education (both primary and secondary) of the mother has a positive impact on the child's nutritional status. In contrast, only secondary schooling of the household head (98.7% of household heads are male) is positively and significantly associated with height-for-age. Regarding the households characteristics, the household size is negatively correlated with height-for-age z-scores but non-significant, while the wealth index enters positively and significantly.

The positive impact of rainfall shocks in prenatal period on child health is robust to controlling for the introduction of various time trend specifications: a municipality-year of birth specific time trend as well as a municipality-month of birth specific time trend.[38] These cross variables capture the temporal variation in the outcome variable that is specific to each municipality and date of birth.

The introduction of multiplicative variables shows that the impact of rainfall shocks in the prenatal period is not significantly different for boys and girls. This result (not reported here) supports the idea that there is no intra-household discrimination between young boys and girls in health and nutrition access in Burkina Faso.

Results are also robust to clustering at the household level (Table 4.4, columns 3 and 4). The coefficient of the rainfall shock variable is positive and significant. According to the Hausman test, the GLS estimator is more efficient when clustering at the household level while the within estimator is more efficient when clustering at the municipality level.

[38] Results not presented here.

Table 4.4: Impact of rainfall shocks in prenatal period on HAZ - TSLS on panel data

	Cluster unit			
	Municipality		Household	
Estimator	GLS for RE (1)	Within for FE (2)	GLS for RE (3)	Within for FE (4)
Rainfall shock in prenatal period	0.282**	0.333***	0.235***	0.484***
	(0.126)	(0.129)	(0.112)	(0.224)
Child characteristics	yes	yes	yes	yes
Mother characteristics	yes	yes	yes	yes
Household characteristics	yes	yes	yes	no
Adjusted R^2	0.120	0.147	0.125	0.268
Observations	12,572	12,572	12,572	12,572
Hausman χ^2d.f.	32		26	
Prob.	[0.001]		[0.387]	
F-stat for fixed effects		2.54**		1.401**
BP $\chi^2(1)$	338.301		281.296	
Panel structure				
Number of cross sections	273		6481	
Minimum number of children	2		1	
Maximum number of children	213		14	
Average number of children	47		1.95	
Median children	39		2	

Cluster robust standard errors in parentheses and p-value are in square brackets. * indicates significance at 10% level; ** at 5% level and *** significant at 1% level of confidence. List of exogenous instruments: rainfall shock in prenatal period measured at the second to fifth closest weather station.

To identify the critical period of life during which an economic shock has the most severe impact on the child's health, we estimate the impact of a rainfall shock occurring in the first and second year of life. The children are, respectively, two to 24 months old and 14 to 36 months old, during the economic shock's period that follows the rainfall shock. Estimation results are given in Table 4.5. They show that a rainfall shock occurring in the first or second year of life does not have any significant impact on the child long term nutritional status.

Table 4.5: Impact of a rainfall shock at first and second year of life (2SLS)

Dependent variable : HAZ	Municipality FE (1)	Household RE (2)	Municipality FE (4)	Household RE (5)
Rainfall shock in 1st year	0.027	-0.161		
[2 - 24 months]	(0.163)	(0.154)		
Rainfall shock in 2nd year			-0.042	-0.231
[14 - 36 months]			(0.220)	(0.202)
Observations	10,164	10,164	7,370	7,370
Adjusted R^2	0.070	0.035	0.068	0.026

In brackets the children age at the time of the economic shock that follows the rainfall shock. All regressions include child, mother and household's characteristics. Cluster robust standard errors are in parenthesis

According to estimation results, children are more vulnerable to a weather shock during their in utero life and the first months of their early life. During this period the vast majority of children are breastfed - 91% of the mothers in the sample declare to have breastfed their children - weaning usually occurring between 18 and 24 months. We thus conclude that weather shocks affect mothers' nutrition, maternal feeding, intake of supplementary foods as well as access to health care.

These results are in line with a large medical and economic literature showing a strong relationship between maternal nutrition, fetal growth and after birth weight and size (see for instance Gajigo and Schwab, 2012). They confirm that the nutrition of mothers during pregnancy and breastfeeding plays a critical role as well as adequate complementary feeding practices. Indeed, late weaning do not protect against under nutrition. The WHO recommends to supplement the alimentation of children more than 6 months old by nutritionally adequate complementary foods, maternal breast being insufficient to achieve optimal growth and health.

Robustness test

As a robustness test, the impact of rainfall shocks is estimated on the sample of children living in urban areas (Table 4.6). As expected the coefficient of the rainfall shock variable is not significantly different from zero. This result indicates that urban households are able to compensate for food price fluctuations following a shock in domestic production. Compared to rural households, urban households have an easier access to imported food and their income is left unaffected by weather conditions.

Table 4.6: Impact of a rainfall shock in prenatal period on urban children. TSLS estimates

Dependent variable: Height for age z-score	Muncipality FE (1)	Household RE (2)
Rainfall shock in prenatal period	-0.015	-0.100
	(0.254)	(0.296)
Child characteristics	yes	yes
Mother characteristics	yes	yes
Household characteristics	yes	no
Observations	1,974	1,974
Adjusted R^2	0.154	0.136

Cluster robust standard errors are in parenthesis.

4.5.2. The failure of risk coping strategies

Previous results lead to the rejection of the permanent income hypothesis. Households do not smooth investment in human capital over "ordinary" income fluctuations. However distinguishing between positive and negative shocks and taking into account the role of livestock assets highlight interesting features of the risk coping strategies set up by farmers.

An asymmetric impact of positive and negative rainfall shocks

The household ability to manage weather related shock may differ according to the sign of the shock. Households may be prone to smooth large positive shock through the constitution of food stocks or savings. But households may be unable to smooth large negative rainfall shocks when stocks are depleted and credit access is restricted. We thus distinguish between large positive shocks (above the mean plus one standard deviation) from large negative shocks (below the mean less one standard deviation) when estimating the impact of rainfall shocks on the child's nutritional status.

Results are line with previous ones. Large positive and large negative shocks have a significant impact on the child's health indicating that shocks are not dampened (Table 4.7, column 1). Children benefit from an increase in food supply and income following a good harvest but they suffer from a deterioration of their nutritional status after a bad harvest. Large negative shocks have a bigger impact than large positive shocks indicating that children benefit less from large positive shocks than they suffer from large negative shocks. This asymmetry in the shocks impact on the child nutritional status may reflect a biological phenomenon. It may also indicate that large positive shocks are partly saved.

Table 4.7: Impact of rainfall shocks in prenatal period according to livestock assets

Dependent variable: Height for age z-score	All sample	Tropical Livestock Units are Below the median	Above the median
Rainfall shock in prenatal period	0.333***	0.447***	0.344*
	(0.129)	(0.162)	(0.189)
Observations	12572	6119	6045
Large positive shocks	0.266**	0.330**	0.293*
	(0.108)	(0.130)	(0.159)
Observations	12572	6119	6045
Large negative shocks	-0.339**	-0.457***	-0.353*
	(0.136)	(0.169)	(0.207)
Observations	12572	6119	6045

Cluster robust standard errors are in parentheses. All regressions include child, mother and household's characteristics; * indicates significance at 10% level; ** at 5% level and *** significance at 1% level of confidence.

Livestock as a buffer asset

In rural Burkina Faso livestock are the main assets used for risk-coping with jewelries or consumer durables (Kazianga and Udry, 2006). Households can also resort to grain storage and transfers to protect consumption from income fluctuations. Unfortunately data on stocks, transfers and other assets are not available. We thus focus on the role of livestock in consumption smoothing.

Small livestock (mainly sheep and goats) are considered as a buffer asset. Most rural households, but also households living in urban area, grow small cattle to be sold with profit for celebrations, to finance extraordinary expenses such as sending a child to school in the capital city, or to offset unexpected economic shocks (health disease, bad harvest…). Large livestock are considered as a productive asset (Zimmerman and Carter, 2003). Relatively wealthy farmers hold oxen, donkeys, cows or camel for animal traction. Sedentary and extensive transhumant pastoralism is also an important activity in Burkina Faso, contributing to about 25% to GDP and export earnings. When livestock are productive assets, selling animals to compensate for an income shock is a last resort strategy that compromises future farm productivity and household's welfare.

To evaluate the ability of rural households to cope with weather-related income risk the sample is stratified according to the number of Tropical Livestock Units held by households. The number of Tropical Livestock Units (TLU) is calculated as the weighted sum of the number of cattle, horses, asses, goats and sheep hold by the household. The vast majority of households hold at least one livestock unit, goats being the more widespread animals (Table 4.8). But the median number of livestock is rather low: 2 cattle, 5 goats and 3 sheep. The sample includes 15% of households who declared breeding to be their main activity[39]. The mean number of livestock units by breeder is 20.22 and the median is 10.95

Table 4.8: Composition of household livestock assets

	TLU	Cattle	Goat	Sheep	Donkey	Pork	Horse	Camel
Mean	9.87	5.98	7.21	6.30	1.12	1.56	0.04	0.05
Median	5.29	2	5	3	1	0	0	0
Maximum	210	200	100	450	15	75	4	15
HH with no livestock	3%	37%	20%	39%	42%	73%	96%	97%

Number of animals (or units) per household

Partitioning the sample at the median LTU (Table 4.7, columns 2 and 3) shows that children living in poor households are more vulnerable to weather-related income shocks than children living in wealthier households (LTU above the median). They are especially sensitive to large negative rainfall shocks in prenatal period. However, even wealthy households are not able to preserve the child human capital from external shocks. These results are in line with those of Kazianga and Udry (2006) for a sample of rural households in Burkina Faso. They found little responsiveness of livestock sales to the severe drought that marked the 1981-1985 period. Neither rich nor poor households were able to smooth consumption in that period of severe drought.

4.5.3. Impact of rainfall shocks on moderate to acute malnutrition

According to previous result, children are at risk of malnutrition in case of an adverse rainfall shock during the prenatal period. We go further in the analysis by examining the impact of weather shocks on moderate and severe malnutrition. Moderate malnutrition (corresponding to height-for-age z-score below -2) is associated with an increased risk of nutrition-related deaths. Children suffering from acute malnutrition (height-for-age z-score below -3) are exposed to life-threatening conditions.

Estimation results (Table 4.9, columns 1 and 2) evidence a negative causality between having experienced a rainfall shock in prenatal period and the likelihood of a being stunted during the first year of life. The results are robust to the inclusion of time trends. According to these results, uninsured weather-related income shocks are cause of moderate malnutrition but not

[39] This percentage is underestimated as some farmers holding more than 100 cattle did not declare themselves as breeders.

of severe malnutrition. The impact of rainfall shocks on severe stunting is not significantly different from zero (Table 4.9, columns 3 and 4).

Table 4.9: Impact of rainfall shocks on stunting

Dependent variable	Moderate stunting		Severe stunting	
	Municipality FE	Household RE	Municipality FE	Household RE
	(1)	(2)	(3)	(4)
Rainfall shock in prenatal period	-0.081*	-0.065*	-0.011	-0.019
	(0.043)	(0.034)	(0.030)	(0.027)
Observations	12,572	12,572	12,572	12,572
Adjusted R^2	0.090	0.076	0.059	0.042

Dependant variable = 1 if *HAZ* < -2 ; 0 otherwise (columns 1 and 2).
Dependant variable = 1 if *HAZ* < -3 ; 0 otherwise (columns 3 and 4).
Cluster robust standard errors are in parentheses. All regressions include child, mother and household's characteristics.

These results suggest that households set up survival strategies to protect children against serious nutritional deficiencies and related health disease that would threaten child survival. These results suggest also that the implementation of weather insurance mechanisms would be useful to fight against moderate malnutrition but would be ineffective in eradicating severe malnutrition. The relative impact of weather shocks and other factors according to the severity of malnutrition are explored below.

Quantile Regression Estimations

To look for a different impact of rainfall shocks according to the position of the health variable in its distribution, we implement the Instrumental Variable Quantile Regressions (IVQR) procedure developed by Chernozhukov and Hansen (2008).

The estimated coefficients for the 10th to 80th quantiles are reported in Table 4.10. At the lowest quantile, (Table 4.10, column 1) rainfall conditions in prenatal period do not have any impact on the child nutritional status. The impact of rainfall shocks becomes significant from the 0.4 quantile and is increasing in size until the last one. According to these results, rainfall shocks have no impact on the most severely malnourished children.

Table 4.10 : Instrumental Variable Quantile Regressions[40]. Dependent variable: HAZ

	10%	20%	30%	40%	50%	60%	70%	80%
	]-6 ;-3.47]	]-3.47;-2.76]	]-2.76;-2.33]	]-2.33;-1.96]	]-1.96;-1.61]	]-1.61;-1.27]	]-1.27;-0.86]	]-0.86;-0.36]
Rainfall shock in prenatal period	0.288 (0.180)	0.249 (0.154)	0.218 (0.145)	0.322** (0.133)	0.290** (0.129)	0.332*** (0.122)	0.433*** (0.122)	0.407*** (0.139)
Sex (1 = male)	-0.434*** (0.043)	-0.333*** (0.034)	-0.303*** (0.030)	-0.274*** (0.029)	-0.251*** (0.029)	-0.203*** (0.029)	-0.168*** (0.032)	-0.126*** (0.037)
Twin (1 = twin)	-0.722*** (0.170)	-0.549*** (0.112)	-0.546*** (0.091)	-0.633*** (0.093)	-0.582*** (0.105)	-0.567*** (0.102)	-0.525*** (0.139)	-0.371** (0.146)
BMI of mother	0.054*** (0.001)	0.046*** (0.001)	0.041*** (0.0057)	0.029*** (0.006)	0.033*** (0.007)	0.035*** (0.007)	0.029*** (0.007)	0.029*** (0.008)
Mother's age	0.0426** (0.017)	0.064*** (0.014)	0.058*** (0.015)	0.043*** (0.013)	0.055*** (0.013)	0.046*** (0.014)	0.047*** (0.015)	0.012 (0.019)
Mother's age²	-0.001** (0.000)	-0.001*** (0.000)	-0.001*** (0.000)	-0.001*** (0.000)	-0.001*** (0.000)	-0.001** (0.001)	-0.001** (0.000)	0.001 (0.000)
Mother primary education	0.092 (0.125)	0.172** (0.076)	0.160** (0.065)	0.009 (0.066)	0.108 (0.071)	0.196*** (0.068)	0.184** (0.068)	0.185*** (0.068)
Mother secondary/ higher education	0.481*** (0.173)	0.346** (0.142)	0.345*** (0.108)	0.150 (0.101)	0.113 (0.093)	0.004 (0.112)	0.064 (0.149)	0.178 (0.174)
Hh head secondary/ higher education	0.116 (0.135)	0.189* (0.111)	0.093 (0.099)	0.249*** (0.093)	0.191** (0.083)	0.155* (0.094)	0.287*** (0.096)	0.1336 (0.095)
Hh head other education	-0.445*** (0.149)	-0.259** (0.129)	-0.166 (0.123)	-0.142 (0.093)	-0.128 (0.087)	-0.126 (0.096)	-0.024 (0.114)	-0.024 (0.114)
Household size	-0.002 (0.005)	-0.007** (0.033)	-0.007*** (0.002)	-0.008*** (0.002)	-0.007*** (0.003)	-0.007*** (0.003)	-0.004 (0.003)	-0.005 (0.003)
Wealth index	0.049 (0.034)	0.067*** (0.024)	0.081*** (0.021)	0.074*** (0.012)	0.071*** (0.019)	0.059*** (0.019)	0.036* (0.022)	0.019 (0.023)

Regressions include exogenous variables given in Table 4.3 as well as municipality dummies. Cluster robust standard errors are in parenthesis. * indicates significance at 10% level; ** at 5% level and *** significance at 1% level of confidence.

These results can be interpreted in two different but non mutually exclusive ways. First, as part of survival strategies, households manage to protect children from weather related income shocks when life expectancy is threatened. Another interpretation is that severe malnutrition results from structurally poor health environment rather than from transitory income shocks. Mother's age and mother's health are highly significant determinants of the child's nutritional status whatever the position of HAZ in the distribution. Most of all, poor maternal education appears to be a key factor of severe malnutrition: mother's secondary education has a positive and significant impact on the first quantiles but is not significant from the 40th quantile to the last one. Therefore, providing women with secondary education is of the utmost importance in the fight against severe malnutrition. These results are in line with a

[40] IVQR estimations for the 90th quantile do no to converge

large literature showing that mother's education is one of the most important factor of child malnutrition if not the most important one (e.g. Smith and Haddad, 2000; Frost *et al*., 2005),

Table 4.11 : Instrumental Quantile Regression Estimations. Dependent variable: HAZ

	0.2	0.4	0.6	0.8	0.2	0.4	0.6	0.8
Large negative rainfall shock in prenatal period	-0.235	-0.386**	-0.444***	-0.442***				
	(0.214)	(0.185)	(0.169)	(0.159)				
Large positive rainfall shock in prenatal period					0.223**	0.195**	0.197**	0.301***
					(0.104)	(0.092)	(0.083)	(0.102)

Cluster robust standard errors are in parentheses. All regressions include child, mother and household's characteristics as well as municipality dummy variables. * indicates significance at 10% level; ** at 5% level and *** significance at 1% level of confidence.

Table 4.11 distinguishes between large positive and large negative rainfall shocks. For the sake of brevity, only the 0.2, 0.4, 0.6 and 0.8 quantiles are presented. Negative rainfall shocks do not have any impact on children in the 0.2 quantile whereas large positive rainfall shocks have a significant impact in all regressions. These results tend to support the hypothesis of the survival strategy: more vulnerable children are protected from deprivation in the case of a negative weather shock. As previously observed, large negative rainfall shocks have a greater impact on children nutritional status than large positive ones, indicating that large positive shocks are partly saved.

4.6. Discussion

Rainfall shocks and diseases

Rainy season precipitations are a key determinant of crop yield which conditions food availability, income and nutrition over the following year. But weather has also a direct and immediate impact on health by fostering the development and spread of vector borne and waterborne diseases (e.g. McMichael *et al.*, 2006; Githeko, 2007). For instance, the prevalence of parasitic and infectious diseases such as such as malaria and cholera expands during the rainy season. In turn, diseases affect the body's ability to absorb nutrients, leading to under-nutrition.

These direct and indirect impacts of rainfall on child's health run in two opposite directions. A high level of precipitations favours the expansion of vector-borne diseases but offers good harvest prospects so that the expected impact of precipitations on child health may be ambiguous. Our results clearly show that rainfall shocks have a significant impact on children in utero at the time of the shock. Therefore, we can conclude that they mainly capture the indirect impact of rainfall conditions on the child health that passes through the level of food supply and household's income. In this respect, results should be regarded as overestimating the global impact of rainfall on health.

Potential Selection bias

As in other studies of this type, we are confronted with a potential attrition bias due to migration, selective mortality and conception rate in relation to rainfall shocks.

Migration is a potential source of attrition bias the direction of which is undetermined. More vulnerable households may have migrated from rural to urban areas in reaction to a negative rainfall shock. They may also send out children to relatives living in areas away from food shortage. Whether wealthier or poorer households migrate is unknown. In the same way, a fostered child may be more or less healthy (Akresh, 2009). Unfortunately, the survey does not provide any information that could shed light on this issue.

The estimated impact of a rainfall deficit on child health is also likely to be underestimated if shocks result in selective mortality. The impact of shocks is indeed estimated on surviving children. Large negative shocks are likely to result in increased mortality so that surviving children may be genetically more resistant to deprivation. The survey does not provide information on child mortality nor on miscarriage and still birth.

Weather conditions may also determine parental choice regarding the timing of birth. Some parents may decide to delay birth after a negative rainfall shock (and conversely), generating a selection bias. However, the magnitude of this phenomenon should not be overstated since birth control and contraceptive means are not widespread in rural areas of Burkina Faso. Moreover, clustering at the household level should control for this potential source of bias.

These potential sources of selection biases may be important when studying the impact of extreme events such as droughts, wars, pandemics, but should be of less importance when examining as we do the impact of "ordinary" rainfall deviations from the mean.

4.7. Concluding remarks

This paper contributes to the economics of risk and insurance and to health economics by providing new insights on households' behaviour in a risky environment as well as on the determinant of child's heath. Four important points emerge from the analysis with policy implications.

First, the significant impact of rainfall shocks in prenatal period on child health shows that households are not able to smooth income shocks related to weather conditions. This result extend that of Kazianga and Udry (2006) who estimated the impact of the most severe drought of the last 30 years on a sample of rural households in Burkina Faso. One would have thought that the failure of risk-coping strategies was due to the exceptional severity of the 1984-85 drought in terms of rainfall deficit and spatial extent. Our results show that households dot no cope with income shocks related to ordinary weather fluctuations.

Second, rainfall shocks translate into nutritional shocks with a delay. In this respect, a drought has an adverse effect on the nutritional status of children born within eleven months after the shock. This is a consequence of the lack of diversification of rural household income. Farm income which is concentrated over a short period of the year determines access to food and health care during the rest of the year.

Third, young children below twelve months are more vulnerable to economic shocks than older children. The in utero period and the first months of life appear to be a critical period. Negative shocks occurring under the age of twelve months should be considered as having a permanent effect. These results are consistent with those of Akresh *et al.* (2012). Based on a sample of children living in the Nahouri region of Burkina Faso, these authors found that children exposed to a negative rainfall shock while in utero or in their first year of life have lower cognitive abilities.

Fourth, large negative shocks have a bigger impact on the child nutritional status than large positive shocks. Children do not benefit as much from large positive shocks as they are negatively affected by large negative shocks, suggesting that large positive shocks are partly saved. Children living in poor households are more vulnerable to weather-related income shocks than children living in wealthier households. They are especially sensitive to large negative rainfall shocks in prenatal period. However, neither rich nor poor households manage to smooth consumption in case of large negative rainfall shocks.

Fifth, rainfall conditions in the prenatal period do not have any impact on the nutritional status of the most severely malnourished children. Two hypotheses about household behaviour seem particularly worth exploring. First, households may set up survival strategies to protect children suffering from acute malnutrition who faced the greatest risk of death. Second, food supply and income are not the main determinants of child malnutrition. As documented by Smith and Haddad (2000), women's education may have the strongest impact on child malnutrition.

These results have important policy implications. They provide additional support for public interventions aiming at protecting rural households from climate shocks. In this respect, promoting the development of weather–based insurance tools appears to be highly desirable. However, weather insurance mechanisms may be unable to protect children suffering from acute malnutrition. The results call for an improvement in women's education and in women's relative status as maternal education emerges as a key determinant on child malnutrition.

These results have also implications for the targeting and timing of assistance in the case of a negative rainfall shock. Assistance should be more specifically targeted at pregnant women and young children who are the most vulnerable. Distribution of dietary supplements to rural women in case of drought may have a positive impact on the health outcomes of the unborn child. Assistance should be provided as earlier as possible in the crop year and not only during the so-called "hunger season".

Last, these results call for further research on intra-household resource allocation. The poor nutritional status of children may reflect gender inequality in food access within the household between men and women.

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Appendix D:

The wealth index is based on a principal component analysis including 17 variables. Table 1 provides the scoring factors of the five principal components. The five factors with an eigenvalue larger than 1 have been kept. The first component accounts for 22 percent of the total variation across the 17 indicators.

Table D1: Composition of the wealth index

Variable	Component 1	Component 2	Component 3	Component 4	Component 5	Mean	S.d
Radio	0.220	0.002	-0.259	-0.369	0.238	0.742	0.438
Table	0.274	0.175	-0.255	-0.158	0.242	0.380	0.485
Chair	0.350	-0.495	0.123	0.100	-0.019	0.653	0.476
Bed	0.236	0.232	-0.279	-0.087	0.242	0.434	0.496
Cart	0.302	-0.200	0.067	-0.013	-0.137	0.513	0.500
Plough	0.350	-0.495	0.123	0.100	-0.019	0.653	0.476
Phone	0.286	0.178	-0.042	-0.211	-0.091	0.303	0.460
Television	0.235	0.249	0.195	-0.172	-0.214	0.066	0.248
Bicycle	0.173	-0.221	-0.098	-0.138	0.231	0.933	0.250
Motorbike	0.327	0.094	-0.019	-0.157	-0.174	0.333	0.471
Car	0.071	0.135	0.596	-0.153	0.236	0.003	0.053
Walls in cement or stones	0.137	0.266	0.188	0.305	-0.157	0.036	0.187
Improved roof (cement, tiles or cogurrated iron)	0.285	0.178	0.023	0.377	-0.079	0.392	0.488
Improved floor (cement or tiles)	0.261	0.248	0.023	0.412	-0.040	0.226	0.418
Electricity	0.010	0.093	0.545	-0.182	0.424	0.004	0.064
Improved water access (tap water, drinking fontain, piped water)	0.035	0.007	-0.128	0.482	0.627	0.653	0.476
Improved toilet facilities (private toilet or flush toilets)	0.191	0.206	-0.027	-0.032	-0.087	0.156	0.363
Eigenvalue	3.744	1.755	1.148	1.112	1.025		
Share of variance associated	0.220	0.103	0.068	0.065	0.060		

Table D2: Summary statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Weight-for-height (WHZ)	12403	-0.62	1.26	-5	4.94
Height-for-age (HAZ)	12572	-1.53	1.64	-6	5.94
Weight-for age (WAZ)	12497	-1.31	1.26	-5.95	5
WHZ<2	12403	0.12	0.33	0	1
HAZ<2	12572	0.39	0.49	0	1
WAZ<2	12497	0.27	0.45	0	1
WHZ<3	12403	0.04	0.19	0	1
HAZ<3	12572	0.16	0.37	0	1
WAZ<3	12497	0.09	0.29	0	1
Child age (in months)	12572	27.14	16.57	0	60
Child sex (male=1)	12572	0.51	0.50	0	1
Twin (=1 if a child has a twin)	12572	0.03	0.16	0	1
Household size	12572	12.05	6.69	2	61
Mother's age (in years)	12572	29.93	7.57	15	60
Household head age	12572	47.88	13.56	17	100
Mother's literacy	12572	0.08	0.27	0	1
Mother's primary education	12572	0.06	0.23	0	1
Mother's secondary education	12572	0.01	0.12	0	1
Mother's other education	12572	0.00	0.05	0	1
Household head literacy	12572	0.10	0.30	0	1
Household head primary education	12572	0.10	0.30	0	1
Household head secondary education	12572	0.03	0.17	0	1
Household head other education	12572	0.03	0.16	0	1
Wealth index	12572	0.01	0.90	-1.41	7.42

Table D3: Estimation results of the first stage IV regression

Dependent variable : Rainfall in birth year measured at the 1st-closest station (T_0)	
Rainfall in birth year at 2nd-closest station	0.247***
	(0.04)
Rainfall in birth year at 3rd-closest station	0.153***
	(0.03)
Rainfall in birth year at 4th-closest station	0.234***
	(0.03)
Rainfall in birth year at 5th-closest station	0.166***
	(0.03)
Observations	12570
R-squared	0.55
F-statistic: Joint significance of all four rainfall variables	126.256
P-value	0.0000
Overidentification test - Sargan Chi2	1.382
P-value	0.71

The regression includes child, mother and household's characteristics as well as municipality dummies. Cluster robust standard errors are in parentheses.* indicates significance at 10% level; ** at 5% level and *** significant at 1% level of confidence.

General conclusion

Main results

This dissertation is an attempt to provide responses to some of the issues raised by the 2008 global food crisis. Between November 2007 and May 2008, the world price of rice tripled. As rice is a major staple food in many African countries, the thesis begins with an analysis of the price transmission of changes from the world price of rice to domestic prices of local and imported rice in three West African countries, namely Senegal, Chad and Burkina Faso. The results of the econometric estimations reveal that the domestic price of local rice in Dakar depends primarily on local supply and demand shocks rather than global market conditions. This may reflect the low degree of substitutability between imported and local rice due to the fact that that local rice is considered as inferior in quality and is available in small quantity in urban markets. Conversely, the price of imported rice in Dakar is integrated with the international market. Results suggest that decreases in the world price are slowly passed-through to the domestic market, as compared to increases. This asymmetric adjustment may be due to market power in the distribution chain or high fixed costs in the distribution industry. The price of local rice in Bamako responds faster to a world price decrease than to a world price increase. This negative asymmetric adjustment may be due to governmental interventions intended to protect consumers such as tax exemptions and food security stock management.

The second chapter analyses by how much trade barriers at the border, transport costs and nominal exchange rate variations impede the market integration between 24 pairs of contiguous countries in the West and Central African region. To do this we assess the extent to which road distances, borders and exchange rate changes explain deviations from the absolute Law of One Price (LOP) as well as the volatility and persistence in relative prices between 173 markets of the region and for six key agricultural commodities (millet, sorghum, cassava, maize, imported and local rice). Results strongly indicate that both borders and road distance matter in regional integration of food markets in the region. On average crossing a border is responsible for an increase of seven percent in relative prices. However this average border effect hides large discrepancies by bilateral borders. Benin, Niger, Nigeria, Cote d'Ivoire, and Burkina Faso have the lowest estimated borders, and thus are found to be the most integrated countries reflecting the intense cross-border trade of grains between those countries. On the other hand, our results evidence the high cost of crossing the Mauritanian, Guinean and Ghanaian borders. Lastly, belonging to an economic union and sharing the same currency appear as major determinants of market integration.

Until recently, the food crisis prevention systems relied almost solely on production forecasts forgetting the demand side of the food security equation. However, production forecasts are rarely accurate and do not really provide early information about the state of future food availability. The purpose of the third chapter is thus to strengthen the existing early warning systems by analysing market food prices collected by the national market information systems of three Sahelian countries, Niger, Burkina Faso, and Mali. Firstly, we identified few leading markets –Maradi, Dori, Gaya and Tenkodogo – that play a significant role in influencing current prices in other markets. Then, we analysed price behaviour of millet in the different countries. Finally, we defined three types of early warning indicators whose predictive power has been tested using three types of nonlinear panel models. This chapter provides new indicators able to detect the warning signs of a looming price crisis about six months in advance. Our results show that crises that start usually in April or May can be anticipated as early as November by monitoring the price movements in few markets, especially in Maradi. The indicators defined in this chapter have the advantage to rely on existing data that are easy to collect. They are proved to be relevant and could usefully be added to the existing early warning systems.

Chapter 4 contributes to the vulnerability literature by studying the impact of weather related shocks on the health of children under five years. We consider that a rainfall deficit has a negative impact on households' income which in turn conditions access to food and health care. Results show that households dot no cope with income shocks related to ordinary weather fluctuations. This can be taken as an evidence of the lack of diversification of rural household income. Given that most farmers depend almost exclusively on income from their harvest which is concentrated over a short period of the year, a drought has an adverse effect on the nutritional status of children born within eleven months after the shock. The in utero period and the first months of life appear to be a critical period during which exposure to nutritional shortfall have long-lasting effects. Results also show that large negative shocks have a bigger impact on the child nutritional status than large positive shocks. Lastly, rainfall conditions in prenatal period do not have any impact on the nutritional status of the most severely malnourished children. Acute malnutrition is above all the consequence of the poor education and poor health status of mothers.

Policy implications

The proportion of undernourished people remains the highest in sub-Saharan Africa. Until now, efforts made by national governments and by the international community failed to prevent food crisis and to reduce significantly year-to-year food insecurity. This thesis suggests some policy implications to achieve this objective.

Given the role played by borders in explaining price deviations between markets in West and Central Africa, attention should be focused on removing transactions costs and reducing delays at the border. Trade barriers undermine Africa’s enormous potential for trade between food surplus and food deficit areas. Measures to actively facilitate trade are among the main urgent actions to assist African countries in expanding trade and benefiting from globalization. Examples of trade facilitation actions include the implementation of policy reforms, the development of new border management systems and the reduction of excessive documentation requirements.

Massive investments in physical infrastructure such as roads, ports and telecommunications networks are needed to improve physical access to food markets. Investments aimed at reducing the costs of trade, are central to stimulating smallholders’ market participation and escape from semi-subsistence poverty traps. Investments should be focused primarily on reducing transport cost in rural areas and to improve cross-border routes in order to link smallholders to regional networks.

Teravaninthorn and Raballand (2009) found that road conditions are not the main determinant of the transport prices in West and Central Africa. They show that investing in road infrastructure is not a sufficient condition for lowering transports prices as long as the market is strongly regulated. In West and Central Africa, the trucking industry is characterized by cartels offering high prices and low service quality. Deregulating the trucking industry and reforming cartels could certainly help reducing the transport costs.

Efficiency gains can be made from enhancing regional integration in the continent. As shown in chapter two, regional integration helps to decrease food price differentials between markets located in opposite sides of a border. Promoting regional integration and harmonizing policies among trading partners can enhance strongly the capacity for trade of African countries. Besides, strengthening international policy coordination can contribute to improve the food trade system towards a more stable and predictable system. In 2008, unilateral actions like exports restrictions have proved to be harmful and have exacerbated the initial shock, especially in the case of rice. The regional dimension should be taken into account in the formulation of food security policies as well. Given the high inter-country correlation of price crisis, African countries must work together to build a regional system for food crisis prevention.

The dissemination of market information including information on prices both within and across countries is likely to reduce differences in the relative price of agricultural products in different markets. Better market information and increased transparency are expected to help farmers by improving the transmission of market signals. Farmers are expected to be able to make more informed decisions and in this way maximize their profits and minimize post-harvest losses due to overproduction of certain crops.

The slow and asymmetric price transmission between the world price and the domestic prices in developing countries is likely to reflect imperfect competition or high fixed costs in the distribution chain. It may be also due to political interventions in the form of price support or marketing quotas. One important challenge to agricultural development in Africa is to improve market access for rural smallholder farmers and to increase the share of the value added captured by farmers along the value chain by raising the bargaining power of smallholder farmers. The main constraints to value chain development are related to market access, market orientation, hard infrastructures and institutions (Trienekens, 2011). Modernizing value chain in developing countries requires among other things to increase farmers' knowledge of market demand, farmers' access to input materials for production and to improving the business environment through clear policy directions.

The thesis provides additional support for public interventions aiming at protecting rural households from climate shocks. Promoting the development of weather–based insurance could provide an effective solution to promote agricultural development and to protect households and particularly children from income variations. However, weather insurance mechanisms may be unable to protect children suffering from acute malnutrition. Results call for an improvement in women's education and in women's relative status as maternal education emerges as a key determinant on child malnutrition.

Scaling up safety net programs should also be among the priorities of policy makers in developing countries. The groups most vulnerable to malnutrition (infants, children under 12 months, pregnant women and lactating mothers) requires special attention and should be targeted adequately in social protection programs. There needs to be a much stronger focus on the critical period during which deprivation has the most severe consequences on children.

Such an approach requires services like prenatal care, breastfeeding promotion, parenting education and early intervention for at-risk children less than one year of age.

Suggestions for future research

Household food insecurity is a complex and multifaceted problem. To provide accurate policy strategies to policy makers, there is need for more research about fundamental questions related to food and agriculture in development.

One direction would be to explore the linkages between smallholder farmers and consumer markets, especially the determinants of the marketing behaviour of food crop producers. We know for instance that only 30 percent of the domestic rice production is commercialized in urban markets in Senegal. An interesting research question would be to assess whether the constraints to commercialization are related to production factors - lack of credit to finance key inputs and low food crop productivity - or to markets factors including transport costs between the farmer's village and the nearest market, non-competitive behaviour among local traders, poor access to price information or lack of demand.

Another possibility would be to investigate how households adjust their consumption in response to changes in prices and income. Although the effect of soaring world food prices largely depends on the extent to which world prices are transmitted to domestic markets, the demand pattern of households' responsiveness to price change must be taken into account. Better knowledge of the patterns of substitution between and within food groups can help to design policies and programs that aim to improve the nutritional status of poor households.

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Summary of the thesis:

This doctoral thesis is in line with the renewed interest in research on agriculture and food security, following the 2008 global food crisis. The aim of this thesis is to contribute to a better understanding of the complex issues surrounding food security. The first chapter investigates whether the changes in the international price of rice are transmitted to the domestic prices of rice in Senegal, Mali and Chad. Results indicate that the domestic prices of imported rice in Dakar and of local rice in Bamako react differently to changes in the world price depending on whether the world price is rising or falling. Chapter 2 analyses by how much trade barriers at the border and transport costs impede the integration of agricultural markets in West and Central Africa. Results highlight the role played by borders in explaining price deviations between markets. Additionally, belonging to an economic union and sharing the same currency appear as major determinants of market integration. The third chapter aims at providing new early warning indicators based on food prices in Mali, Niger and Burkina Faso. Our analysis reveals that price crisis can be predicted about 6 months in advance through the observation of past price movements. Chapter 4 focuses on the analysis of children's vulnerability to climate shocks in Burkina Faso. By combining health data originating from a 2008 household survey with meteorological data, we show the importance of weather conditions in prenatal period and in the first year of life on the future nutritional status of the children.

Keywords: Food security, food prices, households' vulnerability, early warning system, TAR model, border effect, weather shocks, food price transmission, asymmetric adjustment, child health, agricultural trade.

Résumé de la thèse:

La crise alimentaire de 2008 a suscité un regain d'intérêt pour les questions agricoles et de sécurité alimentaire dans les pays en développement. Partant du constat que près de 27% de la population d'Afrique Sub-saharienne souffre de malnutrition, cette thèse a pour objectif de contribuer à une meilleure compréhension des causes complexes de l'insécurité alimentaire. Le premier chapitre étudie les mécanismes de transmission des variations du prix mondial du riz aux prix domestiques dans trois pays ouest-africain: le Sénégal, le Tchad et le Mali. Les résultats indiquent que le prix du riz importé à Dakar et le prix du riz local à Bamako répondent de façon asymétrique aux variations du prix mondial. Le chapitre 2 teste la présence d'obstacles aux échanges agricoles entre pays d'Afrique de l'Ouest et du Centre. Il ressort de l'analyse que le passage des frontières est coûteux. Toutefois, le coût associé au passage de la frontière est plus faible entre pays membre d'une même union économique et monétaire. Le chapitre 3 a pour objectif le renforcement des systèmes d'alertes précoces des crises alimentaires existants au Sahel. Il montre qu'il est possible d'anticiper les crises de prix avec six mois d'avance en analysant les mouvements passés des prix des céréales. Enfin, le chapitre 4 s'intéresse à la vulnérabilité des ménages face aux chocs pluviométriques. Il révèle que les ménages ruraux au Burkina Faso n'ont pas la capacité d'assurer ou d'absorber ces chocs climatiques.

Mots clés : Sécurité alimentaire, vulnérabilité des ménages, systèmes d'alerte précoce, choc climatique, santé des enfants, modèle TAR, marchés alimentaires, commerce agricole, intégration des marchés, effet frontière, transmission des prix.