ZENTRUM FÜR ENTWICKLUNGSFORSCHUNG

Food price volatility: the role of stocks and trade

Inaugural - Dissertation
zur
Erlangung des akademischen Grades
eines
Doktor der Agrarwissenschaften
(Dr. agr.)

der
Landwirtschaftlichen Fakultät
der
Rheinischen Friedrich-Wilhelms-Universität Bonn

vorgelegt von

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aus Stuttgart

Bonn 2015

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Tag der mündlichen Prüfung: 06.07.2015

Erscheinungsjahr: 2015

Abstract

After a period of relatively low international food price volatility since the 1970s, prices spiked in 2007/2008 and 2011. These international price changes transmitted to domestic markets where they generate extra volatility. This volatility adversely impacts on welfare of consumers and producers, while price spikes are a major threat to national food security. This study examines drivers of grain price instability in developing countries and discusses the role of stocks and trade to stabilize prices and consumption levels.

Multiple determinants of food price volatility are identified in this work using a panel of more than 70 developing countries. The econometric approach chosen accounts for volatility clusters and potential endogeneity of explanatory variables. The estimation shows a large spill-over of international price volatility into domestic food markets, in particular for importing countries, with a short-run elasticity between 0.26 and 0.44. In relative terms, stocks and regional trade integration contribute most to price stabilization. In numbers, an increase in the stock-to-use ratio or the share of regional trade by one percentage point diminishes variability by 2.5 percent and 0.8 percent, respectively. Export restrictions, so called insulation policies, significantly reduce volatility for non-importers by about four percent when export quantities are 10 percentage points lower. In contrast, markets in countries that run extensive public price stabilization programs are not found to be associated with lower price instability.

In Ghana, food prices of locally produced staples exhibit strong seasonality, up to an intra-annual price spread of 60 percent, owed to limited storage. Primary data collected from wholesale traders reveals seasonal fluctuations in stock levels and suggests that traders hold a significant share of total stocks, especially towards the end of the marketing year. In addition to that, traders are found to have distinct storage strategies. Some traders only store to resell in bulk or carry working stocks to supply costumers, while a group of traders speculates for seasonal price increases.

Finally, based on a theoretical model to define stocking norms, costs and benefits from storage cooperation are assessed. The empirical application to West Africa reveals great potentials of cooperation emerging from the imperfect correlation of production quantities among these countries. Accordingly, regional stocks under cooperation in an emergency reserve can be up to 60 percent less than without cooperation. Limited intra-regional trade reduces the need for stock releases significantly. Full trade integration would diminish regional consumption variability to 3.4 percent without storage, but is not effective in dampening severe supply shortfalls. Cooperation in a stabilization reserve has only limited impact on consumption stability, and thus storage cooperation should be restricted to an emergency reserve.

Zusammenfassung

Nahrungsmittelpreisvolatilität: die Rolle von Lagerhaltung und Handel

Im Anschluss an eine Phase relativ geringer Volatilität internationaler Nahrungsmittelpreise seit den 1970er Jahren, kam es 2007/2008 und 2011 zu Preisspitzen. Diese internationalen Preisschwankungen übertrugen sich auf nationale Märkte auf denen sie zusätzliche Instabilität verursachen. Preisinstabilität beeinträchtigt die Wohlfahrt von Konsumenten und Produzenten und Preisspitzen stellen eine große Gefahr für die nationale Ernährungssicherheit dar. Diese Studie untersucht die Ursachen von Preisinstabilität in Getreidemärkten in Entwicklungsländern und diskutiert die Rolle von Lagerhaltung und Handel um Preise und das Konsumniveau zu stabilisieren.

Die vielfältigen Gründe von Preisinstabilität werden mit Hilfe eines Panels, das mehr als 70 Entwicklungsländer umfasst, identifiziert und voneinander abgegrenzt. Der gewählte ökonometrische Ansatz berücksichtigt Volatilitätshäufungen und eine mögliche Endogenität der erklärenden Variablen. Die Schätzung zeigt einen starken Übersprungseffekt internationaler Preisvariabilität auf nationale Märkte in Entwicklungsländern, insbesondere für Nahrungsmittelimportländer, mit einer kurzfristigen Elastizität zwischen 0,26 und 0,44. Relativ gesehen tragen Lagerhaltung und Integration in regionalen Handel am stärksten zur Preisstabilisierung bei. In Zahlen bedeutet das: Ein Anstieg im Verhältnis Lagerbestände zu Verbrauch oder des Anteils an regionalem Handel von einem Prozentpunkt reduziert die Preisvolatilität kurzfristig um ca. 2,5 bzw. 0,8 Prozent. Exportrestriktionen von Nicht-Importländern, sogenannte Isolationspolitiken, reduzieren Preisvolatilität signifikant. Dagegen kann nicht festgestellt werden, dass Märkte in Ländern mit weitgehenden öffentlichen Preisstabilisierungsprogrammen weniger Instabilität aufweisen.

Preise im Inland produzierter Grundnahrungsmittel in Ghana sind von starken saisonalen Schwankungen, um bis zu 60 Prozent geprägt, die unzureichender Lagerhaltung geschuldet sind. Die Erhebung von Primärdaten unter Getreidegroßhändlern offenbart saisonale Muster und legt nahe, dass Händler einen signifikanten Anteil an der Gesamtlagermenge halten, besonders zum Ausgang des Agrarjahres. Zudem verfügen Händler über unterschiedliche Lagerhaltungsstrategien. Einige Händler lagern ausschließlich um in größeren Mengen weiterverkaufen zu können oder um Lieferverpflichtungen nachzukommen, während eine Gruppe von Händlern auf einen saisonalen Anstieg der Preise spekuliert.

Zuletzt werden Kosten und Nutzen einer regionalen Lagerhaltungskooperation an Hand eines theoretischen Modells, das optimale Lagerhaltungsmengen festlegt, abgeschätzt. Die empirische Anwendung auf Westafrika zeigt ein großes Potential von Kooperation zu profitieren, das sich aus der unvollständigen Korrelation der Erntemengen der einzelnen Länder ergibt. Demzufolge könnten regionale Lagermengen im Kooperationsfall einer Notfallreserve um bis zu 60 Prozent geringer ausfallen. Geringer intra-regionaler Handel würde die Notwendigkeit der Ausgabe von Lagerbeständen signifikant reduzieren. Vollständige Marktintegration würde die Variation des regionalen Konsums ohne weitere Lagerhaltung auf 3,4 Prozent reduzieren, ist allerdings weniger effektiv um massive Angebotsengpässe auszugleichen. Kooperation bei einer Stabilisierungsreserve zusätzlich zu regionaler Handelsintegration hat nur wenig Einfluss auf die Stabilität des Konsums, deshalb sollte die Lagerhaltungskooperation auf eine Notfallreserve beschränkt werden.

Acknowledgements

This work would not have been possible without the support of many people. First I thank Prof. Joachim von Braun for his trust when he accepted me as a PhD student in 2011 and his guidance thereafter until the completion of this dissertation. Discussions with him always enabled me to re-focus and provided invaluable support to the preparation of this thesis. I also gratefully acknowledge Prof. Thomas Heckelei for accepting to be my second supervisor and for his comments during meetings as part of the cooperation between ILR and ZEF. Further, I am very grateful to my academic advisors, Getaw Tadesse and Matthias Kalkuhl. Matthias Kalkuhl has been a great support throughout the last three years and most of the work was completed in close cooperation with him and benefited a lot from his suggestions and comments. Many of the ideas raised and methods applied in this work were discussed within the Volatility Group at ZEF. I thank Bernardina Algieri, Jan Brockhaus, Mekbib G. Haile, Martha Kozicka, Irfan Mujahid, Christine Waschkeit, and Anna Winter for their comments and patience to listen to many new ideas and problems. In particular Mekbib G. Haile has been a great colleague and friend from my first to my last day at ZEF and I owe him many thanks for his comments and suggestions.

During the last three and a half years, I discussed my research with many researchers and practitioners apart from the aforementioned. At ZEF, Marc Müller and Julia Anna Matz had always time for discussions with many helpful suggestions. In my office in the 3rd floor, Justice Akpene Tambo, Elias Danyi Kuusaana, and Saiful Islam had always an open ear for everyday problems and time to discuss Ghana related issues whenever I needed their help. The individual chapters of the dissertation were presented at many workshops and conferences and they benefited here and there from comments and suggestions by the participants of these meetings and the reviewers in the submission processes. Data collection and cleaning is sometimes very tedious. At ZEF, I was lucky to get excellent assistance by Mikko Bayer, David Schäfer, Christian Zimpelmann, Tobias Heimann, Ling Zhu, and Masha Shahbandeh Najafabadi. I am also indebted to various proofreaders. In particular, Christine Waschkeit and Cem Ermagan sacrificed precious time by reading the entire dissertation.

Field work in a foreign country is a great challenge. I was very lucky to get administrative and organizational support from the Institute of Statistical, Social, and Economic Research (ISSER) at University of Ghana (Legon) and its director Prof. Felix Asante who allocated time for very valuable discussions despite his busy schedule. During the actual field work I was supported by Linus Linnaeus Tannor, Benthil Akuahmoah, and Hanan Abdullah in conducting the interviews in various languages. I am greatly indebted to Linus Linnaeus Tannor who traveled with me across the country for the interviews which he conducted with great expertise. Without his help the data collected would not have a comparable accuracy and quality. I am also very thankful to all participants of the survey who allocated valuable time to let me get insights into their trading business. Moreover, I was supported by personnel at ISSER, MoFA, MoTI, SRID, GIZ, USAID, and WASCAL with information, access to data, and through the establishment of contacts.

I am also deeply grateful to my parents, my girlfriend, and many friends for their steady and unconditional support.

Last, I would like to express my deepest gratitude to the Center for Development Research and its employees for hosting me during my PhD studies. My batchmates have been always a great support during countless and endless coffee meetings and lunch breaks. Günther Manske and Maike Retat-Amin do a great job to facilitate a fruitful and creative atmosphere at ZEF. Financial support for the research from the Federal Ministry of Economic Cooperation and Development (BMZ) of Germany and EU FOODSECURE is gratefully acknowledged.

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Abbreviations

AMIS	**A**gricultural **M**arket **I**information **S**ystem
ARCH	**A**uto**r**egressive **C**onditional **H**eteroskedasticity
AR	**A**uto**r**egressive
ASEAN	**A**ssociation of **S**outheast **A**sian **N**ations
CBS	**C**ommodity **B**alance **S**heet
CEMAC	**C**ommunaute **E**conomique et **M**onetaire d'**A**frique **C**entrale
CFA	**C**ommunautes **F**rancaises d'**A**frique
CILSS	**C**omite permanent **I**nter-Etats de **L**utte contre la **S**écheresse dans le **S**ahel
EAERR	**E**ast **A**sian **E**mergency **R**ice **R**eserve
ECOWAS	**E**conomic **C**omission **O**f **W**est **A**frican **S**tates
ETLS	**E**COWAS **T**rade **L**iberalisation **S**cheme
EGARCH	**E**xponential **G**eneral **A**uto**r**egressive **C**onditional **H**eteroskedasticity
FAO	**F**ood and **A**rgigulture **O**rganization
FAO CBS	**F**ood and **A**rgigulture **O**rganization **C**ommodity **B**alance **S**heet
GIEWS	**G**lobal **I**nformation and **E**arly **W**arning **S**ystem
GARCH	**G**eneral **A**uto**r**egressive **C**onditional **H**eteroskedasticity
GLSS	**G**hana **L**iving **S**tandard **S**urvey
GMM	**G**eneral **M**ethod of **M**oments
IFPRI	**I**nternational **F**ood **P**olicy **R**esearch **I**nstitute
IGC	**I**nternational **G**rains **C**ouncil
IGADD	**I**nter**g**overnmental **A**uthority on **D**rought and **D**evelopment
ISSER	**I**nstitute of **S**tatistical **S**ocial and **E**conomic **R**esearch
MA	**M**oving **A**verage
MoFA	**M**inistry **o**f **F**ood **A**griculture
MENA	**M**iddle **E**ast and **N**orth **A**frican region
NTB	**N**on **T**arif **B**arriers

SADC	**S**outhern **A**frican **D**evelopment **C**ooperation
STAMP	**S**tructural **T**ime Series **A**nalyser **M**odeller and **P**redictor
UCM	**U**nobserved **C**omponent **M**odel
UEMOA	**U**nion **E**conomique et **M**onetaire **O**uest **A**fricaine
USDA	**U**nited **S**tates **D**epartment of **A**griculture
WFP	**W**orld **F**ood **P**rogram

Chapter 1

Introduction

1.1 Background and motivation

Naturally, agricultural commodities are exposed to substantial price instability due to the seasonality of production. After a period of relatively low international volatility since the 1970s, food prices spiked in 2007/2008 and 2011. In a globalized world, international price changes transmit to domestic markets where they generate extra volatility. This volatility adversely impacts on consumers and producers by increasing uncertainty about future market prices. Price spikes are a major threat to national food security and have led to hunger crises in a number of developing countries. Although levels of malnutrition have been successfully reduced over the past decades, food insecurity remains a major concern for policy makers in low income countries [von Braun and Tadesse, 2012].

The international food price surge in 2007/2008 brought the issues of price volatility and food security back on the table. So, food price volatility was discussed at the G20 meetings in Toronto and Cannes in 2010 and 2011 yielding into a special report by a myriad of international institutions [FAO et al., 2011]. A number of developing and emerging economies with India leading the way requested for exemptions from World Trade Organization (WTO) trade and intervention discipline to guarantee national food security at their 2013 meeting in Bali. The topic is expected to continue to influence the international policy agenda.

Traditionally, the literature has acknowledged price instability and its implications for food security and welfare with great attention [Newbery and Stiglitz, 1981; Sahn, 1989; Timmer, 1989]. With the recent international food crises, research has concentrated on qualitative and quantitative assessment of international price spikes and volatility [Abbott et al., 2011; Tadesse et al., 2013]. However, price instability is a major concern especially for developing countries where consumers spend a large share of their income on food and agriculture represents a substantial part of economic activity.

The theoretical and empirical literature on prices of storable and tradeable goods has accepted the theory of storage and its extension with regard to international trade. However, poor data availability has restricted analyses to country level studies often without an explicit integration of the level of stocks into the model. On the contrary, simulation models successfully quantify the impact of stocks and trade on price volatility [Miranda and Helmberger, 1988; Gouel and Jean, 2015]. Yet they are based on restrictive assumptions regarding the functional form of demand and supply curves.

An empirical quantification of the drivers of price volatility is of great importance to policy makers. In the wake of the global food crisis, a great number of developing and emerging economies were forced to take action to dampen the impact of high international volatility and to enhance coping strategies of the vulnerable. Subsidized food distribution and trade regulations are among the most commonly used instruments. In view of the fear for the political economy of food prices and driven by the adverse health impacts of transitory food insecurity, the implementation of public storage systems is a popular choice [Demeke et al., 2009].

Public storage has also been suggested by scholars and policy advisors as a possible tool to reduce volatility and guarantee sufficient supply [Galthier, 2009]. However, this intervention comes at high economic and fiscal costs. Among others, India runs a large public distribution system that demands great shares of the public budget and has pushed private traders out of the system [Kozicka et al., 2015]. The experience with buffer stocks in Africa is also not promising [Deuss, 2014]. Therefore, government interventions should be grounded on evidence based research and comprehensive understanding of the nature of food marketing in the country. In particular storage patterns in developing countries are not well understood due to the large informality of trade. However, this is necessary in order to conclude that an intervention is required to accomplish amended market outcomes.

Apart from traditional intervention tools, it is worth to consider innovative approaches to food security, such as virtual or regional reserves and import facilitation schemes [von Braun and Torero, 2009; Sarris et al., 2011; Wright, 2012]. In particular, regional reserves are considered as a viable means to reduce costs of operation and enhance commitment to regional trade agreements [Wright and Cafiero, 2011].

1.2 Research questions

Given the gap in the literature, this dissertation aims at providing empirical evidence on the causes of commodity price variability, storage behavior, and the possible impact of price stabilizing policy measures in developing countries. More precisely, the objective is to assess what factors can contribute to stabilize domestic prices. This is of great significance to policy makers who target national food security. Specifically, the following questions are be addressed in the course of the thesis:

1. What are the drivers of domestic grain price volatility in developing countries?
2. What storage strategies pursue private players in Ghana and what are the implications for policy design?
3. To what extent can regional storage cooperation reduce the costs of public intervention, and what are the specific benefits for West Africa?

The research has no general geographical focus. The country case study on private storage behavior was conducted in Ghana which is considered as a typical country in many respects. The methodology to analyze costs and benefits from cooperation is also general and applied to West Africa on the account that regional cooperation is intensively discussed in this region.

1.3 Approach and methods

There are multiple ways to model price volatility. In the aftermaths of the global food crisis, several studies appeared using different methods, namely coefficient of variation, standard deviation of returns, and conditional volatility measures [Huchet-Bourdon, 2011; Piot-Lepetit and M‘Barek, 2011]. Therefore, this work starts by critically reviewing the contemporaneous literature on volatility modeling with the purpose to identify the appropriate model which can answer the first research question.

Data availability is not an issue in most high income countries. In large contrast, long and frequent price series are often not obtainable in developing countries. For this reason, a similar approach to volatility modeling, as it is applied to international volatility, is not feasible. Inspired by a less frequently cited work by Lee and Park [2013], a cross-country panel model is identified as the model of choice to satisfy the requirements of the first research objective without extensive data needs. Eventually, it even appeared that the panel approach features advantage over conventional models to capture transmission effects of international price volatility. Simultaneously, the quality of annual stock data that is used as a main explanatory variable was challenging. The difficulty in their estimation and the differences between available sources is discussed in chapter three. Luckily, the Food and Agricultural Organization (FAO) Commodity Balance Sheet (CBS) data was finally provided by FAO's Global Information and Early Warning System (GIEWS) for the analysis, which improved the results considerably.

The cross-country panel allows the inclusion of a wide range of explanatory variables that capture national supply and demand factors, macroeconomic factors, institutional quality of markets, and trade policies. The latter are measured in an innovative way by looking at export shocks to circumvent a subjective and qualitative assessment and to allow policies to vary over time. The dynamic version of the panel is capable of controlling for oft-cited volatility clusters [Serra and Gil, 2012]. Lastly, the large data set also permits the estimation for sub-samples of the whole data set in order to consider the heterogeneity across different types of countries.

The main advantage of cross-country studies is the great scope and relevance of the work. From an empirical point of view, multiple countries are also required to increase the number of observations. On the other hand, there are well known shortcomings of this type of studies [Levine and Renelt, 1991]. Most notably, the specific characteristics of a country are not well acknowledged and coefficient estimates represent sample averages that may strongly vary across countries. Therefore, the results from chapter four must not be misused to give specific recommendations. In order not to fall into suspicion of being too broad and general, the subsequent chapters concentrate on a specific country and region, respectively.

Given the high volatility of prices, national governments attempt to enlarge storage to stabilize food prices and to overcome supply shortages. Economists justify public storage by the combination of risk aversion of consumers as well as producers and the imperfection of insurance markets in developing countries [Newbery and Stiglitz, 1981; Gouel, 2013b].

On the other hand, public storage induces reactions by market participants and can lead to a crowding-out of private storage [Sarris, 1992; Headey, 2014]. In chapter five, market behavior of private stockholders is examined. The research method combines qualitative and quantitative elements. So, the narratives of traders, experts, and stakeholders are linked to primary and secondary data. As a result, the study is more of descriptive than inferential nature. Nevertheless, the insides gained are valuable for further market and price analysis and contribute to the understanding of inter-seasonal price behavior. A better understanding of trade and storage is essential for effective policy design to reduce price volatility and mitigate price spikes.

In the last analytical chapter, regional storage cooperation is discussed as an option to reduce the cost of operation of public stockholding. The idea of international risk sharing became prominent in the 1970s after the international food crisis at the time. As an alternative to the idea of an international insurance system financed by industrialized countries [Johnson, 1976; Konandreas et al., 1978], developing countries could also cooperate among themselves. Cooperation is beneficial when supply shocks are imperfectly correlated. Earlier studies emphasized the potential of regional trade cooperation to stabilize fluctuations in supply [Koester, 1984; Badiane, 1988]. On the other hand, the experiences from the recent global food crisis have shown that reliance on imports may be insufficient when trading partners regulate exports to protect domestic markets. In this case, storage is required to bridge temporary supply shortage in international markets. Storage can be understood as an insurance against supply shortfalls. The model used in chapter six builds on the existing literature and conceptualizes the link to storage. In doing so, storage cooperation is analyzed under two possible reserve schemes. First, an emergency reserve that releases stocks when supply falls short of a predetermined level and second, a stabilization reserve that smoothes both positive and negative deviations from supply trend values.

Overall, the approach and methods of the dissertation are cross-cutting. Drivers of food price volatility and possible instruments to stabilize prices are discussed on a general account, at the regional level, and within the context of a single country. Similarly, the methods applied in this dissertation are diverse and reach from recently developed econometric techniques (dynamic panel estimation with system General Method of Moments (GMM)) over modeling to an innovative trader survey. Approaches and methods should be considered to be complementary and contribute equally to the overall research findings.

1.4 Organization of the thesis

The study is separated into seven chapters. The sequential order of the chapters is purposive. The precedent part aims at making the reader familiar with the topic of food price volatility and creates a link to storage and trade of agricultural commodities. The research background and relevance of the topic is also emphasized in this section. Welfare impacts of price volatility and uncertainty on consumers, producers, and other market participants will be discussed in the remaining part of the introductory chapter.

After the introduction, chapter two outlines the methodology to measure and model food price volatility. On this basis, volatility of staple food prices is computed and estimated for a large number of markets in developing and emerging economies. Furthermore, the performance of the different methods to evaluate volatility is analyzed. Lastly, volatility is compared across commodities, geographical location, and over time. Chapter three follows with the theoretical model on how storage and trade affect prices. The same chapter contains a discussion on the validity of stock data and compares the most prominent data sources. Both chapter two and three are included with the purpose to introduce the reader to modeling of price volatility and the theoretical literature used in this work. In doing so, both chapters set the stage for the further course of the work.

In chapter four, causes of price volatility are discussed theoretically and empirically in a cross-country framework. A particular focus is laid on the heterogeneity of countries as importers, exporters, and trade-switchers. In addition to this, the distinct impacts of public storage and trade policies are addressed. Then, storage behavior of private traders in Ghana is analyzed in chapter five. Findings from primary data collection and policy implications are discussed. In the last analytical chapter, regional storage cooperation as an approach towards food security is reviewed. The chapter contains the description of a methodology to evaluate costs and benefits of cooperation. Then, the methodology is applied to the West African region.

Each chapter appears with its own introduction and conclusion and can generally stand on its own. The respective introduction embeds the chapter in the context of the whole work. Nevertheless, the dissertation closes with a general conclusion including the most important policy messages to take away.

1.5 Why volatility matters

It is of great importance to note that the subject-matter of this dissertation is general price volatility, which is the magnitude and frequency of price movements in both directions. This certainly includes price spikes as they appeared during the global food crisis in 2007/2008, but their appearance alone is not sufficient for volatility. A constant price increase (decrease) is not associated with price volatility. Welfare impacts of high price levels are ambiguous. Farmers benefit, while consumers lose [Ivanic et al., 2011; von Braun and Tadesse, 2012; Headey, 2014]. A reduction in prices has the opposite effect. Conversely, price variability makes future prices less predictable, and thus creates risk for all market participants. The subsequent section addresses the various effects for price volatility and uncertainty.

1.5.1 Microeconomic effects

1.5.1.1 Welfare impacts

Standard welfare theory assumes consumers and producers to be fully rational and to maximize their utility by satisfying a resource constraint. For consumers, changes in prices influence utility by the choice of the optimal consumption bundle. The Slutsky equation describes the variation in demand for good i for price changes of good j. On the one hand, demand changes induced by variation in relative prices (p_i/p_j). On the other hand, variation in prices changes relative income, and thus alters demand. Whether substitution or income effect dominate is not clear a priori. For instance, a change in the relative price of one good may result in increasing demand for a second good. However, the subsequent reduction of relative income can offset this effect and reduce the demand of the second good.

The most common measures to evaluate a change in utility in welfare economics are consumer surplus, compensating variation (CV) and equivalent variation (EV), while the first is an approximation of the latter two. Compensating variation can be understood as the monetary amount that is necessary in order to bring a consumer to his/her initial utility level after the price has changed. In contrast, the equivalent variation is the monetary amount at which households become indifferent to accept the price change [Mas-Colell et al., 1995]. Both can be expressed in the following way:

$$\text{CV }(p_0, p_1) = e(p_1, u_1) - e(p_1, u_0) \tag{1.1}$$

$$\text{EV }(p_0, p_1) = e(p_0, u_1) - e(p_0, u_0) \tag{1.2}$$

where $e()$ is the money metric indirect utility function evaluated at price p and a given level of wealth. It gives the wealth required to achieve a given utility $V(p, w)$ (indirect utility function).

In an uncertain world with stochastic commodity prices consumers maximize their expected utility $E[U]$ based on expected price changes. Turnovsky et al. [1980] derive the benefits from price stabilization by comparing utility under certainty vis-à-vis uncertainty. Their approximation of ex-ante compensating and equivalent variation has the form:

$$\frac{\partial^2 V}{\partial p_i^2} = \Delta V = [s_i(\eta_i - \rho) - \xi_i] s_i \frac{\Delta \sigma_p^2}{2} \tag{1.3}$$

where $\frac{\partial^2 V}{\partial p_i^2}$ is the change of welfare V by changes in price stability σ_p^2. s_i is the budget share for commodity i, ρ the risk aversion parameter, and ξ and η price elasticity of demand and income, respectively.

Accordingly, welfare under uncertainty increases in the level of risk aversion (ρ), but decreases in the magnitude of income elasticity (η) and price elasticity (ξ) of demand. In fact, the effect is very small if the budget share of commodity i is sufficiently low. Gouel [2013a] provides welfare impacts for a wide range of reasonable parameter values and concludes that effects are comparably small. However, literature subsequent to Turnovsky et al. [1980] queries these findings and argues benefits from price stabilization are largely underestimated [Helms, 1985; Wright and Williams, 1988]. Wright and Williams [1988] emphasize the importance of the demand curvature parameter and expect errors in the assessment of benefits from price stabilization to be particularly large for staple foods of poor consumers.

As opposed to the consumer case, welfare impacts of producers are more straightforward. Uncertainty about output prices unambiguously impacts on the utility of risk averse individuals or firms [Sandmo, 1971; Chavas and Holt, 1990; Coyle, 1992]. A typical utility function that allows for risk is the mean-variance approach:

$$E[U] = E[\pi] - (\rho/2)\sigma_\pi^2 \tag{1.4}$$

where the expected utility $E[U]$ arises from a producer's expected profits $E[\pi]$ and its variance σ_π^2. ρ describes a producer's risk aversion being zero for risk neutral producers.

The variance of profits (σ_π^2) depends on variances and co-variances of the output prices. Utility is decreasing in all elements of the co-variance matrix σ_P^2 of the vector of output prices p [Coyle, 1992]. In words, if producers are risk averse ($\rho > 0$), their utility reduces for higher levels of volatility and stronger cross-price correlation. There is convincing empirical evidence that producers in developing countries are indeed risk averse [Rosenzweig, 1988; Townsend, 1995]. While consumers are concerned with prices at all times, producers are interested in harvest prices only. Therefore, in this instance, volatility should be the deviation of the expected price from its actual realization at harvest time rather than from the sample mean. Thus, it is only irregular unpredictable price shocks that reduce producer welfare [Chavas and Holt, 1990].

In the evaluation of consumer welfare above, income is assumed to be exogenous. The separation between consumers and producers may not be appropriate in the context of developing countries. It may only apply for urban households without the possibility of own food production. For this reason, Deaton [1989] proposes to examine price changes with respect to a proportional ratio that considers to what extent households are net buyers or net sellers.[1] Few attempts have been made to quantify heterogeneity in welfare effects between net buyers and net sellers. Simulation results by Myers [2006] yield significantly greater impacts on producers than on consumers. Second, well-off producers benefit stronger than poor households from price stabilization. For low levels of risk aversion, the effects are negligible. Similarly, Bellemare et al. [2013] estimate price risk aversion coefficients for rural Ethiopian households and calculate the willingness to pay for price stabilization for different income groups. Findings suggest willingness to pay to simultaneously stabilize commodity prices to be on average 17 percent of the household income. Overall, willingness to pay is positive throughout all income groups and increasing in income. The authors hypothesize that wealthier households in the sample are likely to be producers.

[1] Net buyers are purchasing more than they sell and net sellers sell more than they buy.

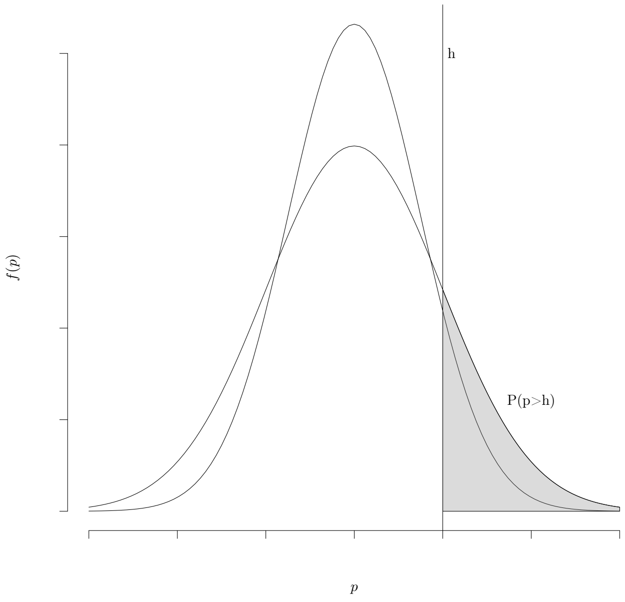

Figure 1.1: Link between consumption and price distribution.

Source: Author's illustration.

Conventional welfare analysis based on the expected utility framework neglects a few important issues. First, dynamic effects of food price volatility and unanticipated price hikes are neglected [Bellemare et al., 2013]. Second, households tend to cut expenses for health and education when facing a price (income) shock, if adequate savings or risk management tools are not available. This can lead to irreversible disinvestment with severe negative consequences in the long-term, for instance school dropouts [Carter and Barrett, 2006]. The theoretical link between consumption shifts and volatility is illustrated in Figure 1.1. h denotes a price threshold for a staple food, whenever $p > h$, households are forced to reduce expenditures of non-staples, health or educational expenditures due to the income effect. The gray-shaded area on the right captures the probability of price spikes. Both price distributions in Figure 1.1 share the same mean, but exhibit different standard deviations. The gray-shaded area is larger for the wider distribution. It follows that price spikes and subsequent consumption adjustments are less likely with lower volatility; to be exact by the area between the curves. In this way, higher volatility induces irreversible disinvestment by greater probability.

To assure basic consumption needs, households may also reduce expenditures on other micro-nutrients-dense food items [Jensen and Miller, 2008; D'Souza and Jolliffe, 2012] which can result in micronutrient deficiencies. Literature on nutrition and labor underlines the indirect effects from undernutrition on household productivity. The relationship between temporary food insecurity and health is also well researched [Barrett, 2002]. Empirical evidence suggests that only short periods of underweight and malnutrition can lead to severe health related problems in the future, but also to immediate infant mortality [Chavas, 2000]. Last, poor consumers will suffer from transactions costs of frequent reallocation of budgetary resources [Timmer, 1989].

For this reasoning, it makes no difference whether volatility is predictable or unexpected. In a recent contribution, Kaminski et al. [2014] find strong evidence for the negative relationship between seasonal price movements and intra-annual fluctuations in consumption of food and non-food items due to a limited ability to smooth consumption over the year. Ziegelhöfer [2014] analyzes the impact of international food price volatility on household welfare using Demographic Health Survey (DHS) data for a comprehensive set of countries. The results show strong impacts of the food price surge in 2007/2008 on child health status, the effect of volatility alone is not conclusively examined.

1.5.1.2 Inefficient resource allocation

Risk aversion is not a necessary condition for negative welfare effects of uncertainty. Economic agents use their full set of information to make decisions about investments. Yet future market conditions are uncertain at the time of investment. Unwillingness or inability to hedge against risks, for instance in the absence of futures markets, increase non-optimal resource allocation [Arrow, 1962]. The larger deviations from expected market outcomes, the higher the welfare losses. A basic reduced form to model this issue is described by Martins-Filho [2011]. The cost function of a producer is given by $c(y, w)$, with w as input prices and y as output. Profit maximization requires $c'(y, w)$ equal to $E[p]$. Whenever markets are competitive, and thus producers cannot influence market prices, suboptimal allocation generates losses since producers cannot instantaneously adjust their production. For a particular functional form of the cost function, expected losses can be represented by:

$$E(L) = \frac{1}{4c(w)}\sigma_P^2 \tag{1.5}$$

where $E(L)$ is the expected loss, σ_P^2 price volatility, and $c(w)$ the cost function.

The model is developed for producers, but can be transferred to commodity stockholders and traders, as well as food vendors. Producers and traders are well informed about predictable seasonal variation in prices. Hence, their concern are unexpected and irregular price changes and market risk at time of their investment.

Apart from immediate individual welfare losses for producers, stockholders, and traders, their behavior has consequences on the whole economy. Uncertainty disincentivizes production of food crops [Haile et al., 2014]. Furthermore, it is reasonable to assume a number of investors, who consider engagement in storage and trade, is discouraged by the uncertainty about future returns. On the same account, small-scale traders select between a variety of consumer goods what to sell, and surely select the products with less volatility given the expected return is the same. In this way, higher uncertainty reduces investment in commodity markets if other areas assure more certainty of returns. This in turn inhibits necessary investment in marketing infrastructure and industrial firms may withdraw investments with consequences for employment and wages [Timmer, 1989].

1.5.2 Macroeconomic effects

Apart from negative microeconomic consequences, volatility involves adverse effects on the whole economy. Generally, and not specific to commodity markets, there is strong evidence on the impact of volatility and uncertainty on economic growth and welfare [Ramey and Ramey, 1995; Jacks et al., 2011]. Myers [2006] formalizes a model to account for positive spill-over effects of price stability to other sectors of the economy. Timmer [2002] estimates these spill-overs have contributed around one percent to overall economic growth in Indonesia.

Exporting countries generate revenue from food production and rely on exports to earn foreign exchange. As the volatility in world prices reduce the predictability of income [Dehn, 2000; Dawe, 2001]. In this way, price instability affects public budgets and monetary stability. In a similar manner, importing countries face uncertainty of required foreign exchange resources to guarantee sufficient supply.

1.5.3 Political distortions

Food price spikes and price volatility also induce governmental responses. Food prices are a major concern for policy makers in developing countries since they affect a large proportion of the population either as source of income or by altering real incomes. Traditionally, governments seek to enhance national production and self-sufficiency by subsidizing agricultural inputs. Conversely, policy responses to food crises usually address short-term price dynamics and have to take distinct forms of intervention. The reason is that the political opinion in many developing countries is shaped by urban consumers who are only concerned with a timely price-reduction of food [Bates, 1981].

Demeke et al. [2009] elaborate on the numerous policies implemented in developing countries during in the wake of the 2007/2008 food crisis. These government actions come at high fiscal costs and take away financial resources for public investment in other sectors. Many economists also criticize state involvement in storage and trade and show that free markets achieve the social optimum. Public intervention distorts market prices and thereby creates wrong incentives for private market actors in the long-term [Newbery and Stiglitz, 1981; Williams and Wright, 1991]. Puetz and von Braun [1991] report on the occurrence of parallel markets in response to market intervention, whenever official markets fail to equate supply and demand at the desired price level. Acting in parallel markets often involves additional costs and risks for traders and farmers. Other than the aforementioned indirect consequences, there are also direct effects of volatility on national food security. For example, the global food crisis in 2007/2008 has undermined progress in the reduction of child malnutrition by a significant margin [von Braun and Tadesse, 2012].

Furthermore, governments in developing countries are usually made accountable for failures in the food system, possibly owned to the long tradition of public market intervention. In an instance of a negative transitory shock, costs of rebellion against the political system are comparably low for the population [Acemoglu and Robinson, 2001; Collier and Hoeffler, 2004]. Empirical evidence establishes a strong link between food crises and social unrests as well as food riots in developing countries [Lagi et al., 2011; Bellamere, 2014]. Political instability in turn can slow down economic growth and reduces welfare [Alesina et al., 1996].

Chapter 2

Recent trends in food price volatility in developing countries

2.1 Introduction

In the wake of the global food crisis, research on price volatility has noticeably risen. Earlier studies engage with the question whether international prices and volatility have really increased beyond historically high levels. This literature suggests that volatility has indeed risen at the end of the last decade calming down within the past three years. But, it also appears that both volatility and levels are high, while not historically exceptional.[1]

At the same time, discussions started how to correctly measure, calculate, or estimate price volatility [e.g. Huchet-Bourdon, 2011]. Most commonly used are the coefficient of variation and the variance of price returns (log returns), which are both easy to compute. Both measure unconditional rather than conditional volatility. However, there is also criticism against the use of realized volatility measures. Thus, Gilbert and Morgan [2010b] propose to use conditional volatility estimated by Generalised Autoregressive Conditional Heteroskedasticity (GARCH) models in order to account for the persistence of price volatility.

With few exemptions, the research focus is much on international markets instead of developing countries. In an analysis very close to the one at hand, Minot [2014] analyzes market level volatility in Africa. His findings are mixed. On the one hand, maize volatility seems to be higher after 2007. On the other hand, for the majority of markets, volatility has

[1]See Gilbert [2006] for a review of price trends and volatility.

decreased. In contrast to the excellent review of Minot [2014], country level studies mainly use conditional volatility models. So far, the literature has been given little attention to the difference between predictable and irregular price volatility [Kaminski et al., 2014].

The objective of this part of this dissertation is twofold. Firstly, an overview of available methods to compute and estimate volatility is provided in section two, while their practical benefits are also discussed. Secondly, using a large set of price data, volatility is calculated by using different measures, namely standard deviation of returns, decomposed volatility, symmetric and asymmetric GARCH. The purpose of this exercise is to test whether measures of volatility substantially differ. Furthermore, this enables testing several hypotheses. For instance, whether differences between commodities and regions exist and whether volatility in developing countries has increased after 2007. In doing so, the chapter provides an overview on methods and literature on volatility modeling. In addition, recent trends in food price volatility in developing countries, which are of relevance for the whole dissertation, are discussed.

2.2 Measuring and modeling volatility

Volatility measures the rate and magnitude of price changes around a trend. In other words, it captures the deviation of the actual observed price from its normal or expected value [Coppock, 1977]. The computation and estimation of price volatility is not unique to agricultural commodities and is heavily discussed in a wide range of economic fields.

In principle, measures of volatility can be classified into two broad categories [Matthews, 2010]. First, realized historical volatility that measures the volatility of observed past prices. And second, stochastic volatility which captures volatility at a given point in time also considering past realization of volatility.

2.2.1 Realized volatility

The most common measures of realized volatility are variance and standard deviation. Both measure the directionless difference of observed prices from their mean. However, they are not unit free. Consequently, commodities with higher price levels show larger levels of volatility. One way to circumvent this shortcoming is to normalize the value by its sample mean which is known as coefficient of variation:

$$\text{Coefficient of variation } = \frac{\sigma}{\mu} \tag{2.1}$$

where σ is the sample standard deviation and μ the sample mean over the same observation period.

The coefficient of variation is easy to compute, however, does entail two major disadvantages. On the one hand, price trends affect the coefficient of variation even if prices increase or decrease constantly [Gilbert and Morgan, 2010a]. Second, variance and standard deviation of random walk variables rise with the number of observations. Thus, volatility will be subject to the length of the price series [Minot, 2014].

Alternatively, the literature on financial markets analyzes returns instead of prices. Returns are the relative price change from one period to the next. They are approximately equal to the difference of logarithmized prices. Then, price volatility is the standard deviation or variance of the returns:

$$\sigma_{p_T} = \sqrt{\frac{1}{T}\sum_{t=1}^{T}(r_t - \overline{r}_T)^2} \tag{2.2}$$

where σ_{p_t} is the price volatility over T time periods, $r_t = \frac{p_t - p_{t-1}}{p_{t-1}} \approx \ln\,(p_t) - \ln\,(p_{t-1})$ is the return of p in t, and $\overline{r}_T$ the mean value in T.

However, volatility changes over time since prices of agricultural commodities exhibit periods of low (high) volatility that follow low (high) volatility periods [Serra and Gil, 2012]. Therefore, it may be advisable to consider structural breaks in time series data and compute volatility for shorter time periods [Jin and Kim, 2012]. Without further analysis and tests for structural breaks, it may reasonable to look at volatility by agricultural marketing year which is defined as the time from the harvest of a commodity to the respective harvest in the next calendar year. In doing so, (2.2) changes to:

$$\sigma_{p_T} = \frac{1}{Y}\sum_{y=1}^{Y}\sigma_{p_y} \tag{2.3}$$

$$\sigma_{p_y} = \sqrt{\frac{1}{12}\sum_{m=1}^{12}(r_{m,y} - \overline{r}_y)^2} \tag{2.4}$$

where m is a month within a marketing year y and $\overline{r}_y$ is the marketing year average return. Y is the total number of marketing years considered.

In summary, realized volatility is easy to calculate. The standard deviation of return (SD log r) has been widely applied to compare volatility across commodities and countries [Minot, 2014; Huchet-Bourdon, 2011]. Yet the usage of realized volatility as dependent variable in regression models seems relatively new. Notable applications are: Balcombe [2009], Algieri [2012], Lee and Park [2013], and Ott [2014a].

2.2.2 Stochastic volatility

It is generally recognized that price volatility is a stochastic process and highly variable over time [Gilbert and Morgan, 2010a]. The main difference of conditional forecasts is that they take into account known realizations of the prices series and other exogenous determinants. In this way, the variance of the forecasting error varies over time conditional on explanatory variables. Time varying and conditional volatility is estimated by Autoregressive Conditional Heteroscedasticity (ARCH) models developed by Engle [1982] and extended by Bollerslev [1986]. A uni-variate (G)ARCH (p,q) specification can be represented by:

$$r_t = \beta_0 + \beta_1\epsilon_{t-1} + \beta_2 r_{t-1} + \beta_3 Z_t + \epsilon_t \text{ with } E_{t-1}\epsilon_t^2 = h_t \tag{2.5}$$

$$h_t = \gamma_0 + \gamma_1\epsilon_{1,t-1}^2 + \gamma_2 h_{t-1} + \gamma_3 Z_t \tag{2.6}$$

where logarithmic price changes (r_t) follow a ARMA(1,1) process and the volatility h_t depends on past squared errors $\epsilon_{1,t-1}^2$ and past conditional volatility h_{t-1}. Z_t can be a vector of explanatory variables.

The parameters p and q represent the number of ARCH and GARCH terms in the conditional volatility equation (2.6). If $q = 0$, the model reduces to an ARCH specification. Equations (2.5) and (2.6) can be estimated subsequently using ordinary least squares (OLS). This estimation is consistent but not efficient. An efficient estimation can be achieved using the maximum likelihood estimator. In general, it is possible to include all types of exogenous variables in both mean and conditional variance equation. In addition to that, the combination of autoregressive (AR) and moving-average (MA) terms is as inexhaustible as in ordinary ARMA models. Similarly, information criteria (Akaike, Schwarz) can be used to identify the best fitting model.

AR terms and/or monthly dummy variables can also be included in the mean equation to increase forecasting efficiency and to correct for seasonal price fluctuations. For the purpose of this analysis, conditional volatility across countries and commodities should be comparable. Therefore, a generic and analogous model should be chosen. Otherwise, the number of AR and MA terms may influence the magnitude of conditional volatility. Gilbert and Morgan [2010b] argue that most often a simple GARCH (1,1) yields sufficient estimates.

In general, GARCH models require a sufficiently large sample period that is not always available for monthly food prices in developing countries. A possible approach is to estimate different types of GARCH models and select the "best" model according to the information criterion. In order to compare volatility between countries and crops, the mean or median of equation (2.6) can be computed. The advantage of the median is that volatility outliers do not carry significant weight in the volatility measure.

There are several extensions to classical conditional heteroscedasticity models. Most notably, it is possible to estimate a system of equations where two variables can endogenously affect each other. These models are referred to as Multivariate(M)GARCH. Furthermore, asymmetric models allow volatility to respond differently to good and bad news.[2] The 'leverage' effect occurs when bad news generate more price volatility than good news [Zheng et al., 2008; Braun et al., 1995]. Nelson's Exponential(E)GARCH is a logharitmized transformation of the conditional volatility model:

$$\ln h_t = \gamma_0 + \sum_{i=1}^{q} \gamma_i g(z_t) + \sum_{j=1}^{q} \xi_j \ln \sigma_{t-j} \tag{2.7}$$

[2]Positive returns are referred to as good news, negative returns respectively as bad news.

$$\text{with } g(z_t) = \theta[|\frac{\epsilon_{t-i}}{\sigma_{t-j}}| - E(|\frac{\epsilon_{t-i}}{\sigma_{t-j}}|)] + \eta\frac{\epsilon_{t-i}}{\sigma_{t-j}} \tag{2.8}$$

where $\eta\frac{\epsilon_{t-i}}{\sigma_{t-j}}$ determines the asymmetric effect. If $-1 < \eta < 0$, then negative shocks have greater influence on volatility than positive shocks and vice versa. The magnitude of the effects is determined by the term $\theta[|\frac{\epsilon_{t-i}}{\sigma_{t-j}}| - E(|\frac{\epsilon_{t-i}}{\sigma_{t-j}}|)]$.

In addition to that, Engle et al. [1987] derive how the relative risk premium of holding an asset can be estimated within the framework of conditional heteroscedasticity models. This is achieved by including the squared root of the conditional variance in the mean equation. So (2.5) changes to:

$$r_t = \beta_0 + \beta_1\epsilon_{t-1} + \beta_2 r_{t-1} + \beta_3 h^{1/2} + \epsilon_t \tag{2.9}$$

$$\text{RP} = \frac{\beta_3 h^{1/2}}{r_t} \tag{2.10}$$

where $h^{1/2}$ is the standard deviation of the conditional volatility. RP is the relative risk premium.

The model is termed (G)ARCH-in-mean and (2.10) yields the time varying relative risk premium. So to say, the markup risk averse traders charge to be compensated for possible losses.

The variety of possible specifications is ample and empirical applications are too numerous to list. In the developing country context, most notably are Shively [1996] and Barrett [1997] who examine effects of market liberalization on volatility. More recently, Rapsomanikis [2011] analyze volatility spill-overs from international to domestic agricultural markets.

However, conditional volatility measures were developed for financial models that are based on the efficient market hypothesis. Markets in developing countries may suffer from information constraints and could deviate significantly from rational expectation frameworks. Moreover, the estimation of conditional volatility models is demanding in terms of computing capacity and requires high frequency data that may not always be available for staple food prices.

The International Food Policy Research Institute (IFPRI) employs a dynamic fully non-parametric model of daily returns.[3] By extreme value theory, high returns are classified as extremely high or not and periods of high volatility are identified by the number of extreme values within a predefined time window (e.g. 60 days) [Martins-Filho et al., 2012]. The model is very precise in measuring and detecting volatility and is used for early warning purposes. On the other hand, it is not of practical relevance to analyze volatility of retail and wholesale prices in developing countries.

2.2.3 Decomposed volatility

Both realized volatility and stochastic volatility measures neglect the different components of a time series. On this account, Dehn [2000] proposes to distinguish between predictable and unpredictable volatility. The latter being a better measure for uncertainty. Hence, volatility can be deterministic as the result of seasonal and cyclical price changes or subject to a general trend, but also the consequence of unexpected irregular price changes resulting from extreme market conditions. Specifically, a time series can be decomposed in its components: trend-cycle, seasonality, and irregular.

The approach of Dehn [2000] contains the estimation of an ARMA model of the random walk or differenced price series that is estimated by OLS. The model includes a trend variable, a number of AR terms, and monthly dummies to account for seasonality:

$$\Delta \ln\, p_t = r_t = \alpha(+\beta t) + \gamma_2 \Delta p_{t-1} + \sum \theta_i M_i + \epsilon_t \tag{2.11}$$

where the time trend t is only included for random walk models; M_i are monthly dummy variables that capture seasonal price movements; Δp_{t-1} is the past realization of the return.

From the regression, predicted values for $\Delta \ln\, p_t$ can be obtained. It is assumed that market participants can successfully accomplish price forecasting by using the variables included in (2.11). Thus, the unpredictable component of the time series is just the difference between fitted values and actual price realizations. In less technical words, the left-over which cannot

[3] Nonparametric Extreme Quantile Model(NEXQ) available at `www.foodsecurityportal.org/excessive-food-price-variability-early-warning-system-launched` .

be explained by simple forecasting. This yields irregular volatility as the standard deviation or variance of the forecasting errors.

However, this method involves two major shortcomings. First, the time trend is assumed to be linear or log-linear. This could lead to severe misspecifications whenever trends are quadratic or stochastic. Second, the seasonal component is fixed and cannot change over time. The latter is only of relevance for longer time series.

Alternatively, seasonal moving average models allow both trend and seasonal cycles to alter over time. The idea is to evaluate each price with respect to the average over the n-month period centered on that month. This yields a series of seasonally adjusted prices. Similar to (2.11), irregular price changes can be understood as the difference between seasonally adjusted prices and actual observed price realizations. A description of the procedure including a calculus example is available at the website of IFPRI's Food Security Portal.[4] The most popular procedure for moving average models is the X-12-ARIMA method that was developed by the U.S. Bureau of the Census. It is widely applied by statistical agencies and central banks to make economic indicators, such as unemployment rate, comparable over time. The program is freely available at the webpage of the Census, but is also included in statistical software packages as Stata and OxMetrics that allow some modification of the program code.[5] The X-12 method rests upon an iterative estimation of the components of the time series.[6] First, a moving average model is used to remove the trend-cycle component. Then, the ratio between actual price and adjusted price brings the first estimate of the seasonal-irregular component. Smoothing these monthly prices yields the seasonal factor [Findley et al., 1998]. The repetition of the procedures minimizes irregularities in trend-cycle and seasonal component.[7] Now, volatility can be easily obtained by computing the variance of the irregular price component. Existence of a stable seasonality can also be tested. The methodology has limitations if trend-cycles or seasonality exhibit a structural break and if extreme outliers exist.

An alternative to seasonal moving averages are unobserved component models (UCM) [Harvey, 2006]. In contrast, to deterministic autoregressive models like (2.11), UCMs allow to

[4] `http://www.foodsecurityportal.org/seasonality-tool`.

[5] `https://www.census.gov/srd/www/x12a/x12downv03_pc.html`.

[6] The decomposition of the time series in its components can be of multiplicative, additive, log-additive, or pseudo-additive nature.

[7] See Ladiray and Quenneville [2001] and Time Series Analysis Branch [2007] for a more detailed description of the methodology.

treat all components of a time series as stochastic processes that are estimated simultaneously. The full model can be depicted as follows:

$$p_t = \mu_t + \gamma_t + r_t + \sum \phi p_{t-1} + \epsilon_t \tag{2.12}$$

$$\mu_t = \mu_{t-1} + \beta_{t-1} + \eta_t \tag{2.13}$$

$$\text{with } \beta_{t-1} = \beta_{t-2} + \xi_t$$

$$r_t = r_{t-1} + r_{t-2} + \kappa_t \tag{2.14}$$

$$\sum \gamma_{t-i} = \omega_t \tag{2.15}$$

where (2.12) depicts the full model with its components. μ_t represents the trend or level component, while γ_t and r_t are seasonal and cyclical components. The irregular leftover is part of the stochastic error term ϵ_t. μ_t can be stochastic if η_t is different from zero and can include a stochastic or deterministic slope β_t. Similarly, cycles and seasonality can be both stochastic or fixed. Alternatively to dummies (for seasonality) and auto-regressive terms (for cycles), they can be modeled by trigonometric functions. All white noise processes $(\epsilon_t, \eta_t, \xi_t, \kappa_t, \omega_t)$ are assumed to be random. For more information see Koopman [2013].

In general (2.13)-(2.15) can be all stochastic. The stochasticity of each component can be statistically tested. Results are obtained by maximum likelihood estimation and subsequent utilization of the Kalman filter. In this way, prediction errors and variances are computed and used to evaluate the likelihood function for a given set of parameters. For the sake of sound comparison, it is advisable to refrain from statistical testing of the correct specification and to apply a generic model specification [Gilbert and Morgan, 2010a]. By taking logarithmized prices, the decomposition is of multiplicative nature which seems more appropriate to allow higher price fluctuations at higher price levels. UCMs can be found in common software applications and an example is illustrated in Figure 2.1.

UCM models are widely applied to de-seasonalize national core inflation. Only few studies decompose volatility of agricultural commodities to analyze predictability of price changes [Rezitis and Sassi, 2013; Labys et al., 2000]. Generally, it is also possible to include explanatory variables in (2.12), but model outcomes should be considered to be of descriptive rather than inferential nature [Gilbert and Morgan, 2010a].

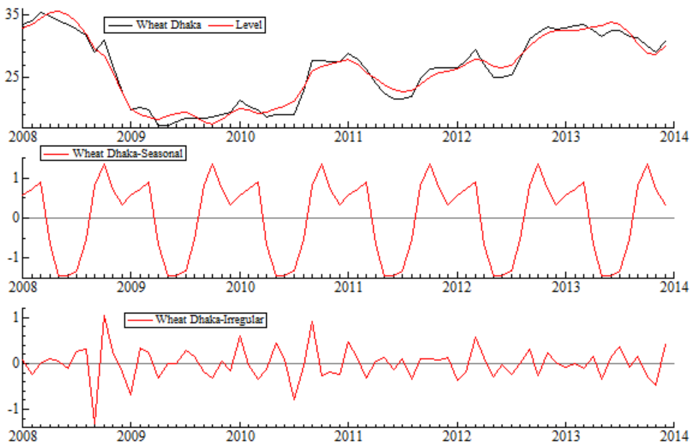

FIGURE 2.1: Variance decomposition of wheat price in Dhaka (Bangladesh).

Source: Author's computation based on [ZEF, 2014].

2.3 Data

In this analysis, price volatility is computed for the three major food commodities: rice, maize, and wheat. Further, all prices used are monthly retail prices from the ZEF Commodity Price Database that uses data from various international and national sources: most notably, the GIEWS Food Price Data and Analysis Tool, an open source platform from the Food and Agriculture Organization (FAO); secondly, United States Agency for International Development (USAID)'s Famine Early Warning System Network (FEWS-NET); and thirdly, the price data bank of the World Food Program (WFP) Vulnerability and Analysis Mapping (VAM).

Figure 2.2 depicts the wide coverage of the database. Most visible are gaps in northern Africa and Central Asia. Black dots indicate when market-level data is available. A couple of markets have several entries from different sources. For the purpose of comparing performance of various volatility measures this is not of relevance.

The methodology applied is general and can be used for any set of price series available. In total, 1,377 price series are included, 545 for maize, 525 for rice, and 306 for wheat. Some of the series are national average prices, others are market specific. National average prices are likely to exhibit less volatility than market specific prices. This is only of relevance for comparison across crops and continents.

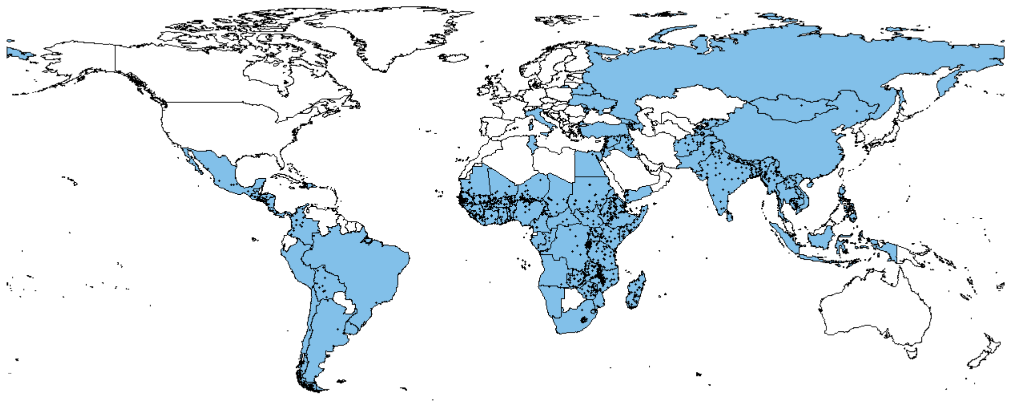

Figure 2.2: Coverage of ZEF Commodity Price Database

The analysis employs Stata 13, but uses Structural Time Series Analyser, Modeller and Predictor (STAMP) of OxMetrics for the decomposition of volatility and PCGive to estimate conditional volatility models. The latter utilizes the Broyden-Fletcher–Goldfarb-Shanno (BFGS) method to find the maximum of the likelihood function. GARCH and EGARCH models are estimated including both one AR and MA term in the level equation and one ARCH and GARCH term in the volatility equation. Constants are included in both equations. Conditional volatility is measured as the average estimated volatility over a selected period.

The selected UCM models the level component by a smoothed trend model that allows the slope to be stochastic. Furthermore, the fixed dummy approach is employed to account for seasonality. No cyclical component is included. The choice of the specification is justified by the observation that both time-varying seasonality and cyclical price behavior are present for a small number of price series only. All prices are logarithmized in order to achieve multiplicative decomposition.

2.3.1 Differences between measures

Notably, none of the measures should be considered to be right or utilized as a benchmark estimator since they indeed differ by definition. Nevertheless, it is interesting to examine how they perform in relation to each other. More specifically, two subjects should be in particular interest of the reader. First, how different are realized and conditional volatility, namely SD log r against GARCH and EGARCH. Second, to what extent is volatility driven by predictable seasonal price movements (SD Season) versus irregular volatility (SD Irreg).

Table 2.1: Summary statistics by commodity and measure

		Seasonal range (%)	**SD Season**	**SD Irreg**	**SD log r**	**EGARCH**	**GARCH**
maize (N=545)	mean	25.7	0.070	0.071	0.140	0.126	0.127
	median	22.7	0.055	0.057	0.125	0.124	0.126
	95th percentile	53.9	0.124	0.125	0.222	0.216	0.215
	5th percentile	6.2	0.017	0.017	0.048	0.054	0.058
wheat (N=306)	mean	10.0	0.036	0.064	0.113	0.092	0.087
	median	8.3	0.024	0.036	0.069	0.069	0.077
	95th percentile	23.3	0.066	0.148	0.236	0.235	0.187
	5th percentile	2.5	0.006	0.010	0.024	0.029	0.036
rice (N=525)	mean	8.4	0.047	0.045	0.075	0.067	0.066
	median	7.1	0.033	0.028	0.058	0.057	0.062
	95th percentile	19.0	0.088	0.077	0.128	0.123	0.119
	5th percentile	1.4	0.010	0.010	0.026	0.026	0.032

Table 2.1 presents some descriptive statistics by commodity. Generally, SD log r and both symmetric and asymmetric GARCH perform very similarly with respect to sample average volatility and the overall distribution of volatility. However, extreme volatility values are significantly higher for conditional volatility than for SD log r. This is caused by the fact that conditional variance is very sensitive to single extreme price changes.

As expected, irregular volatility and seasonal price changes are substantially lower than the other volatility measures. By comparing the numbers, irregular volatility plus seasonality seems to make up less than 50 percent of total volatility. This is the result of the inclusion of a stochastic trend in the decomposition analysis that fits better than the log-linear trend assumed by SD log r. The seasonal price gap is the classical measure to compute the magnitude of predicted seasonal price changes. Albeit, it cannot tell much about the extent of seasonality as compared to irregular price changes.[8] For this purpose, it is more informative to look at overall seasonal variability and at the ratio between seasonal and irregular variation as depicted in Table 2.2.

TABLE 2.2: Seasonality ratio across commodities (SD Season/SD Irreg)

	maize	rice	wheat
mean	1.23	1.66	0.97
median	1.02	1.15	0.64
95th percentile	2.30	4.26	1.75
5th percentile	0.48	0.47	0.34

A ratio greater than one implies that seasonal price variability is higher than unexpected irregular variability. Thus, the ratio is truncated at zero but can easily attain values greater than two. In consequence, the distribution median is more conclusive than the distribution mean. Accordingly, no general difference between predictable seasonal and irregular variability can be observed. Differences between crops will be discussed in the subsequent subsection.

Levels of volatility may not matter as such in order to compare the performance of volatility measures. For this reason, the correlation among measures reveals potential differences. The standard correlation coefficient is Pearson's product-moment correlation coefficient. Yet it captures correlation assuming linear dependence. Conversely, correlation coefficients based on ranks are not based on this assumptions. The two most commonly applied are Spearman's rank correlation coefficient and Kendall's Tau. The former shows the difference between rank values in different variables. In contrast, the latter looks at pairs of ranks and measures correlation as the extent to which variables coincide in the evaluation of the rank classification of pairs. Kendall's Tau is usually lower than Spearman's rank correlation coefficient. In order to compute rank correlation, for each commodity, markets are ordered according to their level of volatility.

[8] The reason is that some commodities exhibit more than one seasonal cycle.

Table 2.3: Correlation in long-run volatility among measures

		SD SEASON	SD Irreg	SD log Δ	EGARCH	GARCH	SD SEASON	SD Irreg	SD log Δ	EGARCH	GARCH
		Spearman					Kendall's Tau				
maize	SD SEASON	1.000					1.000				
	SD Irreg	0.653	1.000				0.465	1.000			
	SD log Δ	0.868	0.865	1.000			0.691	0.683	1.000		
	EGARCH	0.783	0.826	0.932	1.000		0.606	0.643	0.845	1.000	
	GARCH	0.825	0.853	0.991	0.950	1.000	0.634	0.667	0.928	0.865	1.000
rice	SD SEASON	1.000					1.000				
	SD Irreg	0.483	1.000				0.339	1.000			
	SD log Δ	0.652	0.868	1.000			0.473	0.705	1.000		
	EGARCH	0.555	0.732	0.863	1.000		0.393	0.569	0.756	1.000	
	GARCH	0.533	0.824	0.986	0.929	1.000	0.377	0.651	0.908	0.822	1.000
wheat	SD SEASON	1.000					1.000				
	SD Irreg	0.827	1.000				0.640	1.000			
	SD log Δ	0.909	0.916	1.000			0.737	0.770	1.000		
	EGARCH	0.714	0.691	0.829	1.000		0.548	0.558	0.708	1.000	
	GARCH	0.859	0.892	0.991	0.812	1.000	0.659	0.733	0.923	0.690	1.000

Table 2.3 reports the correlation of long-run volatility among measures by commodity. This means, volatility is computed over the entire period. In general, correlation is very high among all measures being lowest between seasonal and irregular volatility. However, the strong positive correlation indicates that neither seasonality nor irregular volatility tell completely contrasting stories.

There is no visible difference between symmetric and asymmetric GARCH apart from the fact that convergence of the maximum likelihood function is achieved more often for EGARCH than for GARCH models. This may indicate the presence of leverage effects in domestic food prices, however, further investigation is necessary to conclude, which is not part of this analysis.

TABLE 2.4: Correlation in short-term volatility with SD LOG Δ

year	SD Irreg	EGARCH	GARCH	SD Irreg	EGARCH	GARCH	SD Irreg	EGARCH	GARCH
	maize			rice			wheat		
2004	0.763	0.870	0.870	0.863	0.827	0.833	0.866	0.867	0.938
2005	0.847	0.541	0.564	0.773	0.781	0.724	0.801	0.721	0.652
2006	0.806	0.864	0.873	0.713	0.589	0.709	0.692	0.705	0.726
2007	0.851	0.839	0.871	0.804	0.743	0.771	0.758	0.798	0.902
2008	0.817	0.824	0.891	0.724	0.756	0.857	0.816	0.756	0.842
2009	0.798	0.827	0.874	0.825	0.763	0.792	0.805	0.781	0.840
2010	0.833	0.850	0.859	0.818	0.780	0.824	0.725	0.739	0.780
2011	0.662	0.667	0.756	0.749	0.737	0.745	0.725	0.707	0.791
2012	0.728	0.782	0.746	0.753	0.788	0.748	0.683	0.586	0.709
2013	0.799	0.701	0.792	0.674	0.710	0.628	0.681	0.572	0.599

Table 2.4 shows rank correlation of different measures with the standard realized volatility measures, SD log r with regard to short-term (annual) volatility. Seasonal volatility is left out as it does not change over time by definition. It is apparent that strong positive correlation holds for shorter term periods as well. There are only few individual years where correlation is below 0.7, while it never falls below 0.5 across all commodities. Lastly, short term correlation with SD log r is not different between conditional volatility and the irregular component from volatility decomposition.

Looking at the detailed list of markets in volatility reveals an interesting observation. GARCH models fail to converge significantly more often for markets that exhibit very high and very low food price volatility according to SD log r. Furthermore, some price series, which are characterized by relatively stable prices, exhibit unrealistically high estimates for their conditional volatility (e.g. rice price in Davoa City, the Philippines). For this reason, and since measures of realized and conditional volatility perform consistently, patterns of volatility across space and time are discussed by looking at realized volatility and its components only.

2.3.2 Differences across crops and regions

In this section, it is discussed to what extent volatility differs across commodities and between different geographical areas. Table 2.1 from above gives already some indication. Accordingly, maize price volatility is highest followed by wheat and rice. This holds for seasonal and irregular price variability in equal manner. Notably, rice exhibits relatively high seasonal variation with a small seasonal range. This is not surprising as rice is often harvested multiple times a year, and therefore prices are likely to increase and drop several times a year. An explanation for the low general volatility of rice and wheat may be the fact that both are imported at considerable margins [Minot, 2014].

Table 2.5: Domestic vs international volatility (in %)

	maize	rice	wheat
sample mean	14.0	7.5	11.3
sample median	12.5	5.8	6.9
IGC index	7.7	6.6	6.6
CBOT futures	7.7	6.6	6.6
IMF 2001:1-2010:2	5.9	6.1	5.2

In fact, domestic price volatility is significantly higher than international volatility when looking at the mean volatility of the sample (Table 2.5). For rice and wheat median volatility of the sample is in the same range of international volatility. Maize price volatility is higher than volatility of rice and wheat at both international and domestic level. Yet domestic maize price instability is substantially higher than international price instability.

Volatility also largely differs across continents. Table 2.6 presents statistics about the distribution of volatility by region for realized volatility and its decomposition into seasonal range and irregular volatility. Clearly, volatility is highest in Africa across all commodities. Wheat price volatility is lowest in Latin America, while maize price volatility is lowest in Asia and both are at similar size for rice. There is no observable difference across different measures: seasonal range, irregular volatility, and total realized volatility. Among the top 10 countries ranked by their volatility (Table 2.7), the large majority is African.[9] Latin

[9] Tables A.1-A.3 in Appendix A show volatility for all markets in the sample ordered by their mean rank across all measures.

America is only represented by El Salvador, the 10th rank in wheat. Several countries appear multiple times in the top 10, namely Malawi, Zimbabwe, Congo, Dem., Guinea-Bissau, Togo, Somalia, and foremost Tajikistan.

TABLE 2.6: Volatility across continents (in %)

		Africa	**Asia**	**Latin America**	**Africa**	**Asia**	**Latin America**	**Africa**	**Asia**	**Latin America**
		maize			rice			wheat		
Seasonal Δ	mean	27.3	11.3	16.7	8.9	8.2	6.4	14.2	9.2	7.9
	median	24.4	12.7	16.7	7.1	7.5	6.3	13.8	7.9	7.0
	5%	8.4	2.6	3.9	2.7	1.8	0.7	2.2	2.7	0.9
	10%	10.5	3.0	5.5	3.3	3.0	1.7	3.0	3.4	1.5
	90%	50.2	20.1	30.2	16.9	14.3	11.0	24.7	17.3	14.8
	95%	22.5	22.8	33.7	20.0	17.0	14.5	26.1	23.2	16.5
SD log r	mean	13.4	10.2	9.1	6.7	6.3	5.9	9.7	9.4	6.1
	median	13.1	5.3	8.4	6.1	5.2	5.9	9.9	6.6	6.3
	5%	6.0	1.8	2.7	3.0	2.7	1.4	1.6	3.2	1.1
	10%	7.0	2.2	4.1	3.3	3.0	2.6	3.1	4.0	1.7
	90%	20.0	21.9	13.6	10.6	10.5	9.0	14.7	20.1	11.2
	95%	22.6	23.6	16.4	12.7	13.6	9.6	18.7	24.1	12.6
SD irregular	mean	6.4	5.8	4.1	3.6	3.0	2.8	5.2	5.1	2.7
	median	6.1	2.1	3.5	3.1	2.2	2.3	4.9	3.7	2.5
	5%	1.9	0.2	0.8	0.8	0.6	0.4	0.9	0.8	0.3
	10%	2.5	0.4	1.6	1.1	0.8	0.7	1.2	1.2	0.6
	90%	11.1	14.3	7.8	6.4	6.4	4.1	8.3	13.5	4.4
	95%	12.4	14.9	8.6	8.0	7.5	5.9	10.6	15.4	6.4

Table 2.7: Top 10 volatility countries (SD log r)

	maize	rice	wheat
1st	Zimbabwe	Tajikistan	Zimbabwe
2nd	Cote d'Ivoire	Yemen	Yemen
3rd	Tajikistan	Chad	Congo, Dem.
4th	South Sudan	Guinea-Bissau	Sudan
5th	Malawi	Tanzania	Ethiopia
6th	Somalia	Malawi	Tajikistan
7th	Togo	Somalia	Guinea-Bissau
8th	Namibia	Togo	Gabon
9th	Congo, Dem	Burundi	Afghanistan
10th	Gambia, the	Mozambique	El Salvador

Interestingly, the picture slightly changes looking at the predictable seasonal range. Yemen and Tajikistan remain the only non-African countries in the top five (Table 2.8). Furthermore, four out of five countries for maize are found in southern Africa. Both Congo, Dem. and Malawi are part of the top five in two commodities, not reporting prices for the third. This may indicate that seasonality exhibits some regional pattern, especially for maize.

Table 2.8: Top 5 seasonal range

	maize	rice	wheat
1st	Malawi	Burundi	Zimbabwe
2nd	Congo, Dem	Guinea-Bissau	Yemen
3rd	Benin	Yemen	Ethiopia
4th	Mozambique	Malawi	Sudan
5th	Zambia	Tajikistan	Congo, Dem

Regional patterns in food price volatility can also be observed by looking at market level data. Figure 2.3 and 2.4 picture markets by maize and rice price volatility quintile. Both figures support the findings from above. Accordingly, price volatility is highest in eastern and southern Africa. With regard to rice, markets in Afghanistan and Nepal are also

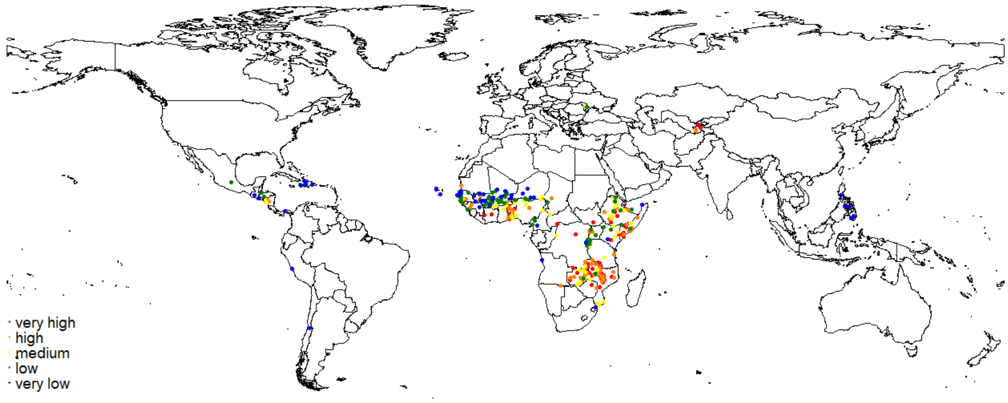

FIGURE 2.3: Volatility of maize price across markets (in quintiles)

Source: Author's illustration based on [ZEF, 2014].

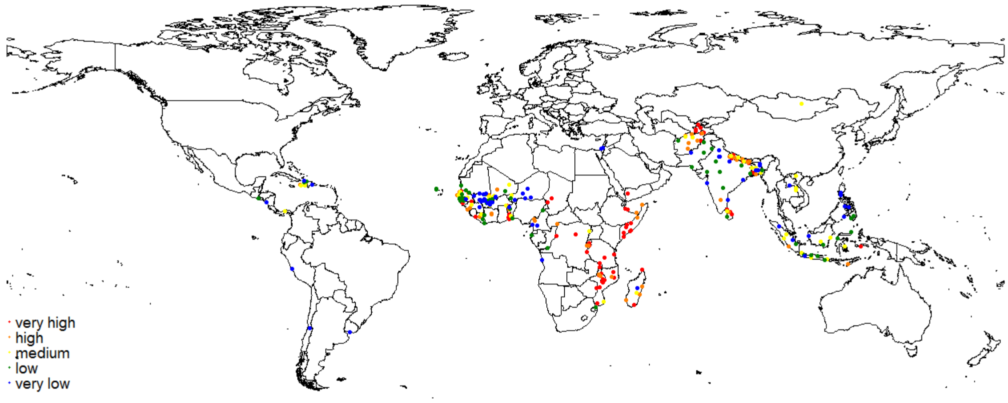

FIGURE 2.4: Volatility of rice price across markets (in quintiles).

Source: Author's illustration based on [ZEF, 2014].

assigned to the higher volatility quintiles. Interestingly, in western Africa markets in Sahel countries exhibit less volatility than markets in coastal countries for both maize and rice.

2.3.3 Changes in volatility over time

Lastly, this section examines whether changes of volatility can be observed since the world food crisis in 2007. For this purpose, variance of returns and irregular deviations are compared using the F-test. The cut is implemented with January 2007 which is an arbitrary structural break, however, it represents what is used by most other empirical studies [Huchet-Bourdon, 2011; Minot, 2014]. Hence, price volatility is compared between the period from the beginning of the price series until December 2006 and the period from January 2007 to the end of the price series. This strategy follows Minot [2014] who analyzes volatility in African markets and compares 2003-2006 with 2007-2010. The estimation is conducted for time series that contain prices at least four years prior to and four years after the structural break.

Tables 2.9-2.11 provide country level results. The last row counts the number of significant increases and decreases in volatility from the perspective of the 2007-2013 period. So, only 15 prices series exhibit higher return volatility after 2007 and 91 show a decrease in volatility. The results are similar for wheat, while rises and falls for rice offset each other. In general, the results for SD log r and irregular volatility correspond strongly.

TABLE 2.9: Changes in maize price volatility over time

		SD log r			SD Irreg		
Country	N	N (+)	N (-)	Conclusion	N (+)	N (-)	Conclusion
Benin	7	0	1	-	0	0	-
Chad	2	0	1	*fall*	0	0	-
Colombia	2	1	0	*rise*	2	0	*rise*
El Salvador	1	0	0	-	0	0	-
Ghana	1	0	0	-	0	0	-
Guatemala	2	0	2	*fall*	0	2	*fall*
Guinea	3	0	2	*fall*	0	1	*fall*
Honduras	3	1	0	*rise*	0	0	-
Kenya	7	1	1	-	1	1	-
Mali	45	1	16	*fall*	1	21	*fall*
Malawi	1	0	0	-	0	0	-
Mozambique	14	0	6	*fall*	0	5	*fall*
Nepal	7	3	1	*rise*	3	0	*rise*
Nicaragua	5	0	2	*fall*	0	2	*fall*
Niger	16	0	9	*fall*	0	10	*fall*
Peru	1	1	0	*rise*	0	0	-
Philippines	11	3	1	*rise*	1	0	*rise*
Senegal	1	1	0	*rise*	0	0	-

Continued on next page...

... Table 2.9 continued

		SD log r			SD Irreg		
Country	N	N (+)	N (-)	Conclusion	N (+)	N (-)	Conclusion
Somalia	27	12	1	*rise*	10	2	*rise*
Tajikistan	8	0	6	*fall*	0	8	*fall*
Tanzania	1	0	1	*fall*	0	1	*fall*
Togo	6	0	4	*fall*	0	2	*fall*
Uganda	1	0	0	-	0	0	-
Zambia	2	0	1	*fall*	0	0	-
Total	166	15	91		15	94	

Source: Author's computation based on ZEF [2014].

By looking at country level results, three observations are prominent. First, with few exemptions, there is a clear direction of volatility evolution over time. In other words, different markets within one country do not provide contrasting results. At the same time, it is uncommon to find statistically significant results for each market in a country. Third, the total number of significant rises or falls in volatility (in the last row) is not conclusive. Some countries are well represented in the sample (e.g. India, Tajikistan). Their weight skews the results. Following this, the majority of countries experience increasing volatility in rice. Against this, maize volatility has decreased since 2007 in most countries, while wheat volatility has increased in two, but decreased in four countries. This shows a great heterogeneity of volatility trends across countries.

TABLE 2.10: Changes in rice price volatility over time

		SD log r			SD Irreg		
Country	N	N (+)	N (-)	Conclusion	N (+)	N (-)	Conclusion
Benin	4	0	2	*fall*	0	2	*fall*
Brazil	1	0	0	-	1	0	*rise*
Colombia	2	1	0	*rise*	2	0	*rise*
Costa Rica	2	0	0	-	1	0	*rise*

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... *Table 2.10 continued*

		SD log r			SD Irreg		
Country	N	N (+)	N (-)	Conclusion	N (+)	N (-)	Conclusion
Guatemala	2	0	0	0	0	0	-
Guinea	10	0	4	*fall*	0	2	*fall*
India	21	16	0	*rise*	13	0	*rise*
Indonesia	26	0	15	*fall*	1	15	*fall*
Laos	2	0	2	*fall*	0	2	*fall*
Liberia	3	3	0	*rise*	3	0	*rise*
Malawi	1	0	0	-	1	0	*rise*
Mozambique	9	3	2	-	2	1	-
Nepal	7	3	1	*rise*	3	0	*rise*
Nicaragua	3	2	0	*rise*	1	0	*rise*
Niger	5	0	0	-	1	0	-
Peru	2	1	0	*rise*	2	0	*rise*
Philippines, the	14	5	0	*rise*	5	0	*rise*
Senegal	1	1	0	*rise*	1	0	*rise*
Somalia	11	7	1	*rise*	4	0	*rise*
South Africa	3	2	1	-	0	1	*fall*
Tajikistan	10	0	10	*fall*	0	10	*fall*
Togo	6	0	1	-	0	1	-
Tunisia	1	1	0	*rise*	1	0	*rise*
Total	146	45	39		42	34	

Source: Author's computation based on ZEF [2014].

Table 2.11: Changes in wheat price volatility over time

		SD log r			SD Irreg		
Country	N	N (+)	N (-)	Conclusion	N (+)	N (-)	Conclusion
Afghanistan	12	0	5	*fall*	0	6	*fall*
Brazil	2	1	0	*rise*	1	0	*rise*
Guatemala	2	0	2	*fall*	0	2	*fall*
India	15	8	1	*rise*	8	1	*rise*
Indonesia	26	6	5	-	5	9	-
Nepal	5	2	1	-	3	2	-
Peru	2	0	0	-	0	1	*fall*
Tajikistan	38	0	28	*fall*	0	27	*fall*
Tunisia	3	0	2	*fall*	0	0	-
Total	105	17	44		17	48	

Source: Author's computation based on ZEF [2014].

At the first glance, the results contradict with findings from Minot [2014] whose results suggest increasing volatility of maize and decreasing volatility of rice prices. Yet volatility of maize has significantly reduced since 2008 as illustrated in Figure 2.5. This effect is not captured by looking at a period that ends 2010. In contrast, wheat and rice prices returned to their pre-crisis volatility levels (Figure 2.6 and Figure 2.7). An increase in food price volatility during 2007/2008 is evident, however, volatility has not remained at this high levels.

2.4 Summary

This chapter deals with commodity price volatility in developing and emerging countries and contributes to the intensive current debate on the topic. The aim of the study is to review possible approaches to measures of food price volatility and their use in the literature. However, the research is much skewed towards the analysis of international price behavior. Therefore, the findings provide a better basis for the discussion on price volatility in the context of developing countries.

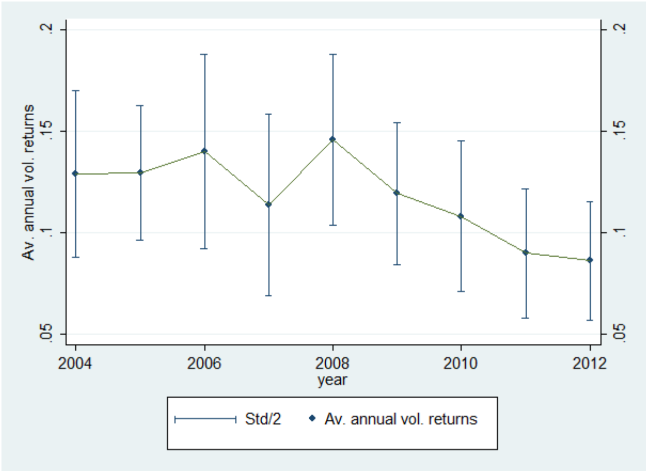

FIGURE 2.5: Maize price volatility over time (SD log r)

Author's illustration.

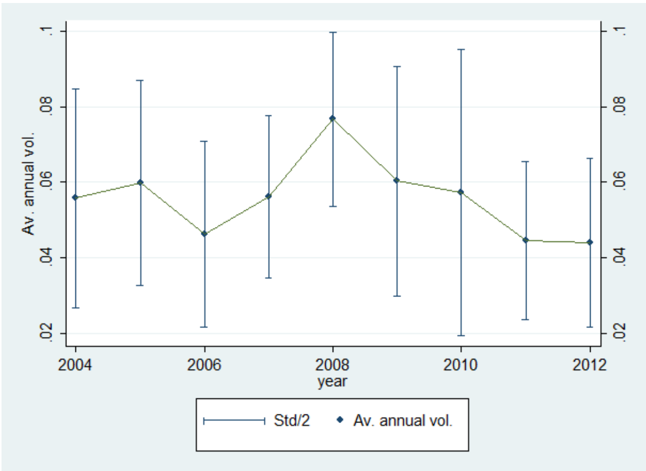

FIGURE 2.6: Rice price volatility over time (SD log r)

Author's illustration.

The correlation analysis reveals that conditional and unconditional volatility correspond greatly for a large set of price series. The correlation remains high, albeit at slightly lower levels for individual years, when looking at short-term price fluctuations. For this reason, it is fully legitimate to concentrate on realized volatility instead of conditional volatility when comparing volatility over time and across commodities and countries. However, conditional volatility models allow the inclusion of several counterfactuals in both level and volatility equation. Furthermore, they have advantages to capture market risk at a particular time and allow the estimation of a relative risk premium.

Calculated volatility for rice, maize, and wheat show substantial differences across commodities and regions. First, maize prices are more volatile than rice and wheat prices across

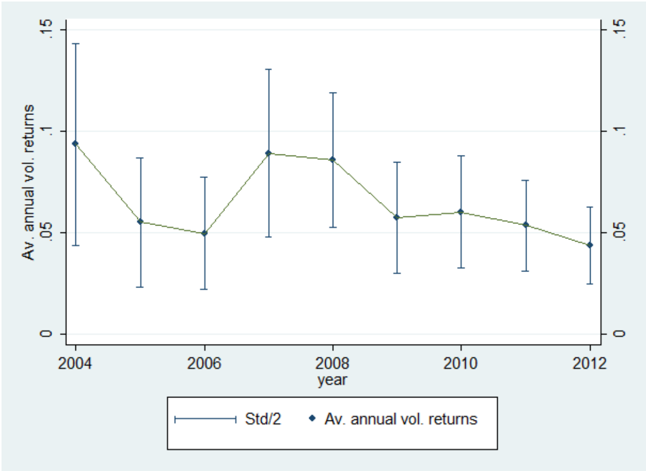

FIGURE 2.7: Wheat price volatility over time (SD log r)

Author's illustration.

all regions. Second, Africa exhibits the highest volatility across all continents included in the analysis. This high volatility seems to be partly driven by extreme seasonal price fluctuations. The analysis with regard to change in volatility over time reveals two results. On the one hand, rice volatility has increased for a majority of countries, while maize volatility has decreased. On the other hand, there is evidence for great heterogeneity across countries, but barely differences across different markets within one country. In general, the increase in price volatility is due to the years of the global food crisis in 2007/2008 and volatility declined afterwards and returned to pre-crisis levels.

Chapter 3

Stocks: theory and data issues

3.1 Introduction

Commodity stocks occupy a central role in this work. Their role in price formation is extensively discussed in the course of this and the following chapters. Stocks are currently a hot topic in the public debate related to food price volatility. On the one hand, low stock-to-use ratios have been identified as a driver of the price surges in 2007/2008 [Wright, 2012; von Braun and Tadesse, 2012]. Further, they are considered as possible instruments to regulate price volatility in domestic markets and protect markets from price spikes. Last, stocks are also increasingly used as early warning indicators for international food price spikes [Bobenrieth et al., 2013].

The aim of this chapter is to provide information to the reader which are of importance across all analytical chapters. This relates to the theoretical model to explain commodity price formation and the data issue with regard to stocks. The competitive storage model is the theoretical backbone of this dissertation. It describes how storage relates prices between two periods and how stocks can stabilize prices. Empirical applications of the model are mostly built on price data since information on stocks is scant and not reliable. The reasons are discussed in this chapter, while the main data sources are introduced.

The chapter is organized as follows. First, section two introduces the competitive storage model and its solution with rational expectations. Then, extensions of the classical model are discussed. Section three and four engage with the way agricultural statistics are generated and the problems associated with the estimation of stocks. Additionally, available data sources are presented and discussed. A summary is provided in section five.

3.2 The storage model

3.2.1 Competitive storage

Two different lines of thought exist to explain commodity price behavior in a formalized model. On the one hand, the competitive storage model [Williams and Wright, 1991] that treats supply shocks as exogenous, whereas demand and supply as well as price expectations simultaneously determine the equilibrium price. On the other hand, cob-web type models, where supply is endogenously determined and prices follow cyclical fluctuations (e.g. pork cycle) as a result of under- or oversupply [Mitra and Boussard, 2012]. The former is more common for storable commodities whose harvest is less controllable. Thus, this work makes only use of the competitive storage model.

There is a natural imbalance between production and consumption of agricultural commodities. More specifically, consumption is primarily stable, while production is highly volatile, in particular in rain fed agricultural systems which are predominant in many developing countries. Since market prices are simultaneously determined by supply and demand, there is a market for commodity storage that transfers excess supply from one year to the other. Thus, the demand for storage arises from the fact that consumption demand exists in $t, ..., tn$. The inverse demand function can be written as:

$$p_t = f_t(C_t), \qquad \frac{\partial f_t}{\partial C_t} < 0 \tag{3.1}$$

$$\text{with } C_t = S_{t-1} + Z_t - S_t \tag{3.2}$$

where p_t is the current market price and consumption (C_t) comprises of stocks at the end of period $t-1$ (S_{t-1}), production in t (Z_t) minus stocks that are carried out of the period (S_t).

In a situation where production and stock levels are known, an increment in carryover stocks from period t to $t+1$ yields in an increase of the current price p_t and a reduction of the future price p_{t+1}. The demand for storage arises from the differences in market prices across periods and can therefore be expressed as a function of the price difference:

$$p_{t+1} - p_t = f_{t+1}(Z_{t+1} + S_t - S_{t+1}) - f_t(Z_t + S_{t-1} - S_t) \tag{3.3}$$

The derivative with respect to S_t is negative. In consequence, the price spread is a decreasing function of the stock level [Brennan, 1958]. Since supply is stochastic and prices in $t+1$ are unknown, there is always a positive demand for storage. In consequence, at any time there will be firms or individuals possessing stocks to carry it from period to period. Following the notation of Brennan [1958] anyone who holds stocks is referred to as supplier of storage.[1]

Similar to producers of goods and services in a competitive setting, risk neutral suppliers of storage hold stocks at a level where per unit storage costs are equal to the expected price spread. This is equal to the usual condition: marginal costs = marginal revenue. Formalized as:

$$\pi'(S_t) = c_t'(S_t) \tag{3.4}$$

$$\text{with } c_t(S_t) = k_t(S_t) - cy_t(S_t) \tag{3.5}$$

where $\pi'(S_t)$ is marginal revenue and $c'(S_t)$ are marginal costs that arise from the cost function $k_t(S_t) - cy_t(S_t)$. $k_t(S_t)$ are physical costs of storage such as interest and deterioration and $cy_t(S_t)$ is the *convenience yield* which can be understood as negative cost.

In a micro context, where suppliers of storage have individual cost functions, while the second derivative of the cost function $(\frac{\partial^2 c_t}{\partial^2 S_t})$ should ensure a unique maximum [Brennan, 1958; Sarris, 1984]. In contrast, when considering the market equilibrium, most contributions assume linear storage costs [Williams and Wright, 1991; Newbery and Stiglitz, 1982; Deaton and Laroque, 1992]. In the latter case, profit maximization leads to:

[1]In the course of the work, they will be given several other names whenever the context demands it.

$$\begin{aligned} p_t + k &= \beta E_t[p_{t+1}] \text{ if } S_t > 0 \\ p_t + k &> \beta E_t[p_{t+1}] \text{ if } S_t = 0 \end{aligned} \tag{3.6}$$

where p_t is the price of the commodity at time t and k denotes fixed costs of storage. $\beta = \frac{1-\delta}{1+r}$ contains the interest rate r and deterioration δ, both are conditional on the future market price; $E_t[\cdot]$ refers to the price expectation at time t.

This condition also holds if suppliers of storage prefer not to bear risk and hedge their short position for delivery in $t+1$. At organized commodity exchanges $E_t[p_{t+1}]$ equals the futures price $F_{t+1,t}$ [Williams and Wright, 1991]. In this way, stockholding will be completely riskless.

(3.6) describes two possible states. In words, if storage is profitable prices will be linked over periods which explains the high autocorrelation observed from actual price data [Deaton and Laroque, 1992, 1996]. In contrast, if current storage is zero, prices are a function of random supply and stocks carried from the previous period. However, in reality stocks never completely deplete. Supply and demand of storage are depicted in Figure 3.1. Storage in face of a negative price spread sounds perverse (intersection $D' \times c_t'(S_t)$). This artefact has lead to intense discussions in the literature (see Box 1).

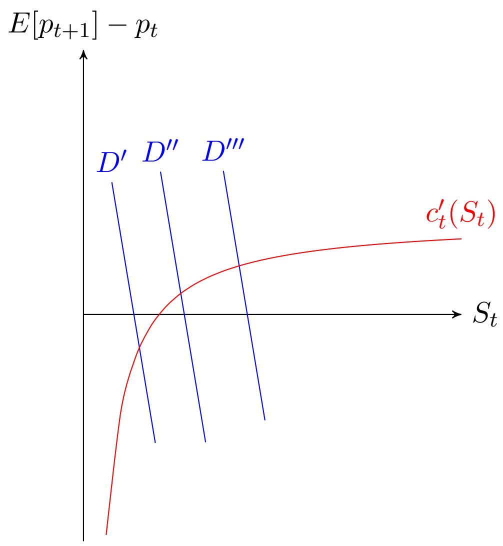

FIGURE 3.1: Supply and demand of storage.

Source: Adapted from Brennan [1958].

The completion of the model requires an assumption on how available information are used by economic agents to form price expectations. Following the seminar papers of Gustafson [1958] and Muth [1961] rational expectations have been widely employed.

The non-linearity of the supply of storage (non-negativity of stocks) and the endogeneity of the variables inhibit a closed form solution. Therefore, a numerical approximation of the price function is required. There are several attempts to apply the model in order to simulate features of actual observed price data. Most notably, Deaton and Laroque [1992, 1996] use a GMM estimator for the model without *convenience yield*. In a less famous work, Miranda and Rui [1999] account for the *convenience yield* and employ Chebyshev's polynomial projection method. These methodological papers are able to generate prices that fit the original data quite well with respect to mean, variance, skewness, and kurtosis. However, they fail to explain high autocorrelation of first and second order. Attempts to improve this by incorporating news are equally unsuccessful [Osborne, 2004]. Recent advances in computer programming allowed the utilization of a finer grid to approximate the price function [Cafiero et al., 2011]. Consequent estimates imitate high serial correlation observed in actual price data. An observed feature of storage is the stabilization of commodity prices [Deaton and Laroque, 1996], while the non-negativity of stocks explains why low prices are more easily absorbed than price spikes.

Box 1: Stocks and backwardation:

Backwardation of commodity prices, synonymous to a negative price spread, has led to some controversy in the literature on storage. The original explanation includes the existence of a *convenience yield* that is the intrinsic value of possessing physical stocks instead of having an option [Working, 1949; Brennan, 1958]. This value comes from relatively constant demand even if prices surge and "the possibility of making use of them [the stocks] the moment they are wanted" [Kaldor, 1939, p.6]. In this way, the *convenience yield* can be interpreted as a negative cost that explains the price spread's negativity. The value of the *convenience yield* decreases in supply, and is highest for low levels of stocks [Zulauf et al., 2006]. Empirical findings support the hypothesis by showing positive levels of stocks even if markets are in backwardation [Carter and Revoredo Giha, 2007; Joseph et al., 2011].
This view has been challenged by Benirschka and Binkley [1995], Brennan et al. [1997], and Frechette and Fackler [1999]. According to their argumentation, observed stocks under backwardation are the result of mis-measurement and aggregation across different grades of the commodity and different locations with distinct market prices. A more convincing explanation is the heterogeneity among suppliers of storage which goes in hand with diverse motives of storage [Carter and Revoredo Giha, 2007].

3.2.2 Model extensions

3.2.2.1 Storage and trade

Likewise storage, trade affects commodity prices in an open economy by transferring excess supply or demand to another country. The price relationship between two spatially separated markets is described through the spatial price equilibrium [Enke, 1951; Samuelson, 1952; Takayama and Judge, 1971]:

$$\begin{aligned} p_i \; + \; m &= e_t p_j \quad \text{if } T > 0 \\ p_i \; + \; m &> e_t p_j \quad \text{if } T = 0 \end{aligned} \tag{3.7}$$

where p_i and p_j are price in country i and j; e_t is the exchange rate between the countries and m the cost of transaction; T indicates the quantity traded.

Trade is profitable as long as the price margin between the countries does not exceed the cost of transportation. Resulting from (3.7), domestic prices also depend on transaction costs (shipment and trade barriers) and export prices. Incorporation of international trade in the storage model affects the model in two ways. Firstly, similarly to storage, trade can reduce price variability [Makki et al., 1996, 2001]. Secondly, storage and trade interact and equilibrium quantities of storage and trade in country i and i must be determined simultaneously [Williams and Wright, 1991]. From (3.6) and (3.7) four scenarios can be derived:

TABLE 3.1: Market prices under storage and trade

Case 1	no current storage and no trade	$p_{t,i} = P[Z_t + (1-\delta)S_{t-1}]$
Case 2	current storage but no trade	$p_{t,i} \geq \beta E[P(Z_t + (1-\delta)S_{t-1})] - k$
Case 3	no current storage but trade	$p_{t,i} \geq e_t p_t^* + m$
Case 4	both storage and trade	$p_{t,i} \geq \max\ \{\beta E[P(Z_t + (1-\delta)S_{t-1})] - k, e_t p_{t,j} + m\ \}$

Source: Adapted from Shively [1996].

All four cases in Table 3.1 determine the equilibrium price. Again the model is not analytical resolvable, while the solution becomes even more tedious due to the additional constraints.

3.2.2.2 Intra-annual storage

A major simplification of the model is the time-constant distribution of Z without a distinction between harvest and non harvest periods. More realistic, Z is only positive for some months and zero for others. Peterson and Tomek [2005] present a monthly version of the competitive storage model where m, n, and o represent harvest months:

$$Q_t = \begin{cases} Z_t + S_{t-1} \text{ if } t = m, n, o \\ S_{t-1} \text{ if } t \neq m, n, o \end{cases} \quad (3.8)$$

Thus, total available supply in non-harvest months is comprised of inventories only. Rational expectations yield the same temporal arbitrage conditions as in (3.6). In reality, it is likely, that the distribution of the harvest across harvesting months is not deterministic but stochastic. Further, it is also possible to experience variation in the timing of the harvest. The intra-annual model is capable of accounting for these non-regularities. Accordingly, Q_t becomes a probability function that depends on expectations based on past prices and weather conditions during planting and growing period.

As a consequence of these non-linearities in supply, prices are naturally volatile throughout the year. Positive consumption guarantees the impossibility of stock-outs except for the final month preceding the next harvest [Peterson and Tomek, 2005]. Similar to the annual model, great significance is given to the costs of storage. Empirical applications from developing countries, emphasize the strong seasonality in prices predicted by the model [Shively, 1996; Osborne, 2004; Tadesse and Guttormsen, 2011]. Shively [2001] and Tadesse and Guttormsen [2011] identify stock-outs induced by speculative storage as the cause of price spikes and market volatility.

3.2.2.3 Risk averse traders

In an uncertain world, there is always a risk involved in the business of storage. Early attempts have added a risk premium as additional cost into the classical storage model. Here, the approach of Sarris [1984] is presented that takes off by representing the utility of a risk averse supplier of storage by the mean-variance utility function:

$$U = E[\pi_t | t-1] - \frac{\rho}{2}\sigma^2_{[\pi_t|t-1]} \tag{3.9}$$

$$\text{with } \pi_t = (p_t - p_{t-1})S_{t-1} - c(S_{t-1}) \tag{3.10}$$

where $E[\pi|t-1]$ and $\sigma^2_{[\pi_t|t-1]}$ are conditional expectations for profits and their variance in $t-1$ based on price expectations, while p_t and p_{t-1} are observed prices; $c(S_{t-1})$ is the quadratic cost function of the form $c(S_{t-1}) = \frac{\mu}{2}S^2_{t-1}, \mu > 0$; ρ is the parameter of relative risk aversion.

Given the utility function of (3.9) with $\sigma^2_{[\pi_t|t-1]} = (E_{t-1}[p_t] - p_{t-1})^2 S^2_{t-1}$, maximization yields:

$$S_{t-1} = \frac{E_{t-1}[p_t] - p_{t-1}}{\mu + \rho\sigma_p^2} \tag{3.11}$$

$$\text{with } \sigma_p^2 = (p_t - E_{t-1}[p_t])^2 \tag{3.12}$$

For ρ=0, (3.11) illustrates the optimal storage for risk neutral speculators. However, the important message is the relationship between stocks and price uncertainty for risk averse suppliers of storage. In the context of a developing country without the possibility to hedge risk at futures markets, market uncertainty reduces the level of stocks. This can be of substantial importance, in particular when costs of storage are already large.

3.2.2.4 Heterogeneous traders

The models presented are based on the representative agent hypothesis. In reality, economic agents are not homogeneous. This fact has been studied extensively in agricultural futures markets. Most prominently, heterogeneity is attributed to inconsistent expectations about the formation of market prices [Frechette and Weaver, 2001].

The financial markets literature usually distinguishes between noise traders (also chartists) and fundamentalist traders. Chartists believe in the stochasticity of stock prices and usually observe and follow existing market trends, while fundamentalists analyze fundamental data to predict price returns. These models have been very successful in describing price dynamics of financial assets and commodity futures. Analyzing the corn futures market after 2005, Grosche and Heckelei [2014] find that the additional entry of index traders increases return volatility, but does not alter the average price level. The interaction of different traders affect the equilibrium price. Such results contain essential information for effective policy design.

This is not one-to-one transferable to physical commodity markets. So, physical commodity traders who own warehouses and have gained expertise in their specific market environment cannot easily switch to markets that exhibit better price prospects at that time. With respect to physical commodity trade, two types of heterogeneity are subject to examination: first, the heterogeneity of price expectations [Chavas, 1999; Frechette, 1999]; and second, differences in the motive of storage [Carter and Revoredo Giha, 2007]. The latter also involves the interaction between different types of traders [Lowry, 1988].

At least four types of price expectations are known and discussed in the literature: naive, adaptive, quasi rational, and rational expectations. They differ by the amount of information which is taken into account to predict the future price. Market information is usually costly and demands capacity to efficiently process it. Thus, heterogeneous expectations are based on individual specific costs and benefits of information [Chavas, 1999]. A number of studies find evidence for the existence of multiple expectations in a range of markets [Frechette and Weaver, 2001]. Frechette [1999] argues that traders with quasi-rational expectations make losses on average and exit the market in the long run. However, in the short-run they can make a significant influence on the market and explain abnormalities in price dynamics.

In contrast, Carter and Revoredo Giha [2007] emphasize the heterogeneity of stockholding motives. So, millers and processing companies base their decisions on the conditions in the processed good market and their storage capacity, instead of the inter-temporal price spread. The interaction between speculative and working stocks has important implications. In case the inter-temporal price spread is positive, speculators enter the market and drive profits to zero. In this situation, processors also have interest to increase their stocks, but they also stay in the market when profits fall below zero [Carter and Revoredo Giha, 2005].

3.3 What is it about stock data?

Agricultural market data is the fundament of empirical research and evidence based policy advice. A great number of market actors also rely on public statistics to form their expectations on future price developments in order to make economic decisions. This applies to small scale farmers in Africa, but also to fund managers in Chicago, London, and Paris. Fundamental data commonly consists of supply, demand, and trade. Supply and demand comprises of production, consumption, and stocks. The data is usually combined in commodity or food balance sheets. Available quantities in balance sheets strictly correspond to used quantities as the identity equation of supply and demand implies [see FAO, 2001].[2]

[2] $Z_t + S_{t-1} + IM_t = C_t + S_t + EX_t$; In words, production Z_t plus beginning stocks S_{t-1} plus imports IM_t equal final consumption C_t plus endings stocks S_t plus exports EX_t.

The easiest part should be import and export quantities as long as they pass official channels through customs offices. This is the case for most industrialized countries and for international imports and exports to and from developing countries that enter and leave the country through port facilities. On the contrary, cross-border trade in Africa, Asia, and Latin America is often informal and not statistically recorded [Josserand, 2013].

Next, production data is obtained by multiplying the yield per hectare for each crop by the area cultivated. In the United States and other exporting countries information on area cultivated is collected through field surveys and in recent years also by using satellite images. Yields can be projected using information on fertilizer usage and rainfall. Naturally, yields in irrigated agricultural systems vary less than when rainfall is the only source of watering. In many developing countries, data on yield and area is scant, also because field surveys are costly and private sector companies do not have much incentive to acquire this information.

What remains are stocks and consumption. Apart from the United States, no country is equipped with sufficient information to adequately estimate stocks from field surveys. Therefore, a widely applied approach is to compute stock changes as the residual from the identity equation. Unfortunately, consumption data is also hardly available.[3] However, it is comparably easier to estimate consumption given the knowledge about previous consumption, the current production, and elasticities of supply and demand. Mistakes in the estimation of trade, production, and consumption data all reflect in estimated stock figures.

But what makes it so difficult to obtain actual stock data directly? The causes are multiple: first, stocks are very dispersed among farmers, traders, retailers, industrial companies, and state owned institutions; second, a large amount of stocks are kept by smallholders farmers and small to medium sized enterprises which are partly informal and difficult to track [FAO et al., 2011]; third, stockholders often have good information about the current market situation, but are not willing to share it. This information represents an important asset to their company. Therefore, sharing this information, in particular with the public, is not in their interest. In contrast to private stocks, public stocks by national and regional governments should be known. However, often the parastatal institutions that operate the public stock claim that public knowledge about their stocking behavior impedes their objective to stabilize prices by providing the private sector with this information. All in all, it is not advisable to have strong confidence in estimates of food stocks.

[3] Consumption consists of human consumption, feed use, seed use, and waste.

Thus, it is no surprise that empirical estimations of the competitive storage model employ price data only. In general, the empirical literature abstains from using stocks in regression models, especially to explain short-run price dynamics. Albeit, a couple of studies exist that use data on public stocks.

The trouble of researchers to obtain adequate data is probably less of concern than the misinformation for private and public actors who take decisions based on the imprecise estimates. An example for this is how the market reacted to Russia's wheat export ban in 2010 in consequence of severe wildfires. Misinformed agents responded by panic-induced purchases that further drove prices and volatility, although world stocks at that time were sufficient to offset absent supply from Russia [Immenschuh, 2012].

In their 2011 meeting, the G20 member countries agreed on an action plan to improve exchange of market information and transparency. An important pillar is the availability of timely data on stocks in each country based on the assumption that better market information can stabilize prices more effectively than direct market intervention [Wright, 2009]. Data collection and transparency shall be achieved through the Agricultural Market Information System (AMIS) which provides data free of charge on its webpage, releases market indicators, and publishes research findings.[4] For a more detailed description of its tasks refer to AMIS Secretariat [2011] and Brockhaus and Kalkuhl [2014].

3.4 Data sources and comparison

Traditionally, there are three major open sources for agricultural statistics. First, the United States Department of Agriculture (USDA) that is interested to provide market information to the US farmers and the large agricultural industry in the country. Second, FAO's FAOSTAT has a great interest in developing countries and a wide country coverage. FAO also provides technical support to its member countries to generate adequate data. Last, the International Grains Council (IGC) which concentrates on its member countries, the major exporters, and their trading partners and lacks data for small countries and developing economies.

FAOSTAT has to publish official data from national statistics which are obtained from a questionnaire that is sent to national statistical agencies or agricultural departments.

[4] http://www.amis-outlook.org/

Often this data is imprecise. So, FAOSTAT reports only stock changes which are the residuals of demand and supply. When summing up all stock changes for a particular crop in one country, we expect the sum to be zero or positive if we assume stocks to increase with agricultural production. Yet the opposite is the case since most countries record almost always negative stock changes. Being aware of these problems, FAO also compiles Commodity Balance Sheets (CBS) based on expert knowledge of focal contacts in member countries. These balance sheets are not publicly available for most countries, but data for important exporters and importers is presented at the AMIS webpage. Apart from these data sources with international coverage, several regional organizations collect data from their member countries. Most notably are the Permanent Interstate Committee for Drought Control in the Sahel Zone (CILSS) for West Africa, the Southern African Development Community (SADC), the Association of Southeast Asian Nations (ASEAN), and the Regional Agricultural Trade Intelligence Network (RATIN) for eastern Africa.

Differences in the data are acknowledged by the literature and a discussion on particular data (stocks, production, trade) can be found in Brockhaus and Kalkuhl [2014]. Here, the aim is to discuss how differences arise and which data should be used for what type of analysis. All statistics are generated by the balance sheet approach described above. The main problem with respect to comparison is a distinct definition of the marketing year which is specified as the time from the harvest to the same harvest in the subsequent calender year. Table 3.2 presents this marketing definition for China and India. Some overlap is recognizably, however, some variation as well. Generally, it is very reasonable to collect data on a marketing year base. Thus, stocks always represent stocks just before the next harvest. On the other hand, most trade statistics are collected on a calendar year base (see UN Comtrade [2014]), and therefore this data will not help to estimate import and export volumes for the commodity balance sheet.

TABLE 3.2: Marketing years of selected crops and countries

		rice	wheat	maize
China	USDA	Jan-Dec	Oct-Sep	Oct-Sep
	FAO	Jan-Dec	Jul-Jun	Jul-Jun
	IGC	Jan-Dec	Jul-Jun	Oct-Sep
India	USDA	Oct-Sep	Apr-Mar	Nov-Oct

Continued on next page...

... *Table 3.2 continued*

		rice	wheat	maize
	FAO	Jan-Dec	Apr-Mar	Apr-Mar
	IGC	Oct-Sep	Apr-Mar	n.a.

Source: USDA [2014], FAO CBS [2014], IGC [2014]

To understand country coverage and differences in estimates of FAO CBS, USDA, and IGC, it is helpful to consider the purpose of the data collection of the respective institution. USDA wants to supply American citizens and companies with relevant information. The United States are the largest grain exporter in the world, being number one in maize, sorghum, and wheat, number three in soybeans, and number five in rice.[5] Naturally, the United States as exporter are interested in market data from all trading partners of significant size, but also in data from all important markets in the world regardless of importer, exporter, or trading partner. This interest reflects in data quality. For instance, stocks of sorghum and millet are zero for a great number of countries. Similarly, Ghana's maize stocks were zero during the 1990s, when imports were at relatively low levels, while they jumped from zero to 200,000 tons in 2003, the same time Ghana started to enhance importation again [USDA, 2014]. This makes two issues apparent. On the one hand, USDA has the financial and personnel resources to provide very precise data estimates for foreign countries. This is achieved by the work of agricultural attachés at US embassies in the respective countries. On the other hand, data is provided for current use and against better knowledge ex-post changes are not carried out.

Similar to USDA, IGC serves its clients. In this case its member countries.[6] This makes it obvious why data for smaller countries is not provided. The assignment by multiple countries can be advantageous if these countries provide agricultural data. However, this data is often not better than what USDA, IGC, and FAO CBS have. In contrast to IGC and USDA, FAO CBS attempts to compile data for food balance sheets no matter how large the market is and whether the data is of value for a particular exporter. For this reason, the country coverage is large and with few exemptions data is available. From the point of

[5]Sorghum contributes the smallest share of total exports among the commodities notes.

[6]IGC members are: Algeria, Argentina, Australia, Canada, Cote d'Ivoire, Cuba, Egypt, European Union, India, Iran, Iraq, Japan, Kazakhstan, Kenya, Korea (Rep.), Morocco, Norway, Pakistan, Russia, Saudi Arabia, South Africa, Switzerland, Tunisia, Turkey, Ukraine, United States, and Vatican City.

view of a researcher, it is important to note that FAO CBS attempts to correct estimates ex-post which yields a consistent data series.

3.5 Summary

This section introduced the competitive storage model to the reader. It explains price dynamics of storable commodities with stochastic production. Accordingly, prices are largely driven by current supply, but can be stabilized by storing excess surplus from one period to the other. The uncertainty of future supply creates an incentive to stockholders as long as the expected return exceeds the costs of storage. The model can be extended to include international trade which is also capable of stabilizing prices by transferring excess supply from one country to another. The seasonality of production explains why prices largely fluctuate within a year, while constant consumption guarantees positive returns from storage until the new harvest pushes down prices. When stockholders are risk-averse, stocks decrease with the uncertainty about future price development.

An empirical estimation of the competitive storage model and the importance of stocks is usually limited to analyzing price behavior given a probability distribution of the harvest. This is caused by insufficient data quality for stocks. Stocks are often computed as the residual between supply and demand in commodity balance sheets. A direct estimation seems difficult for multiples reasons. Nevertheless, three data sources are available that publish statistics which approximate stock levels. The estimates of the different data sources differ sometimes, partly due to a distinct definition of the marketing year. Generally, USDA and IGC have greater resources, but provide data only for a small number of countries and crops. Furthermore, they do not correct their data ex-post. Conversely, FAO has less resources to construct its commodity balance sheets. Its balance sheets are compiled for every country and commodity and are ex-post corrected. The right source to use depends on the purpose of the research. With respect to developing countries, FAO CBS data is the only source with wide coverage and reasonable estimates across all countries. Therefore it is considered as the best choice for the analyses in this dissertation. Nevertheless, USDA data is provided whenever it is appropriate.

Chapter 4

Determinants of food price volatility in developing countries[1]

4.1 Introduction

The poor in developing countries spend a large share of their income on food [Banerjee and Duflo, 2007]. Food price volatility adversely affects their livelihood (see introduction). But it also endangers macroeconomic stability and growth [Myers and Jayne, 2012] as well as impedes the achievements of the Millennium Development Goal (MDG) on the eradication of hunger. Policies to manage food price stability play a prominent role in the current political debate. However, clear understanding on drivers of price dynamics is necessary to effectively design food security policies.

A large body of literature examines causes of international food price volatility and concentrates on the new drivers of price movements, such as financialization of commodity markets and the linkage to energy markets. International price spikes are transmitted at a considerably large extent to domestic food markets [Kalkuhl, 2014]. In response, national governments imposed export restrictions and founded national food companies to engage in public storage. These policies come at high fiscal and economic costs.

[1] An earlier version of this chapter is published as Kornher, L. and M. Kalkuhl [2013]: "Food price volatility in developing countries and its determinants". Quarterly Journal of International Agriculture, 52 (4):277-308. Other versions of the chapter are published in the proceedings of the 2014 Nordic Conference on Development Economics and the 19th Annual Conference of the African Econometric Society on Econometric Analysis and Policy Challenges in Africa [2014].

Food price volatility differs significantly across crops and countries and is recently declining after strong increments at the end of the last decade [Minot, 2014] (see also chapter two). This analysis looks at determinants of domestic food price volatility in developing countries and attempts to capture the effects of national stabilization policies. According to the literature reviewed, there is no comparable cross-country analysis apart from Lee and Park [2013] and Pierre et al. [2014]. This literature provides evidence on the importance of prominent supply and demand factors and international price volatility to explain domestic price dynamics. Similarly, country-level evidence supports the theory of competitive storage [Shively, 2001; Osborne, 2004; Tadesse and Guttormsen, 2011]. Stabilizing effects of public storage is also found to be evident [Jayne et al., 2008; Mason and Myers, 2013]. However, no other study successfully incorporates restrictive export policies and regional market integration in an empirical model to explain price volatility. Regional Free Trade Agreements (RTAs) represent a promising tool to enhance bilateral trade and trade flow stability [Mujahid and Kalkuhl, 2014]. Furthermore, the number of explanatory variables in the present analysis is exceptional and the heterogeneity of countries with respect to trade status is considered.

The analysis in this chapter contributes to the debate on drivers of food price volatility and the impact of public market intervention. It fills a gap of the existing literature with respect to developing countries by using a comprehensive data set and innovative approaches to measure policy involvement. A particular focus of the study is to address non-linearities with respect to trade status and the impacts of stabilization policies. The empirical analysis employs a dynamic panel, estimated by system GMM that successfully accounts for changes in volatility over time [Serra and Gil, 2012]. The remainder of the chapter is organized as follows. Section two reviews existing empirical literature by distinguishing between internal and external drivers of domestic price volatility. Section three briefs the reader on public market interventions, namely public storage and trade policies. Then, section four and five deal with the empirical strategy and introduce data and variables, followed by the discussion of the results in section six. Lastly, section seven concludes.

4.2 Literature review

The theory of storage is the underlying theoretical model to explain price dynamics. It is described and discussed in chapter three of this dissertation. Volatility of prices originate from frequency and magnitude of changes in price levels. However, there is a notably difference between inter and intra-annual volatility [Ott, 2014b]. The former measures the variation between annual average prices without taking into account the intra-annual seasonality. The latter emerges precisely from this seasonality and other irregular price movements within a year.

4.2.1 International volatility

International price volatility has attracted considerable attention by the literature in recent years. Most of it deals with causes for the global food crisis in 2007/2008. After a period of relative calmness since the 1970s, price movements were extreme in the second half of the previous decade and calmed down only after 2011. There is a broad consensus that no single cause has led to the extreme price spikes [Trostle, 2008; Abbott et al., 2011].

Von Braun and Tadesse [2012] differentiate the effects into root causes, as well as intermediate and immediate determinants. Supply and demand factors remain the major source of instability, while contemporaneous characteristics make agricultural markets prone to these shocks [von Braun and Tadesse, 2012]. In addition, trade policy responses to high prices by major food exporting countries fueled international price dynamics in 2007/2008. An analysis by Martin and Anderson [2012] suggests that 30 percent (for wheat), respectively 45 percent (for rice), of the increase in international prices are linked to these insulation policies. The matter can be characterized as a classic collective action failure.[2]

Another explanation for high price volatility can be identified in the linkage between food and energy markets as a consequence of the usage of cereals in biofuel production [Serra and Gil, 2012; Tadesse et al., 2013; Algieri, 2014]. Others argue that this additional demand affects long term price levels, but not short term volatility. In addition to that, the impact of intensified financialization of commodity markets on price spikes and volatility evolvement is examined without consensus among academics [Irwin et al., 2009; Algieri, 2012; Tadesse et al., 2013; Grosche and Heckelei, 2014]. The reason for this is the inadequacy of available empirical methods and the shortcomings co-integration techniques to establish causality [Grosche, 2014]. A more comprehensive summary and discussion of the literature on international food prices can be found in Hajkowicz et al. [2012], Ott [2014b], and Serra and Gil [2012].

[2]This implies, the higher international prices in consequence of export restrictions, the more exporting countries follow suit and impose own restrictions to protect their markets [Anderson, 2012].

4.2.2 Domestic volatility

The nature and causes of price volatility of staple foods in developing countries largely differs from the international case described. International trade guarantees constant supply in international markets throughout the whole year. In contrast, many countries are characterized by a single harvest and limited accessibility to international markets. Furthermore, only few developing and emerging countries have sound risk management institutions (e.g. commodity exchange) in place and the production of biofuels is undertaken in only few major producing countries. In the following, determinants of domestic price volatility classified into external and internal drivers are discussed accordingly.

External factors

External factors are drivers of domestic volatility that have their origin outside of the country or the food market. In general, tradeable commodities are largely driven by supply and demand in export countries and international markets [Minot, 2011]. Therefore, international price volatility is considered to be a major source of domestic price instability.[3] With the notable exemption of a few studies [e.g. Rapsomanikis and Mugera, 2011; Lee and Park, 2013], the literature looks at spatial transmission of price levels or changes instead of volatility. Rapsomanikis and Mugera [2011] find significant volatility spillovers when world markets are extremely volatile for selected countries. Lee and Park [2013] apply a country panel model using national food price indices (fpi) rather than commodity prices to investigate determinants of volatility, in a similar study to the work at hand, and find a significant but small impact of international food price volatility.[4]

The vast majority of spatial price transmission analysis - from international to national markets - follow Granger-causality models or vector-error-correction approaches to distinguish between short and long term adjustment [Conforti, 2004; Minot, 2011; Robles, 2011; Greb et al., 2012]. The evidence for market integration is mixed. In most cases a co-integration relationship can be established for roughly half of the price series. This fact limits the comparability of different studies and between countries. Although well accepted in the analysis of price transmission and market integration, Granger-causality models are subject to the usual controversy. Estimations based on auto-regressive distributed lag models have

[3]The study follows the literature and considers futures prices (at major commodity exchanges) and export prices (at main ports) as international prices since they serve as reference prices for market participants globally.

[4]Using FAO's Food Price Index as international reference price.

the advantage to reveal transmission elasticities for all price series and country pairs [Ianchovichina et al., 2014; Baquedano and Liefert, 2014; Kalkuhl, 2014]. These results show large discrepancy between countries. However, taking into account large transaction costs, a transmission elasticity of 20-30 percent can be considered to be substantial. Looking at co-movement of international and regional price indices, Cachia [2014] finds transmission to be strongest in Africa due to its high import dependency for rice.

A number of countries are not inter-linked to international commodity markets but trade extensively within the region. Proximity plays a critical role for the extents of spatial price adjustments [Aker et al., 2014; Brunelin and Portugal-Perez, 2015; Mengel and von Cramon-Taubadel, 2014a,b]. In summary, price transmission appears to be far from complete, but can make a large difference when domestic food prices in developing countries already follow increasing trends. A lack of price transmission could be explained by a large portion of transaction costs and agricultural policies [Rapsomanikis, 2011]. Further, asymmetries and structural breaks in transmission mechanisms are acknowledged, but difficult to quantify [Greb et al., 2012].

Apart from international and regional price movements, the variability of the USD exchange rate is regarded to be exogenous to domestic commodity markets. An (de) appreciation of the local currency has clear impacts on the price of imported commodities. If the USD price varies strongly, commodity prices will also fluctuate. Conversely, international price volatility can be offset by exchange rate fluctuations [Cachia, 2014]. Findings from cross-country analyses provide mixed evidence for the impact of exchange rate volatility [Valera et al., 2010; Lee and Park, 2013; Pierre et al., 2014]. However, country-level studies usually include it as an additional explanatory variable [e.g. Shively, 1996; Kilima et al., 2008; Maitre d'Hotel et al., 2015].

General inflation also affects food prices by putting an upward or downward (less likely) pressure on suppliers. Usually, inflation impacts only on the price trends and not on volatility. Due to the great share of food in the aggregated consumption bundle of consumers in developing countries, general consumer price indices (cpi) often exhibit seasonal patterns of food price data. This makes the interpretation of a causal relationship difficult and many of the aforementioned studies use real instead of nominal prices in order to omit inflation in the regression. Alternatively, Lee and Park [2013] include the growth rate of money supply in their model which should capture inflation related shocks; yet without seeing a significant contribution to price volatility.

Lastly, trade restrictions remain to be the major source of distortion in agricultural markets [Anderson and Nelgen, 2012]. During the global 2007/2008 food crisis, restrictions of major exporters severely impacted on import depending countries [Martin and Anderson, 2012]. However, developing countries have often limited capacity to engage in disputes with food exporting countries [Götz et al., 2010]. On the other hand, exporters like India and Vietnam successfully isolated and stabilized their domestic markets through export controls [McKay and Tarp, 2014]. Against this, Porteous [2012] does not find similar positive effects of export restriction for regional exporters without significant weight in international trade.

Internal factors

The classical theory of storage considers annual production to be stochastic with independently distributed shocks. By their annual nature, production shocks primarily cause inter-annual volatility [Dehn et al., 2005; Ott, 2014b]. Stocks can absorb production shortfalls by increasing available supply, and thus mitigate price instability between and within marketing years. On the other hand, greater supply at the beginning of the marketing year guarantees sufficient supply in the course of the whole year and dampens price increases towards the end of the season. Therefore, a higher production level can reduce volatility [Lee and Park, 2013; Pierre et al., 2014]. Empirical evidence on the competitive storage model relies on price data only. National grain price dynamics exhibit characteristics as predicted by the theoretical model [Shively, 2001; Osborne, 2004]. Yet without adequate stock data stabilizing effects of storage are difficult to quantify, but the literature emphasizes on price spikes as a result of stock-outs [Tadesse and Guttormsen, 2011].

Likewise storage, imports can overcome a temporary supply shortage. The theoretical link is clear and simulation models have shown the unambiguous impacts on price stabilization [Wright and Williams, 1982; Makki et al., 1996, 2001]. To empirically evaluate the effects of imports on domestic price levels and variability is difficult, since imports decrease with self-sufficiency. As a result, the positive effects of imports are canceled out by the negative production shock. Trade regime changes impact on price adjustment mechanisms between countries as empirical evidence from spatial transmission analysis shows [Myers and Jayne, 2012; Stephens et al., 2012]. Generally, the importance of production, stocks, and imports depends on the characteristics of a country as closed economy, importer, or exporter. For importers, the socially optimal composition of stocks and imports is determined by total domestic supply and world prices. It is to note that, due to the substitutability of imports and stocks, great flexibility can be gained through an optimal combination of both storage and trade [Gouel and Jean, 2015].

As against other markets and sectors, demand side shocks carry less weight in food markets in developing countries due to the low price elasticity of demand. In other words, consumers hardly adjust their demand when prices fluctuate. An increment in the price of a staple food could even lead to an increase in its demand which is referred to as Giffen behavior [Jensen and Miller, 2008]. Theoretically, this is caused when the substitution effect exceeds the income effect. More importantly, spill-overs from other food commodities could have short to medium term effects on commodity prices [Alderman, 1993; Rashid, 2011]. Other demand shocks as induced by population growth or change in preferences are only long term drivers of prices and do not affect short term volatility.

Furthermore, transaction costs matter for the price formation of spatially traded commodities. Changes in transaction costs are passed to market prices until the new price equilibrium is reached. This applies for internationally traded imports [Barrett and Li, 2002], but also for intra-regional or national trade [Staatz and Diallo, 2012]. In addition to that, institutional economics emphasizes the importance of transaction costs for the performance and functioning of markets, in particular in developing countries [e.g. Rujis et al., 2004]. With regard to food markets, efficiency can be gained in facilitating fast and costless contacts between buyers and sellers [Overa, 2006; Aker, 2010] as well as enforcing liability of contractors [Gabre-Madhin, 2001].

Finally, governments are able to influence commodity prices by imposing agricultural. Firstly, production related policies that have indirect impacts on market prices. Secondly, trade policies in form of import and export restrictions. Lastly, public price stabilization programs through government intervention in storage. The latter two are discussed in detail in the subsequent section.

4.3 Public price stabilization policies

4.3.1 Motivation and history

The motivation for governments to intervene in agricultural markets and to implement stabilization programs is twofold. First, food price spikes and volatility have diverse microeconomic consequences. Production and investment decisions of farmers, traders, and investors are distorted when uncertainty on price changes is high [Coyle, 1992; Haile et al., 2014]. Such inefficiencies are mainly due to risk averse behavior, but can also be of relevance for risk neutrality individuals and firms [Martins-Filho, 2011]. Second, standard welfare economics also predicts negative consequences from volatility for consumers when the expenditure share of the product, which exhibits strong price variability, is significant [Turnovsky et al., 1980]. Further, food price shocks can have adverse impacts on nutrition and human capital investment [Kalkuhl et al., 2013].

If these negative aspects are accepted, intervention is justified when free markets are imperfect in insuring market actors against these risks [Timmer, 1989]. Yet in most developing countries, this is reality [Newbery and Stiglitz, 1981; Gouel, 2013b].

Apart from negative microeconomic impacts that governments intend to mitigate, price volatility also involves adverse macroeconomic consequences on the economy. On the one hand, unpredictability of export earnings and the size of the food import bill [Myers and Jayne, 2012]. On the other hand, fallout on national food security. The latter causes costly government actions that take away financial resources for public investment [Timmer, 1989]. There is strong evidence for the impact of volatility and economic unpredictability on growth and welfare [Ramey and Ramey, 1995; Jacks et al., 2011]. In extreme cases, price changes can also be a major driver for political unrests and instability [Lagi et al., 2011; Bellamere, 2014]. This in turn is associated with a slow down of economic growth and reduction in welfare [Alesina et al., 1996].

Traditionally, states have a great interest to control food prices via involvement in agricultural production, marketing, and foreign trade in order to generate sufficient farm incomes and to ensure affordable prices [Bates, 1981]. Nowadays, grain markets are still not free in the neoclassical sense. After industrialization, developed countries shifted their policy focus to producer subsidy schemes in order to maintain self sufficiency or boost exports (e.g. United States, European Union). In contrast, in developing countries public interventions particularly target urban consumers [Lynton-Evans, 1997; Kherallah et al., 2002; Anderson and Nelgen, 2012]. The set of policy instruments is diverse and reaches from input subsidies to the ban of private trade.

In developing countries, food markets became organized only during the colonial period. After independence, markets remained under strict government control until market liberalization started in response to the structural adjustment programs in the 1980s [Wiggins and Keats, 2009]. While governments in some countries (e.g. Benin and Madagascar) entirely liberalized markets, others (e.g. Malawi, Zambia, India) continued to heavily intervene through public buffer stock schemes and marketing boards.[5]

In the following, the two of most common agricultural price policies are discussed. First, public storage in form of buffer stocks and strategic reserves. Second, trade restrictions like export duties and quotas. The latter are discussed not only with respect to consequences on national markets but also by looking at negative externalities of trade restrictions.

4.3.2 Buffer stocks and strategic reserves

Public storage is a traditional policy instrument to manage agricultural price levels and stability. Most commonly, it is distinguished between buffer stocks and strategic reserves. The former are synonymous to interventions stocks, while the latter are also often referred to as emergency reserves. The difference between the two is the extent of intervention. Buffer stocks try to mitigate price movements in both directions by permanently intervening in the market to affect prices. Unlike buffer schemes, strategic reserves are created to overcome supply shortage in markets as result of harvest failures or unavailability of international supply. However, they can also be used to mitigate price spikes [Gérard et al., 2011; Galthier, 2013]. By doing this, the level of interventions is much lower than in the case of a buffer regime.

Likewise strategic reserves, international food aid is not distributed with the intention to impact on prices, but to guarantee supply for the vulnerable. Yet a viable food purchase and distribution system must be in place in order to enable successful activities during times of crises [Grosh et al., 2011]. In doing so, the World Food Program acts similarly to buffer stocks in selected countries with the intention not to affect market prices in normal market situations.[6]

High costs of capital and transactions cause market inefficiencies and costs of storage are usually high. In consequence, private stocks carried may not be optimal from the perspective of a policy maker having a desired level of price stabilization. The idea of buffer stocks sounds simple. On the one hand, the state creates additional demand when prices are low. On the other hand, it provides additional supply when prices are high. In this way, the state

[5]See Fafchamps et al. [2005].

[6]This information was obtained through expert consultations at the WFP office in Accra, Ghana.

institution is involved in buying and selling of commodities at any time. Ideally, prices are only influenced when they exceed or undercut politically determined thresholds (ceiling and floor price). In such a framework, the bandwidth ultimately determines the level of price volatility. The narrower the band, the lower the volatility. Yet a smaller bandwidth requires higher levels of stocks to effectively alter market prices [Newbery and Stiglitz, 1982].

Partial equilibrium analysis shows strong stabilizing effects of public stabilization programs [Miranda and Helmberger, 1988] that are accompanied by positive overall welfare impacts [Gouel and Jean, 2015]. The major challenge of a sound empirical assessment of public interventions is that with-without comparisons are not possible. Minot [2014], for instance, compares price volatility between low and high intervention African countries. He finds significant higher volatility in high intervention countries than in low intervention countries without controlling for counterfactuals. However, high volatility countries are also more prone to intervene in markets to stabilize prices.

Country level evidence seems to be more solid. An evaluation of Zambia's Food Reserve Agency (FRA) by Mason and Myers [2013] reveals that its involvement has both raised and reduced market prices during different episodes of the study period and dampened variability significantly. These findings are similar to those of Jayne et al. [2008] assessing the activities of Kenya's National Cereals and Produce Board (NCPB). Similarly, market liberalization are found to have increased market price variability [Barrett, 1997; Yang et al., 2001; Kilima et al., 2008]. Conversely, Shively [1996] and Chavas and Kim [2006] find lower volatility after economic liberalization processes in Ghana and the United States. This is often explained by increasing competition as a result of low market entry barriers [Sitko and Jayne, 2014]. Overall, the impact seems to be largely context dependent and also depends on administrative quality and functionality in the design of the reserve [Rashid and Lemma, 2011].

Noteworthy, empirical analysis is aggravated by difficulties to adequately measure public interventions. Furthermore, theoretically changes in public stock levels imply price stabilization no matter in which direction they go.

4.3.3 Trade policies and liberalization

The effects of trade policies, namely import taxes, export taxes and quotas, and export subsidies are discussed in many textbooks on international trade. Price impacts are clear and straightforward, however, depend on a country's share in international trade.[7] Import taxes are motivated by revenue generation and protection of producers in importing countries to increase competitiveness of domestic industries. Similarly, revenue generation is the main motivation for export taxation. Export quotas and taxes also allow controls of export quantities and attempt to guarantee target levels for domestic supply. Usually, export taxation is general for all products, while non-tariff restrictions are applied to single key commodities [Anania, 2013].

In order to control domestic price levels and stability, trade policies can be used to mitigate externalities of international price movements on national food security by changing the status quo trade regime [Diaz-Bonilla and Ron, 2010]. Importers achieve this by reducing import taxes, a de facto subsidy for consumers. This comes at high fiscal costs. Against this, exporters and countries that switch between net-importer and net-exporter aim at reducing exported quantities to increase domestic availability. It is a general observation that policy responses in developing countries aim at protecting and benefiting consumer, while developed countries more commonly support its producers [Anderson and Nelgen, 2012]. In addition, revenues from import and export taxation have gained a significant importance in governments' budgets across the developing world.

During the last decade, trade policies have appeared to be the most common policy response to international food price surges [Demeke et al., 2009; Sharma, 2011]. Apart from positive impacts on domestic food price stability, export restrictions are associated with externalities for food importers and geographical neighbors [Martin and Anderson, 2012; Porteous, 2012]. Export restrictions of main exporters cause scarcity in supply at international markets, and thus boost export prices.

International negotiations on market and trade liberalization intensified after the creation of the World Trade Organization (WTO) in 1994. Subsequent meetings attempted to reduce agricultural subsidies and trade restrictions. However, WTO agreements are not characterized by strong discipline and its rules allow export restrictions when countries face domestic supply shortage, a term not clearly defined [Konandreas, 2012].

Trade liberalization can reduce agricultural price volatility through the intensification of trade between member countries. But, using standard gravity model techniques, Rose [2004] finds little evidence that WTO membership effectively enhances bilateral trade. It

[7] Textbook cases: small country vs. large country.

also does not stabilize trade flows and predictability by diminishing temporary trade restrictions [Rose, 2005]. In a more detailed analysis, Subramanian and Wei [2007] show how liberalization of both trading partners strongly determines the level of benefits from WTO membership. In line with this, regional free trade agreements (RTA) effectively enhance agricultural trade [Sun and Reed, 2010; Baier and Bergstrand, 2007; Mujahid and Kalkuhl, 2014]. Moreover, empirical evidence is given that RTAs significantly reduce trade policy unpredictability [Mansfield and Reinhardt, 2008; Cadot et al., 2009]. On this account, amplified regional trade integration stabilizes agricultural commodity price volatility.

4.4 Empirical strategy

4.4.1 Modeling volatility

How to model price volatility is extensively discussed in chapter two of this dissertation. In brief, price volatility is generally recognized as a stochastic process and as highly variable over time [Gilbert and Morgan, 2010a]. To account for these characteristics, GARCH models are widely applied, especially to model financial data. Among agricultural economists there is some doubt that random walk models can capture the transitory nature of shocks that are caused by fundamental determinants [Balcombe, 2009; Piot-Lepetit and M'Barek, 2011]. However, Barrett [1995] emphasizes the importance of structural variables in volatility models for agricultural commodities that are frequently omitted in GARCH models. Indeed, with the exception of the spline-GARCH model [Engle and Rangel, 2008; Karali and Power, 2013] conditional volatility models are incapable of incorporating further explanatory variables of lower data frequency. Furthermore, analysis in Chapter 2 shows little differences between conditional and realized volatility when ranking countries and markets according to their volatility.

Therefore, here volatility is estimated as a reduced form equation model which is inspired by Lee and Park [2013] and extends their analysis by including a larger set of explanatory variables and expanding the analysis to crop specific estimates. Data availability allows an estimation on annual base only. Volatility is computed as the standard deviation of log returns within a particular year, as done by Balcombe [2009] and Ott [2014a]:

$$\sigma_{p_t} = \sqrt{\frac{\sum_{m=1}^{12}(\Delta \ln p_{mt} - \overline{r}_t)^2}{12}} \quad (4.1)$$

where σ_{p_t} is the marketing year volatility in year t; $\Delta \ln p_{mt}$ is the difference in logarithmized prices between two subsequent months m; $\overline{r}_t$ is the mean log return over the same marketing year.

To account for volatility clusters, implying that periods of high volatility follow periods of high volatility and low volatility periods of low volatility, respectively [Serra and Gil, 2012], volatility is modeled as a dynamic process. This is accomplished by including the lagged value of the dependent variables as an explanatory variable.

4.4.2 Model structure

The literature overview shows that price volatility can be attributed to multiple causes and a clear linkage between market fundamentals as well as macroeconomic variables and price volatility is established. Apart from these variables, variability is subject to country and crop specific factors. Some of them are observable or attributable to a broader category. By their nature, some of these factors are constant over time. In addition to this, data on public policies, governance, market performance, and transaction costs are difficult to obtain, particularly for such a large data set. In order to nevertheless include these variables, indicators need to be used. Some of them are dummies and constant over time. For this reason, the structure of the empirical model may be written as:

$$\delta_{ijt} = \gamma X_{ijt}^{'} + \theta I_{ij}^{'} + u_{ijt} \quad (4.2)$$

where δ_{ijt} denotes price volatility of country i and crop j in period t and X' and I' are vectors of time-varying and time-invariant but observable regressors; u_{ijt} is the error term.

Besides observable time-invariant determinants, variables exist that cannot be observed by the econometrician. The ordinary least squares (OLS) estimator suffers from omitted variable bias (OVB) due to unobserved heterogeneity when these unobservables are correlated with the observed independent variables [Cameron and Trivedi, 2005].[8] The unobserved heterogeneity is owed to crop characteristics and regional or country specific demand and supply patterns. Unobserved individual heterogeneity is widely assumed to be present in cross country samples [Acemoglu et al., 2008; Lee and Park, 2013].

In contrast to the OLS estimator, the within-estimator, or fixed effects estimator, purges out constant unobserved individual fixed effects α_{ij} by subtracting its crop-country averages from (4.2):

$$\delta_{ijt} - \overline{\delta}_{ij} = \gamma(X'_{ijt} - \overline{X'}_{ij}) + \theta(I'_{ij} - I'_{ij}) + u_{ijt} - \overline{u}_{ij} \tag{4.3}$$

$$u_{ijt} = \alpha_{ij} + \epsilon_{ijt} \tag{4.4}$$

where $\overline{\delta}_{ij}$, $\overline{X'}_{ij}$, and I'_{ij} denote average values over the entire observation period. The error term reduces to ϵ_{ijt} which is assumed to be i.i.d.; α_{ij} is the country-crop fixed effect that is purged out.

Albeit, the procedure also removes the time-invariant variables of interest I'_{ij} and renders an estimation of θ impossible.

4.4.3 Dynamic panel bias and estimation of time-invariant regressors

Another source of bias comes from the inclusion of the lagged dependent variable into the model. Consider the dynamic version of (4.3):

$$\delta_{ijt} - \overline{\delta}_{ij} = \beta(\delta_{ijt-1} - \overline{\delta}_{ij}) + \gamma(X'_{ijt} - \overline{X'}_{ij}) + \theta(I'_{ij} - I'_{ij}) + u_{ijt} - \overline{u}_{ij} \tag{4.5}$$

The endogeneity comes from the fact that δ_{ijt-1} is correlated with u_{ijt-1}, but also with u_{ijt}. In consequence, the regressor $\delta_{ijt-1} - \overline{\delta}_{ij}$ is correlated with $u_{ijt} - \overline{u}_{ij}$ and the within-estimator becomes inconsistent unless $T \to \infty$ and the weight of u_{ijt-1} in $\overline{u}_{ij}$ is relatively small [Nickell, 1981]. In addition, δ_{ijt-1} may also predetermine other explanatory variables,

[8] $E[X'_{ijt}|u_{ijt}] \neq 0$.

and hence those regressors are also correlated with $\overline{u}_{ij}$ [Roodman, 2009a]. OLS and the random effects estimator also yield inconsistent estimates [Cameron and Trivedi, 2005].

An alternative way, in order to purge away unobserved individual effects, is the first differences estimator that uses lags instead of averages:

$$\delta_{ijt} - \overline{\delta}_{ij} = \beta(\delta_{ijt-1} - \delta_{ijt-2}) + \gamma(X'_{ijt} - X'_{ijt-1}) + \theta(I'_{ij} - I'_{ij}) + u_{ijt} - u_{ijt-1} \tag{4.6}$$

In this case δ_{ijt-2} can be used as an instrument for $\delta_{ijt-1} - \delta_{ijt-2}$ [Anderson and Hsiao, 1981], however, at the cost that one entire period of observations is lost.

So far, it has only been dealt with the consistent and efficient estimation of the dynamic panel and the inclusion of time-invariant variables was neglected. For the static case, the instrumental generalized least squares (GLS) estimator by Hausman and Taylor [1981] can be used. The omitted variable bias is dealt with by instrumenting potentially correlated regressors with strictly exogenous ones. Yet the estimator may lack efficiency, for not using all available instruments. Making use of all available moment conditions, Blundell and Bond [1998] propose to estimate a system of equations including the difference-equation (4.6) and its corresponding level equation:

$$\delta_{ijt} = \beta\delta_{ijt-1} + \gamma X'_{ijt} + \theta I'_{ij} + u_{ijt} \tag{4.7}$$

Hereby, the differences serve as instruments for the level equation, whereas lagged levels are instrumentalized in the difference equation (4.6). Through additional instruments, the estimators for β and γ gain efficiency. In addition, time-invariant variables are not purged out and an estimate for θ can be obtained. However, the estimation is unbiased only if I'_{ij} is not correlated with the fixed effect (α_{ij}) [Roodman, 2009a].

As a matter of fact, it is very likely that observed time-invariant country characteristics are correlated with the fixed effect [Hoeffler, 2002]. As a result, the system GMM estimator is inconsistent. Among others, Cinyabuguma and Putterman [2011] and Kripfganz and

Schwarz [2013] apply a two stage estimation approach. In this instance, only time-variant regressors are included in the first stage using either difference or system GMM. Thus, GMM estimates are not biased through the inclusion of endogenous time-invariant regressors. From the GMM regression, u_{ijt} is obtained containing observed and unobserved time-invariant effects as well as the normally distributed regression error ϵ_{ijt}. In the second stage, the errors (u_{ijt}) are regressed on the time-invariant regressors within a cross sectional regression framework:

$$u_{ijt} = \theta_1 F_{ij}^{'} + \theta_1 f_{ij}^{'} + \alpha_{ij} + e_{ijt} \tag{4.8}$$

where $F_{ij}^{'}$ contains strictly exogenous time-invariant regressors and $f_{ij}^{'}$ contains endogenous time-invariant regressors. Both constitute to $I_{ij}^{'}$ from above.

Equation (4.8) can be estimated using two stage least squares (2SLS). The difficulty in the estimation is to find feasible instruments that are sufficiently correlated with the endogenous time-invariant variables $f_{ij}^{'}$, but not correlated with the fixed effect.

As in any instrumental variable regression, the quality of the first step GMM estimator depends on the relevance and validity of its instruments. The exclusion restriction can be tested using Hansen J-Test or the Sargan Test of overidentifying restrictions. Both difference and the system GMM potentially suffer from inconsistency as a consequence of too many instruments. Alongside, results on Hansen's J-Test may be compromised by a large number of instruments [Roodman, 2009b].

4.5 Description of the data

The data set used in this analysis is unique in three ways. First, the coverage of countries from all continents is great with a total of more than 70 countries. Then, a large set of explanatory variables is used, while combining a number of existing cross-country data sets. Last, innovative approaches are taken to capture the impact of policy variables on food price volatility. The observations periods is from 2000 to 2013.

4.5.1 Variables of interest and controls

The empirical analysis is based on a comprehensive data set of agricultural fundamental data and macroeconomic variables. A contribution of this study is to combine different existing data sets in order to estimate the effect of several explanatory variables in a single econometric model.

Research with a similar econometric approach to identify causes of price volatility in the form of a cross country analysis is scant. Pierre et al. [2014] and Lee and Park [2013] are the only comparably studies that look at volatility in developing countries. Ott [2014a], Balcombe [2009], Tadesse et al. [2013], and others analyze international volatility and therefore their set of explanatory variables used deviates from studies with regard to developing countries (see discussion in section two). Principally, the model allows to include a large variety of potential drivers of volatility discussed in the literature review section. Yet the selection of explanatory variables for the analysis at hand is largely leant on the related literature. In addition, an attempt is undertaken to account for trade and price stabilization policies quantitatively. The full set of independent variables is provided in Table 4.1.

The identification of causal effects of time-invariant regressors in cross country data sets, in particular in a dynamic setting, adds complexity to the model. Therefore, most independent variables are designed as time variant. Yet data availability and frequency of updates do not permit to observe all determinants on an annual base. Besides, country characteristics, such as net trade position, do hardly change over time; others are naturally constant (geography).

Table 4.1: Description of variables

Name	Description	Source	Sign
Dependent variable			
vol dom price	volatility of domestic commodity prices †	ZEF Commodity	
L.vol dom price	lagged volatility of domestic commodity prices †	Price Database	+
External factors			
vol int price	weighted international export prices †	IGC	+
vol exchange rate	LCU/USD exchange rate †	IMF	+
int exp res.	export restrictions by main trading partners	UN Comtrade	+
M1	average annual growth rate in money supply	WDI	+

Continued on next page...

... Table 4.1 continued

Name	Description	Source	Sign
WGI	Kaufmann's World Governance Indicator	WGI	-
Internal factors			
stocks	annual stock-to-use ratio	FAO GIEWS	-
production	relative annual production	FAO GIEWS	-
insulation	export restrictions by home country	UN Comtrade	-
reg trade	share of intra-regional trade	UN Comtrade	-
market institutions	measure for market performance	ITU, WDI, Fraser Institute	-
importer	dummy equals 1 if country i is an importer of commodity j	FAO GIEWS	?
exporter	dummy equals 1 if country i is an exporter of commodity j	FAO GIEWS	?
non-importer	dummy equals 1 if country i is not an importer of commodity j	FAO GIEWS	?
trade switcher	dummy equals 1 if country i is neither importer nor exporter	FAO GIEWS	?
high intervention	dummy equals 1 if country i runs influential public stockholding	desk research	?

Note: †calculated using (4.1). The list of countries by trade status and intervention level is provided in Table B.2 in Appendix B.

The dependent variable in the regression is the standard deviation of price returns across a calender year. It is preferred to use national retail prices. In some instances, they are not accessible, then the average is constructed from available market level price data. In some rare cases, wholesale price data is used. The difference should not be of concern within the panel framework that is applied. In order to achieve a normal distribution of residuals, which is required for inferences testing, the standard deviation of returns is logarithmized.[9]

To assess the transmission of volatility from international to domestic markets, and to account for spatial price adjustment, international volatility is a main variable of interest. It is computed over an annual period in the manner of the dependent variable. So, international volatility is not weighted by national trade activities. Exchange rate volatility represents

[9]Figure B.1 in Appendix B shows residuals from the preferred specification.

national currency fluctuations towards the USD. It controls for price adjustment which does not affect real prices. For exporters, exchange rate volatility also captures their trade competitiveness. Growth rate of money supply accounts for demand shocks and inflation pressure. Both lead to an import of volatility into the food sector. The overall score of Kaufmann's World Governance Indicator (WGI) is included to control for political stability and governance effectiveness.

In order to consider the quality of market institutions, a variable is constructed by the author. The motivation is that existing data sets do not explicitly consider institutional quality of the agricultural sector. In this study, institutional quality is measured by road infrastructure, economic freedom, mobile phone penetration rate, and the presence of an agricultural exchange to hedge price risk and to gain better price information.[10] Then, they are equally weighted evolving into a single index. One main advantage is the time-variant structure of the index which cannot be achieved for all variables composing the index, but for the index as a whole. In all, market institutions measure institutional quality, transactions costs, and infrastructure.

Fundamental supply data is controlled for by the stock-to-use ratio and the relative change in annual production. They are standard variables in volatility models and signs are unambiguously predicted by the theory. However, existing studies on developing countries exclude stocks due to the low data quality and measurement errors associated. Here, FAO CBS stock data from the FAO's GIEWS is incorporated. To the knowledge of the author it is the best and most comprehensive data set available with respect to developing countries (see discussion in chapter three).[11] Notably, there is still legitimate doubt on the precision of the data, as it is also constructed from commodity balance sheets. Yet stocks are the main determinant of price dynamics in the competitive storage model and the stock-to-use ratio adds significant value to the information on domestic supply.

Then, trade policies are captured by three different variables. They are constructed from annual bilateral trade flow data for individual agricultural commodities published by UN Comtrade.[12] Data until 2013 is available only for trade values, but not for quantities. In

[10] Mobile phone penetration and economic freedom are measured relative to penetration and freedom in the US. Road infrastructure is measured as the percentage of paved roads. Missing values are linearly interpolated. If a commodity exchange exists a country gets 100 percent and zero if no commodity exchange exists. Institutional quality is an equal weighted average.

[11] FAOSTAT only provides stock changes. USDA provides reliable data for big importers but generally bad data for sorghum and millet.

[12] The idea to approximate trade policies through trade flow stability was developed with Irfan Mujahid who is also a co-author of the latest paper version of this chapter.

order to make quantities comparable over time, trade values are divided by the annual international grain price index that is also used to compute international price volatility. National protectionist behavior (insulation), so called insulation policies, are approximated by the deviation of actual national export quantities from its HP-filter trend value; the *normal* export quantity. As elaborated above, these insulation policies are expected to reduce domestic volatility. In contrast, export restrictions of large exporters (int exp res) measure endured protectionism by trade partner. They are captured by shocks in the deflated export value of a country's five main trading partners. These shocks are also computed as negative deviation from their HP-filter trend value. The theory predicts endured trade restrictions to be positively associated with national commodity price instability. Against this, trade liberalization and regional market integration are expected to stabilize market prices. Regional integration is measured as the share of total trade with partners in regional trade agreements as compared to the total trade value.[13]

Both Pierre et al. [2014] and Lee and Park [2013] also include Gross Domestic Product (GDP) or GDP growth rate in the empirical model with the intention to capture demand shocks, inflation pressure, and quality of the market. However, there seems to be no persuasive economic argument why income should affect price volatility, but for indirect channels as quality of market institutions and money supply. Studies on drivers of international price volatility include measures for financialization of commodity markets, speculation, and demand shocks from the energy sector [e.g. Tadesse et al., 2013]. Given the context of developing countries, these variables do not seem to be of relevance.

The classification into external and internal drivers is used by several other authors [Lee and Park, 2013; Tadesse et al., 2013; Pierre et al., 2014]. Here, internal factors are limited to the agricultural sector and are considered to be most easily amenable to influence by policy makers, in order to stabilize commodity prices. The strategy is to estimate the econometric model for the whole sample, and distinct country groups, namely importers, non-importers, trade-switchers, and high and low intervention countries.[14] Further, the two-step estimation allows to test for difference in the level of volatility between these groups of countries. The elaboration of heterogeneity between countries is an innovative approach with no comparable application in empirical research.

[13]Data on regional trade agreements is collected by Mujahid and Kalkuhl [2014].

[14]The number of observations for exporters is relatively small. Therefore, non-importers are exporters plus trade-switchers. Differences between non-importer and trade-switchers should be carried by exporters; Exporters are countries that exported throughout the whole period of observation. Importers are defined as countries that imported in each year of the observation period with a median import-to-consumption ratio greater than 15 percent.

4.5.2 Country coverage

Countries and crops that are part of the data set are selected based on availability of price data from existing commodity price databases and national publicly open sources. Table 4.2 summarizes the number of country-crop groups by continent, country type, and commodity. Accordingly, the country coverage is particularly comprehensive in Africa where a variety of grains is consumed. A detailed list of countries is provided in Appendix B. The exact number of groups varies by specification.

TABLE 4.2: Number of groups in sample

	maize	rice	sorghum	wheat	millet	Total
Africa	26	29	17	16	11	99
Asia	2	19	-	16	-	37
Latin America	14	14	2	9	-	39
Europe	1	1	-	2	-	4
landlocked	14	17	7	15	6	59
importer	19	38	2	33	0	92
exporter	6	7	3	3	2	21
non-importer	24	25	17	10	11	87
trade switcher	18	18	14	7	9	66
high intervention	7	19	4	13	4	47
All	43	63	19	43	11	179

4.6 Results

4.6.1 Model selection and specification tests

The discussion of the results should start with the selection of the right model and its validation by common specification tests. All models are run in Stata 13, the dynamic panel versions with Rodman's xtabond2 [Roodman, 2009a]. All reported standard errors are robust. For GMM, the two-step estimators are applied. The two-step estimator is more efficient than the one-step estimator in system GMM, while they are equivalent in difference

GMM [Hoeffler, 2002]. However, the standard errors of the two-step estimator are found to be seriously downward biased. Therefore, Windmeijer's correction is used.

Time dummies are not included in the model, but used as exogenous instruments in both GMM regressions. Usually, it is recommended to include time dummies as explanatory variables as well. In the present case, time effects are unlikely since supply and demand shocks are correlated across countries only through trade, which is captured by the inclusion of international price volatility. Correlation across commodities in a particular year arises from common production shock and is purged away by including commodity specific supply variables. Furthermore, the dependent variable is stationary and time effects through the global food crisis are caught by higher values of international price volatility.

In all regressions domestic price volatility is the logarithmized value of the standard deviation of monthly prices across a year. Column one of Table 4.3 presents the results of a simple OLS regression. Then, the fixed effects estimation is presented in column two. Both GMM regressions are shown in column three and four. Lastly, column five presents results of the fixed effect estimator without the inclusion of the lagged dependent variables. The results and their interpretation are discussed in detail in the next section.

Generally, only few explanatory variables are significant at usual levels of significance, but those have the expected sign. OLS and fixed effect estimation represent an upper and lower bound for the coefficient of the lagged dependent variables. So, the GMM estimation lies well in the expected range. The high significance of the lagged dependent variable across all models requests for a dynamic version. In consequence, the static model in column five is obsolete, although coefficient estimates are similar to all other models, but system GMM. International volatility is also significant across all models with the largest coefficient in the system GMM estimation. Similarly, institutional quality is found to be significant consistently. Conversely, for all other variables, deviations between the different models exist.

Differences may be explained as follows. Only system and difference GMM account for the dynamic panel bias and endogeneity of explanatory variables. The fixed effect estimator only deals with OVB by controlling for time-invariant unobservables.[15] In both GMM models, stock-to-use ratio, share of regional trade, and export restrictive policies are considered as strictly endogenous. Change in relative production is assumed to be predetermined.

[15]Endogeneity in fixed effect regression in a static model can be handled by an instrumental variables regression.

Table 4.3: Model comparison

	p.OLS	FE	sysGMM	diffGMM	FE
	(1)	(2)	(3)	(4)	(5)
L.vol dom price	0.521***	0.0592*	0.263***	0.186***	
	(7.88)	(1.86)	(5.25)	(4.12)	
vol int price	0.218***	0.231***	0.302***	0.245***	0.237***
	(4.78)	(4.25)	(6.23)	(4.14)	(4.38)
production	0.00468	0.00611	-0.0835	-0.00734	0.00860
	(0.08)	(0.11)	(-1.11)	(-0.12)	(0.15)
stocks	-0.189*	-0.352*	-1.218	-0.125	-0.321
	(-1.66)	(-1.73)	(-1.65)	(-0.36)	(-1.52)
insulation	-0.0864	-0.128	-0.400**	-0.0200	-0.119
	(-1.21)	(-1.31)	(-2.01)	(-0.10)	(-1.21)
int exp res.	0.0780	0.0653	0.0271	-0.194	0.0800
	(0.68)	(0.53)	(0.16)	(-1.21)	(0.64)
reg trade	-0.0537	-0.0960	-0.881***	0.0806	-0.0892
	(-0.98)	(-1.12)	(-4.06)	(0.28)	(-1.03)
M1	0.484***	-0.161	0.343	-0.140	-0.158
	(2.98)	(-0.94)	(1.12)	(-0.66)	(-0.90)
WGI	-0.110**	-0.00610	0.111	0.251	-0.0226
	(-2.11)	(-0.02)	(1.13)	(0.76)	(-0.09)
market institutions	-0.636***	-1.19***	-0.973***	-1.59***	-1.17***
	(-3.88)	(-4.08)	(-2.73)	(-3.77)	(-3.86)
vol exchange rate	0.00218	0.0112	0.0122	0.00786	0.00968
	(0.14)	(0.38)	(0.34)	(0.22)	(0.32)
_cons	-0.555***				
	(-2.66)				
N	996	996	996	848	1004
N of instruments			67	66	
AR(2)			0.397	0.198	
Sargan Test			0.171	0.536	
Hansen Test			0.664	0.653	
Diff.Sargan(gmm)			0.792	0.901	

t statistics in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; Note: stocks, reg trade, and insulation are treated as endogenous, production is considered to be predetermined. Regressions use orthogonal deviations instead of first differences as instruments. Years are included as exogenous instruments.

Therefore, GMM estimators are preferred to obtain unbiased coefficient estimates. Table 4.3 also displays specification tests for dynamic panel models. First, the Arellano-Bond test for autocorrelation in the idiosyncratic disturbances is used to test the validity of all lags as instruments [Roodman, 2009a]. For both system and difference GMM, the null of no autocorrelation of second order cannot be rejected. Second, Sargan and Hansen test for instrument exogeneity are performed. The first is not robust, whereas the second weakens with too many instruments. Following the suggestion of Roodman [2009b], the number of GMM type instruments is collapsed. Both Sargan and Hansen accept the null hypothesis of instrument validity. The difference-in-Sargan test confirms the validity of GMM type instruments. Therefore, it is assumed, that the specifications chosen, pass standard testing procedures.

Difference GMM and system GMM show substantial differences with respect to point estimates and standard errors. Most notably, share of regional trade and insulation policies are significant only in the system GMM regression. On the other hand, in both regressions the lagged dependent variable, international volatility, and institutional quality are significant. Inconsistency between the two estimators may be explained by a greater number of instruments utilized by system GMM [Hayakawa, 2007]. Blundell and Bond [1998] discuss biased results of the difference GMM estimator for moderately high coefficients of the autoregressive term. In addition, their findings suggest higher efficiency of the system GMM estimator. Simulation results also detect efficiency gains from system GMM in the estimation of further explanatory variables [Soto, 2009]. Therefore, system GMM is chosen as the preferred model in this analysis. In doing so, the study follows the empirical literature that is closest to this analysis [Lee and Park, 2013; Ott, 2014a].

4.6.2 System GMM results

The discussion of the results is limited to the system GMM model introduced above. All specification tests, as well as the number of instruments, are reported beyond the regression output in Table 4.5. The test results do not reveal a general problem with instrument validity although some test statistics are not sufficient to conclude on this for a single regression. On a general note, there are numerous possibilities to choose the number of instruments and regression options. It is preferable to estimate all models with equal options and assumptions with regard to endogeneity and predetermination of explanatory variables in order to make results comparable. The details are also noted at the end of the regression outputs.

In Table 4.5 four different specifications of the model are presented. The reason is twofold. First, some explanatory variables reduce the sample size substantially. And second, institutional quality is highly correlated with other explanatory variables which may distort test statistics with regard to these variables. The correlation among all explanatory variables can also be found in Table 4.4.

Throughout all specifications, significant variables exhibit the sign predicted by the theory. International food price volatility, measured as the weighted average of most prominent export prices, exhibits a strong significant impact on domestic volatility in each specification. Due to the log-log nature, the coefficient represents an elasticity. Thus, in the short run, around 30 percent of international price volatility is transmitted to domestic markets. This estimate is of similar size as in Pierre et al. [2014], but larger than in Lee and Park [2013]. A comparison with findings from price transmission analysis based on vector error correction models is not reasonable as they measure transmission of price levels instead of volatility spill-overs.

Table 4.4: Correlation of variables in model

	vol dom price	L.vol dom price	vol int price	production	stocks	insulation	int export res.	reg trade	M1	vol exchange rate	market institutions	WGI
vol dom price	1											
L.vol dom price	0.6158	1										
vol int price	0.2576	0.1945	1									
production	0.0361	0.0377	0.0315	1								
stocks	-0.0927	-0.0643	0.0464	-0.0578	1							
insulation	-0.0464	-0.017	-0.0545	-0.0119	-0.0843	1						
int export res.	0.1499	0.1443	0.1771	0.0413	0.0061	-0.0142	1					
reg trade	-0.1097	-0.0973	-0.0502	-0.0067	-0.0832	-0.0315	-0.0385	1				
M1	0.167	0.1634	0.0509	0.0428	-0.0202	0.0109	0.0579	-0.0665	1			
vol exchange rate	0.0482	0.0646	0.1396	0.0294	-0.0663	-0.0013	0.0616	-0.0085	-0.038	1		
market institutions	-0.2968	-0.2692	0.0276	0.0075	0.2107	-0.0406	-0.1725	0.1086	-0.037	0.0519	1	
WGI	-0.2259	-0.1819	-0.0553	0.0185	0.0957	0.0937	-0.1408	0.2308	-0.077	0.0965	0.3969	1

Fundamental supply factors are significant when excluding institutional quality from the regression.[16] Specifically, volatility reduces by 2.5 percent given an increase in the stock-to-use of one percentage point. This coefficient is much larger as compared to estimates on the impact of stocks on international price volatility. Similarly, when national production rises by 10 percentage points, the impact on domestic volatility is between 1.8 and two percent. This effect is of similar size as the one for yield found by Pierre et al. [2014]. In contrast, the evidence on impacts of production and yield on international price volatility is mixed [Balcombe, 2009; Ott, 2014a]. Considering the stochasticity of production shocks, 10 percent is not much. Production shocks are also not under control of policy makers and a policy driven enhancement of production by 10 percent is not likely to be accomplished in the short run.

Furthermore, institutional quality and money growth rate are found to significantly impact on price volatility. Institutional quality is measured by a ratio that lies between zero and one. Thus, an increase of 10 percentage points would lead to a reduction of price volatility of around 10 percent. Money growth rate is also given as a ratio and to be interpreted the same way as institutional quality. Thus, an increase in money supply by 10 percentage points induces price volatility to rise by only three percent. On the contrary to money supply and institutional quality, governance is not significant in any specification. Exchange rate volatility is also not found to be an important driver of domestic price dynamics.

In particular interest of this analysis is the impact of trade policies on domestic price dynamics. The regional share of total trade is significantly negatively associated with price volatility. Hence, higher regional market integration and trade liberalization successfully stabilizes market prices. These results are robust across all specifications. Conversely, price insulation through export restrictions is found to have a dampening effect on price volatility, however, to a smaller extent. An enlargement of regional trade and a restriction of exports by 10 percentage points lead to a reduction of volatility by eight and four percent, respectively. Export restrictions by the five largest trading partners are significant in specification (2) and (3) of Table 4.4 only, but hardly in any other specification tested.[17] So, there is limited evidence for direct negative externalities of export policies. However, this is no contradictions to [Martin and Anderson, 2012] who find international prices to be significantly driven by export policies. Supply shortages at international markets are likely

[16]This can be explained by relatively high correlation between stock-to-use and institutions, but also by the increment in degrees of freedom.

[17]This also holds when excluding international price volatility.

Table 4.5: System GMM results

	(1)	(2)	(3)	(4)
L.vol dom price	0.262***	0.357***	0.355***	0.328***
	(5.17)	(6.35)	(6.19)	(6.30)
vol int price	0.291***	0.280***	0.271***	0.354***
	(6.18)	(5.93)	(5.84)	(6.83)
production	-0.0757	-0.202**	-0.176*	-0.0867
	(-1.03)	(-2.20)	(-1.89)	(-1.00)
stocks	-1.200	-2.544***	-2.575***	-1.326*
	(-1.65)	(-3.66)	(-3.56)	(-1.92)
insulation	-0.417**	-0.402*	-0.409*	
	(-2.10)	(-1.66)	(-1.81)	
int export res.	0.0566	0.240*	0.238*	
	(0.41)	(1.70)	(1.70)	
reg trade	-0.858***	-0.880***	-0.926***	
	(-3.94)	(-3.66)	(-3.66)	
M1	0.141	0.327*	0.302*	0.305
	(0.61)	(1.78)	(1.88)	(1.55)
vol exchange rate	0.0169	0.0301	0.0380	0.0397
	(0.54)	(1.14)	(1.59)	(1.23)
market institutions	-0.956***			-1.23***
	(-2.77)			(-3.74)
WGI	0.115	0.0617		-0.0104
	(1.18)	(0.61)		(-0.14)
N	996	1270	1323	1020
N groups	140	155	157	144
N instruments	67	72	72	46
AR(2)	0.397	0.994	0.828	0.736
Sargan Test	0.171	0.015	0.388	0.000
Hansen Test	0.664	0.428	0.570	0.022
Diff.Sargan(gmm)	0.792	0.601	0.124	0.164

t statistics in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; Note: stocks, reg trade, and insulation are treated as endogenous, production is considered to be predetermined. Regressions use orthogonal deviations instead of first differences as instruments. Years are included as exogenous instruments.

to have an impact on international prices and volatility, but domestic policies of importers can compensate for this effect. On this account it is possible to conclude that national food crises in 2007/2008 and 2011 were driven by the transmission of international food prices into national markets, instead of absent availability at international markets.

Lastly, the impact of the lagged dependent variable is positively significant at the one percent level with a magnitude between 0.25 and 0.35 across specifications. This implies high persistence of domestic food price volatility. Due to the inclusion of the lagged dependent variable, long run effects of other explanatory variables are obtained by dividing the respective estimated coefficient by one minus the autoregressive parameter.[18] Hence, long term effects exceed short term effects by approximately 45 percent. A detailed overview on short and long run impacts is given in Table 4.6. Significance of variables alone is not much enlightening with respect to their relevance on food price volatility. Therefore, and to improve readability, explanatory variables are shocked by one standard deviation. This is equivalent to normalizing a variable by diving it by its standard deviation. In doing so, the relative importance of each explanatory variable can be assessed. The procedure is very similar to standardized coefficients but yields a more intuitively interpetable number.

The percentages given in Table 4.6 are to be interpreted as the change in domestic price volatility if the explanatory variable of interest changes by one standard deviation. Accordingly, marginal effects of stocks and share of regional trade are considerably higher than for all other explanatory variables, while the effect of regional trade is more stable across specifications. Impacts of international prices, market institutions, and insulation policies are of medium magnitude, but robust across specifications. Changes in national production, money supply, and export restriction of trading partners have relatively little consequences on domestic volatility. Worth to note, an increase (decrease) of explanatory variables by standard deviation may not be equally realistic. On the other hand, it is difficult to a priori determine a realistic variation in explanatory variables. Thus, the estimated marginal effects should be interpreted with the usual caution.

Table 4.6: Relative importance of explanatory variables

	short term		long term	
	min	max	min	max
vol int price	17%	22%	25%	32%
production	-2%	-7%	-4%	-10%
stocks	-22%	-48%	-33%	-70%
insulation	-14%	-15%	-21%	-22%

Continued on next page...

[18] $\gamma/(1-\beta)$.

... Table 4.6 continued

	short term		long term	
	min	max	min	max
int export res.	1%	4%	1%	5%
reg trade	-35%	-38%	-51%	-55%
M1	2%	5%	3%	7%
market institutions	-17%	-22%	-25%	-32%

Note: The autoregressive term is averaged across the four specifications which yields $\beta = 0.3135$. Min and max represent minimum and maxium value of specifications shown in Table 4.5.

4.6.3 Heterogeneity across countries

The impacts of some explanatory variables are suspected to be highly non-linear. Therefore, the regressions are performed for subsets of the full data set to test for differences resulting from trade status and public market intervention through price stabilization programs. Specifications chosen are synonymous to (1) and (2) from Table 4.5, but exclude insulation and international export restrictions for importers and non-importers, respectively. The results with respect to trade status are presented in Table 4.7. Table 4.8 concentrates on differences in results of public intervention through price stabilization programs.

First, results with regard to trade status are discussed. Lagged domestic price volatility is positive and significant in all specification in Table 4.7 with no notable difference in the size of the effect. Similarly, international price volatility remains strongly significant at the one percent for all types of countries. Yet the coefficient for importers is almost twice the size of the one for non-importers. Hence, the rise of international price volatility hits importers particularly hard, since almost 50 percent of the volatility is transmitted to domestic markets. Heterogeneity in the magnitude of volatility spill-overs is also evident in Rapsomanikis and Mugera [2011] who use BEKK conditional variance models for several countries. Besides, market institutions remain highly significant with a greater impact in countries with limited integration in international markets.

The segmentation of the data set yields to the insignificance of production shocks for all countries. This is in line with the literature on international price volatility which finds

TABLE 4.7: Regression results by trade status

	importer		non-importer		trade switcher	
	(1)	(2)	(3)	(4)	(5)	(6)
L.vol dom price	0.244**	0.340***	0.215***	0.352***	0.232***	0.386***
	(2.47)	(3.00)	(3.60)	(4.97)	(3.54)	(5.59)
vol int price	0.437***	0.420***	0.268***	0.271***	0.261***	0.270***
	(4.43)	(4.91)	(6.72)	(5.50)	(4.45)	(4.81)
production	-0.0817	-0.113	0.0529	-0.0805	0.0203	-0.0269
	(-1.00)	(-1.27)	(0.43)	(-0.65)	(0.11)	(-0.20)
stocks	-2.091	-3.497**	-0.623*	-1.530***	-0.832	-1.599**
	(-1.38)	(-2.49)	(-1.78)	(-3.31)	(-0.76)	(-2.61)
insulation			-0.413**	-0.370*	-0.393*	-0.459*
			(-2.24)	(-1.97)	(-1.70)	(-1.95)
int expo res.	-0.213	-0.0286			-0.105	0.0475
	(-0.37)	(-0.06)			(-0.83)	(0.29)
reg trade	-0.763***	-0.713*	-0.797***	-0.631***	-0.503***	-0.737***
	(-3.09)	(-1.87)	(-4.41)	(-2.68)	(-2.86)	(-3.08)
M1	0.421	0.504	-0.249	0.0367	0.108	0.145
	(1.10)	(1.46)	(-1.11)	(0.19)	(0.35)	(0.77)
vol exchange r.	0.000890	0.0129	0.0571*	0.0504	0.0588	0.0340
	(0.02)	(0.38)	(1.95)	(1.50)	(1.52)	(1.17)
market instit.	-0.844*		-0.978***		-1.44***	
	(-1.75)		(-3.42)		(-3.30)	
WGI	-0.0973	-0.297	0.224**	0.183*	0.0833	0.104
	(-0.47)	(-1.43)	(2.17)	(1.75)	(0.70)	(0.84)
N	429	561	567	709	420	533
N groups	65	73	75	82	55	81
N instruments	57	61	66	71	67	72
AR (2)	0.346	0.061	0.091	0.178	0.149	0.224
Sargan Test	0.139	0.091	0.082	0.003	0.364	0.001
Hansen Test	0.364	0.201	0.724	0.428	0.894	0.837
Diff.Sargan(gmm)	0.797	0.610	0.939	0.746	0.979	0.990

t statistics in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; Note: stocks, reg trade, and insulation are treated as endogenous, production is considered to be predetermined. Regressions use orthogonal deviations instead of first differences as instruments. Years are included as exogenous instruments.

production to be a driver of inter-annual rather than intra-annual volatility [Ott, 2014b]. On the contrary, the stock-to-use ratio remains significant in the specification without market institutions. Interestingly, the price stabilizing effect of stocks is much higher in importing countries, while the effect for exporters and trade-switchers has the same magnitude. The gap between importers and non-importers may be caused by the inability of importers to effectively manage price stability through trade because imports are indispensable to satisfy consumption needs.

With respect to regional trade integration, no difference between different types of countries can be observed, while the effects remain significant and at similar relevance as compared to the full model. Export restriction of trading partners are not significant, possibly due to the reduction in the number of observations. Lastly, exporters and trade-switchers successfully stabilize domestic prices through export regulations. This is in line with the state of research regarding insulation policies. While Martin and Anderson [2012] base their conclusions on theoretical consideration on the formation of prices and transmission mechanisms as well as changes in nominal assistance coefficients, here the impact on price volatility is directly observed. Hence, the findings provide empirical evidence for the predictions with regard to welfare impacts of importing and exporting countries made by Martin and Anderson [2012]. Moreover, price stabilizing effects are also found for trade-switching countries which contradictsPorteous [2012] who finds no positive effect of insulation policies for regional exporters in Africa.

Variability in the USD exchange rate and growth rate of money supply are both insignificant in all but one specification. WGI is significantly positively associated with price volatility for non-importers only. Counter-intuitively, the sign implies that better governance increases volatility. Since the coefficient is positive and significant only in the specifications for non-importers, this should not be attached with great importance.

Among countries with high public market intervention, the coefficient of lagged domestic volatility is roughly 0.1 greater than in any other specification. It implies higher persistence of volatility with public storage. This is theoretically convincing because additional storage enhances autocorrelation of commodity prices. The impact of international volatility remains at similar size.

Stocks are more important in determining domestic price dynamics for low intervention countries than for high intervention countries. Production is insignificant for both types of countries, albeit the effect of production changes is close to reach significance for low intervention countries. Regional market integration is significant across all specifications, but the effect is considerably larger for low intervention countries. Furthermore, export restrictions of main trading partners and money growth rate are significant with the expected sign in specification (2) of Table 4.8. Lastly, the coefficient for market institutions is significantly

Table 4.8: Regression results by level of public intervention

	low intervention		high intervention	
	(1)	(2)	(3)	(4)
L.vol dom price	0.228***	0.370***	0.356***	0.439***
	(3.29)	(4.97)	(3.35)	(4.17)
vol int price	0.351***	0.293***	0.281***	0.283***
	(4.78)	(4.12)	(6.95)	(3.88)
production	-0.0712	-0.137	0.0144	0.0159
	(-1.16)	(-1.43)	(0.08)	(0.09)
stocks	-0.781	-1.982**	-0.556	-1.252*
	(-1.31)	(-2.42)	(-0.84)	(-1.68)
insulation	-0.620***	-0.526*	-0.217	-0.266
	(-2.66)	(-1.88)	(-1.41)	(-1.16)
int exp res	0.146	0.338*	-0.235	-0.00492
	(0.74)	(1.95)	(-0.86)	(-0.01)
reg trade	-0.741***	-1.049***	-0.639**	-0.607**
	(-3.18)	(-5.04)	(-2.03)	(-2.30)
M1	0.354	0.449**	-1.14*	-0.224
	(1.39)	(2.15)	(-1.72)	(-0.71)
vol exchange rate	0.0257	0.0309	0.00479	0.0124
	(0.59)	(0.80)	(0.16)	(0.26)
market institutions	-1.19***		-0.723**	
	(-3.04)		(-2.64)	
WGI	0.00500	-0.0178	0.210	0.224
	(0.04)	(-0.17)	(1.32)	(0.89)
N	673	876	323	394
N groups	75	82	55	61
N instruments	66	71	67	72
AR(2)	0.091	0.178	0.149	0.224
Sargan Test	0.082	0.003	0.364	0.001
Hansen Test	0.724	0.428	0.894	0.897
Diff.Sargan(gmm)	0.939	0.746	0.977	0.990

t statistics in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; Note: stocks, reg trade, and insulation are treated as endogenous, production is considered to be predetermined. Regressions use orthogonal deviations instead of first differences as instruments. Years are included as exogenous instruments.

greater in the specification for low intervention countries. All these differences take the same line. Market forces, such as supply and demand, market integration, and institutional quality are of less importance in a system in which governmental institutions dominate and affect private sector decision making.

Furthermore, export regulations are significant for low intervention countries only. A possible explanation is that countries with public storage generally control exports in order to prevent the outflow of subsidized stock releases. Conversely, high intervention countries like India, Thailand, and Vietnam restricted exports to successfully accomplish isolation from international markets. Exchange rate volatility and governance are not significant in any specification.

In the last part of the empirical analysis, it is aimed at testing whether a portion of the country-crop fixed effect can be attributed to time-invariant country characteristics. Again, the focus lies on trade status and public intervention. Table 4.9 depicts a priori differences in volatility without controlling for further explanatory variables and differences in residuals after controlling for explanatory variables. The residuals of the system GMM estimation are obtained by subtracting the fitted values from the actual volatility values. From this, high intervention countries have lower volatility than countries without intervention only before controlling for observable counterfactuals. With regard to trade status, importers seem to exhibit lower volatility as compared to exporters and trade-switchers. This does not change after controlling for other explanatory variables.

Yet mean comparison alone is not sufficient to conclude on these differences. Causality is established only when the effect is properly identified. Following the two-step estimation procedure described above, estimation errors are regressed on the time-invariant dummy variables by 2SLS. Importantly, the estimation requires relevant instruments that are not correlated with the country-crop fixed effects. As possible instruments geographical variables are discussed in the literature [Cinyabuguma and Putterman, 2011]. On the other hand, it is also possible that geographical characteristics implicitly determine parts of the fixed effect through agro-ecological country characteristics.

Table 4.9: Volatility by country characteristics

	sd return				e_{ijt}			
	yes		no		yes		no	
	mean	median	mean	median	median	median	mean	median
high interv.	6.0%	4.1%	8.9%	6.0%	-0.022	-0.007	-0.050	-0.029
importer	8.3%	4.6%	7.9%	6.4%	-0.189	-0.180	0.071	0.058
exporter	8.5%	6.6%	8.1%	5.4%	0.167	0.138	-0.077	-0.067
trade-swit.	7.7%	6.2%	8.3%	4.9%	0.037	0.029	-0.098	-0.085

Note: The standard deviation of returns was logarithmized for the regression.

Three external instruments for high intervention are identified: per capita gdp, financial freedom, and the share of rural population.[19] It is assumed that they are not correlated with the country-crop fixed effect, but strongly correlated with the endogenous variable.[20] The relevance of the instruments is revealed by the first stage of the 2SLS regression in which the endogenous variable is regressed on its instruments. The results are presented in Table 4.10.

Table 4.11 shows the results of the second stage. Geographical variables are included and treated as exogenous in specifications (3)-(5). But results change when they are also instrumentalized by the available instruments as in specifications (6)-(8). For the sake of comparison, specification (1) presents a simple OLS regression. A conclusive assessment of the impact of geographical variables is not feasible. The coefficient for high intervention is positive in each specification with values between 0.1 to 0.6 which is equivalent to a marginal effect between 10 and 80 percent.[21] Significance at usual levels of significance is only found in specifications with an exogenous treatment of geographical dummies.[22]

More importantly, no evidence can be found that intervention is associated with lower price volatility. Does this mean public intervention should stop immediately? No. But

[19] Per capita gdp and share of rural population are part of the WDI. Financial freedom is an indicator generated by the Fraser Institute.

[20] An instrument is always disputable. The correlation between residuals and instruments was tested and found to be -0.0066, -0.0495, and 0.0143, for gdp financial freedom, and share of rural population, respectively. Nevertheless, the instruments can be correlated with the fixed effects. One can only argue that inherent or natural volatility is independent from the instruments, instead it is rather correlated with geographical and climate conditions.

[21] In a semi-log functional for the marginal effect of a dummy variable is equal to $e^{\beta} - 1$.

[22] But estimates are significant at 15 percent in specification (1)(7)(8).

TABLE 4.10: First stage regression results for IV estimation

	(1)
	high intervention
per capita gdp	0.0000503***
	(8.49)
financial freedom	-0.00498***
	(-6.48)
share of rural population	0.00872***
	(11.13)
_cons	-0.0770
	(-1.05)
N	1664

t statistics in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

it gives indication that stocks decrease volatility, not intervention. This is consistent with empirical evidence that market liberalization, implying the absence of public storage or similar intervention tools, reduces price volatility [Shively, 1996; Chavas and Kim, 2006]. This is attributed to the unpredictability of interventionist policy actions [Maitre d'Hotel et al., 2015; Gouel, 2013c]. On the other hand, positive effects on the level of stocks through public storage need to be considered and weighed against against the costs of intervention. A possibility could be to implement market friendly policies that encourage private storage without creating additional risk for private businesses.

External instruments could be found only for high intervention. GDP, financial freedom, and share of rural population are not relevant for importers, exporters, or trade-switchers. Thus, the discussion needs to be based on Table 4.9. But differences are also conclusive. Importers exhibit lower intra-year price volatility since supply is less concentrated within the year due to constant imports. In contrast, exporters and trade-switchers mostly rely on seasonal supply which leads to strong intra-year price variation.

Table 4.11: Results for two step IV estimation on residuals for high market intervention

	OLS	2SLS - IV						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
africa	0.129*			0.0706			-0.0870	
	(1.78)			(1.06)			(-0.31)	
landlocked	-0.0536		-0.148**	-0.0818	-0.0545	-0.0277	-0.0410	-0.0456
	(-0.90)		(-2.01)	(-1.31)	(-0.93)	(-0.07)	(-0.11)	(-0.13)
latin	0.141				0.156			0.104
	(1.62)				(1.62)			(0.31)
high_intervention	0.0902	0.208	0.602*	0.191	0.516*	0.0373	0.382	0.453
	(1.54)	(1.30)	(1.93)	(1.27)	(1.96)	(0.03)	(1.57)	(1.49)
asia			-0.435**			0.490		
			(-2.32)			(0.31)		
_cons	-0.149**	-0.105*	-0.0892	-0.104	-0.209**	-0.124	-0.0859	-0.181
	(-2.14)	(-1.83)	(-1.40)	(-1.35)	(-2.02)	(-1.29)	(-0.92)	(-0.71)
N	892	991	888	888	888	888	888	888
N instruments	-	3	3	3	3	3	3	3
Underidentification Test	-	0.0000	0.0000	0.0000	0.0000	0.1359	0.0000	0.0000
Sargan Test	-	0.9672	0.5113	0.3863	0.8035	-	-	-

t statistics in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; Note: (3),(4), and (5) treat geographical variables as exogenous to the fixed effect. (6),(7), and (8) treat them as endogenous. All regressions apply robust standard errors.

4.7 Conclusion

This chapter discusses the determinants of food price volatility and fills a gap in the literature with respect to the empirical evidence from developing countries. The study employs a comprehensive data set with great country coverage across Africa, Asia, and Latin America.

The empirical model chosen is a dynamic panel estimated by system GMM. The significant coefficient of lagged price volatility confirms the choice of the model to account for persistence of volatility. A great number of instruments can lead to overidentification of endogenous variables and distort common test statistics. For this reason, the number of instruments was limited and the exclusion restriction was successfully accepted.

The regression results support evidence that international price volatility strongly influence domestic volatility. The estimate is in line with existing studies using a similar approach [Lee and Park, 2013; Pierre et al., 2014], but do not account for heterogeneity across countries. Furthermore, institutional quality of agricultural markets positively affects price stability. Among internal drivers, stocks and change in production significantly impact on volatility. An increase in the stocks-to-use ratio by one percent reduces price variability by 2.5 percent. The effect of production is weak and appears to be less robust across specifications.

Most insightful are the findings with respect to trade policies and regional integration. Using a unique data set on bilateral trade agreements, regional trade appears to have a dominant role in stabilizing national food prices across all types of countries. This contributes to the literature that emphasizes the positive effect of regional integration on trade flows and trade policy volatility [Cadot et al., 2009; Sun and Reed, 2010; Mujahid and Kalkuhl, 2014]. From this, a clear policy recommendation towards regional market integration can be deduced.

Distinguishing by types of country provides striking results in multiple ways. First, volatility spillovers from international to domestic markets are almost twice as large for importers as compared to exporters and trade-switchers. Second, insulation policies are found to be a successful price stabilization tool not only for large exporting countries, but also for regional traders. Third, quality of market institution is particularly important in countries that are little involved in international trade. The price stabilizing effect of stocks is notably high in importing countries. Last, market forces, such as supply and demand, exhibit less impact on price volatility in countries that are characterized by public price stabilization programs.

Using a two-step estimation procedure to properly identify the effect of high public intervention, no positive effect on market stability is established. Considering the strong positive impact of stocks, a recommendation towards complete market liberalization should not be deduced. In many developing countries stock levels are below their social optimal level. In this instance, public storage is desirable. Alternatively, policies may be more effective when promoting private storage and trade without extensive interference in markets.

Chapter 5

Grain storage and trade - evidence from Ghana

5.1 Introduction

Grain markets in many African countries exhibit large price volatility which is driven by strong seasonality. Seasonal production and limited storage are identified as major causes for intra-annual price variation [Jones, 1972; Sahn and Delgado, 1989]. Price spikes often occur in consequence of stock-outs at the end of the marketing season [Shively, 2001; Osborne, 2004; Tadesse and Guttormsen, 2011]. The adverse consequences of seasonal hunger and poverty are well accepted and functioning of markets is recognized as a prerequisite to their resolution [Payne, 1989; Vaitla et al., 2009; Maxwell, 2013].

Structures and efficiency of markets improved since the liberalization process in the 1980s. But, the price surges and international food crisis in 2007/2008 brought grain marketing and public intervention back on the agenda of policy makers around the world [Vaitla et al., 2009; Kaminski et al., 2014]. This is partly driven by the lack of confidence in free markets and competitive behavior of traders [Osborne, 2005; Sitko and Jayne, 2014] and a growing fear for the political economy of food prices [Arezki and Brückner, 2011; Brückner and Ciccone, 2011]. Governmental intervention in form of price stabilization programs and trade policies are often made without profound knowledge of the marketing system. "Under these circumstances, interventions [are likely] to impair the functioning of the system more than" they improve it [Jones, 1972, p.4]. Thus, evidence based research is indispensable to endow policy makers with adequate information in order to design agricultural policies to successfully enhance food security.

In this study, Ghana is chosen as a case country as it is a typical developing country in many respects. It has made considerable progress in poverty alleviation and the fight against hunger over the past 20 years. Regardless, price volatility remains among the highest in the world and seasonal food insecurity is prevailing in large parts of the country, especially the north [Quaye, 2009]. On the other hand, markets are at the crossroads. Wheat and rice imports gain importance with a growing free-spending middle class. Poultry and fish farming as well as increasing demand for processed food items shift market shares towards the industrialized food sector. These changes will undoubtably impact on the traditional marketing system.

The empirical literature on grain markets in Ghana is segmented. On the one hand, time series econometrics approaches are used to explain dynamics and variability of wholesale market prices [Alderman and Shively, 1996; Shively, 1996, 2001] and spatial market integration [Badiane and Shively, 1998; Abdulai, 2000]. All studies focus on maize, the most important domestic crop. And on the other hand, survey-data-based market analyses stressing the role of the various actors of the value chain. Much of these studies are of qualitative nature and give insights on marketing channels, spatial trade patterns, and transaction costs [Alderman, 1992a; Armah and Asante, 2006].

None of the existing studies examines storage behavior of large wholesale traders and national seasonal stocking trends, which is the main objective of this chapter. This is of particular importance since wholesale traders play the key role to guarantee sufficient supply throughout the whole year. The present work fills this gap in the literature based on primary data collected from July to November 2013. This contains quantitative data from a survey among wholesale traders with significant storage capacity on their operation in spatial trade and inter-temporal storage. Qualitative interviews were conducted with processing companies, market experts, and further relevant stakeholders. The analysis is enriched by wholesale prices from major trading centers, information from a literature review of governmental and scientific publications, and secondary data from the Ghana Living Standard Survey (GLSS). The information is put into context and policy implications are deduced.

The analysis is structured as follows. First, section two provides a brief introduction on the case country Ghana and its agricultural sector. This includes a description of the present policy environment and of the agricultural value chain and its most important actors. Then, grain price trends are outlined and reviewed by reference to the existing literature. Section four starts by describing the primary data collection and the sample. Subsequently, motives for stockholding are discussed and theoretically underpinned with reference to the empirical literature and the data. Furthermore, the survey data is exploited by differentiating between aggregated results and individual trading strategies. Section five concludes.

5.2 Background on Ghana

Ghana is a West African country with a coastal line on the Atlantic Ocean. As a former British colony, it became Africa's first country gain independence in 1957. After a period of several military coups in the 1960s and 1970s, Ghana became politically stable and is nowadays considered as one of Africa's lighthouse examples for good governance and democracy.

With a population of approximately 25 million, Ghana is the second largest country of the regional political and economic zone: Economic Community of West African States (ECOWAS). The economy is largely based on agriculture and services with a small industrial sector. Major export goods are gold, timber, cocoa, and recently oil and gas. The southern part of Ghana is characterized by coastal savanna, forest, and forest-savanna transition agroecological zones where high agricultural productivity is utilized to cultivate high value cash crops.[1]

In Ghana, agriculture is a main determinant of people's livelihood and an important source of income for a large share of the population [ISSER, 2013]. Ghana relies on foodgrain imports (rice and wheat) to satisfy domestic consumption. Agricultural markets are organized similarly and perform alike markets in many other African countries. This includes that only a small portion of total production is actually marketed or formally traded. Moreover, the Ghanaian government responded to the 2007/2008 food crisis by changing trade regulations and the establishment of the National Food Buffer Stock Company (NAFCO) which involves in purchasing and selling of staple foods. For these reasons, Ghana is considered to be a good case to be studied and many aspects analyzed are transferable to other African countries.

[1] http://www.apipnm.org/swlwpnr/reports/u_g/g.htm.

5.2.1 Demand and supply patterns

Different to many other developing countries, in particular in eastern and southern Africa, the staple diet in Ghana is diverse. Despite high consumption of roots and tubers, grains represent an important source of caloric intake (26.6 percent) especially in urban centers. Looking at the change over time (Table 5.1), most notably, rice and wheat consumption have increased over the past 20 years. Both are not traditionally grown in West Africa.

Table 5.1: Per capita consumption of selected food groups

	kg/capita/year					kcal/capita/day
commodity	1990	1995	2000	2005	2010	2010
Roots and tubers	245.3	247.5	249.7	234.8	242.0	1143(38%)
Cassava	148.0	149.7	151.4	152.9	154.0	639
Yam	43.3	42.8	42.3	41.9	50.0	401
Cocoyam	54.0	55.0	56.0	40.0	38.0	
Plantain	83.0	83.5	84.0	84.8	85.0	320(10.1%)
Cereals	68.0	78.6	88.8	83.4	92	791(26.6%)
Maize	40.3	41.4	42.5	43.8	45.0	250
Rice(milled)	13.3	13.9	14.5	15.1	24.0	292
Millet	5.1	12.6	9.0	6.4	5.0	54
Sorghum	9.3	21.7	14.8	10.1	5.0	71
Wheat	-	-	8.0	8.0	13.0	124
Fish	23.6	24.2	27.0	30.2	31.0	51(1.7%)
Meat	8.0	6.3	6.7	7.1	11.8	49(1.6%)

Source: MoFA [2013]; FAO [2014].

Consumption patterns vary across income groups, regions, and between urban and rural setting. So, rice and wheat are mostly consumed by well-off households. Conversely, sorghum and millet are a more important part of the diet in the three northern regions which are characterized by lower income levels [Minot and Dewina, 2013]. Maize is the only grain consumed by all income groups and across the whole country at fairly similar levels [Cudjoe et al., 2010].

Table 5.2: Grain production in Ghana by region

	maize		rice		sorghum		millet	
	2011	2012	2011	2012	2011	2012	2011	2012
Western	71.3	82.8	23.1	25.5	-	-	-	-
Central	202.4	192.1	5.4	3.2	-	-	-	-
Eastern	364.4	405.4	22.3	24.6	-	-	-	-
Greater Accra	4.5	4.7	18.8	0.8	-	-	-	-
Volta	97.9	84.9	75.4	82.5	-	-	5.3	5.4
Ashanti	173.7	205.4	27.6	27.7	-	-	-	-
Brong-Ahafo	434.7	570.3	6.2	6.3	-	-	0.7	0.8
Northern	192.6	209.4	171.3	165.3	79.3	80.5	130.6	126.4
Upper East	75.3	65.8	109.5	120.2	50.5	51.3	69.5	58.6
Upper West	82.7	129.1	6.5	7.0	54.3	47.9	80.8	88.7
Total	1699.5	1949.9	466.1	463.1	184.1	179.7	286.9	279.9

Source: MoFA [2013].

Note: In 1000 mt.

Agriculture production has kept the pace with increasing food demand, the result of high population growth. This was achieved by both increasing agricultural productivity and expansion of area under cultivation [FAO, 2014].

Maize

Maize is grown by 35 up to almost 50 percent of Ghanaian farmers [Chapoto et al., 2014]. Production is rainfed, and therefore varies largely between years. The main production area is the middle belt with Brong-Ahafo and Ashanti (see Table 5.2). In the coastal and forestry zones the climate enables two harvests per year, the major in July/August and the minor in November/December. In contrast, in the Guinea Savannah Zone in the north the only harvest takes place in October/November. Post harvest losses are reported to be as high as 40 percent in the south during the first harvest when the dry season has not started [ZEF-ISSER Trader Survey, 2013]. The reason is that storage is advisable only if the moisture content is below 13 percent [WABS Consulting Ltd., 2008].

Overall, Ghana is almost self-sufficient in maize with time-varying imports depending on the quantity of the annual crop. In addition to that, yellow maize is imported for feed use. Official inter-regional trade is generally low [Keyser, 2013], however, traders report substantial trade flows with other Sahel countries on an irregular base [ZEF-ISSER Trader Survey, 2013].[2]

Consumption of maize is relatively stable, although production is increasing over-proportionally. The reason is that maize is the primary fodder for poultry whose population has almost doubled since 2000 [MoFA, 2013]. Apart from direct human consumption and feed use, maize is increasingly processed and sold as final consumer good with two big players in the market: Premium Foods Limited and Nestle Ghana Limited.

Data on annual carry-over stocks is limited and difficult to verify since it is constructed from annual food balance sheets based on supply and demand estimates. USDA has reported zero stocks until 2003, while FAO CBS states very low stocks before 2003. The trend for stocks for FAO CBS is increasing as depicted in Figure 5.1. Unlike FAO CBS, USDA assumes maize stocks until 2007 to be substantially higher, while the estimates converge in recent years.

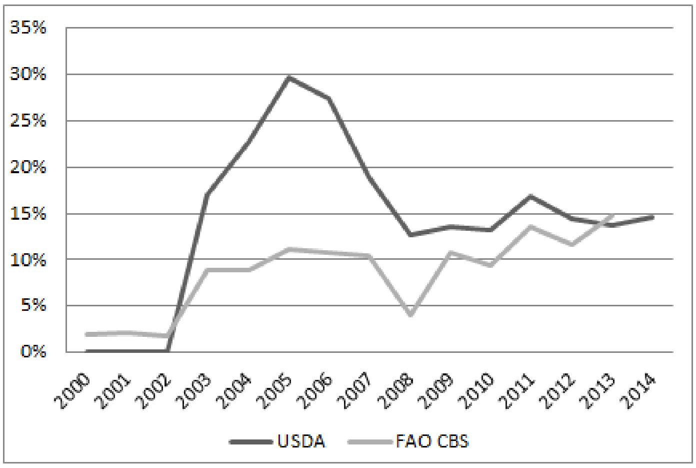

Figure 5.1: Stock-to-use ratio of maize by source

Source: USDA [2014]; FAO CBS [2014].

[2]Traders reported that Malian, Burkinabe, and Nigerien traders purchase when crops in their countries are insufficient.

Sorghum/Millet

In total, less than 10 percent of Ghanaian farmers grow sorghum or millet [Chapoto et al., 2014]. With rare exemptions, they are located in the three northern regions (Northern Region, Upper East, and Upper West). The only harvest takes place from September to December. Production and overall importance for food security has decreased within recent year. Both, sorghum and millet are not extensively traded internationally and sub-regionally.

Consumption of sorghum and millet is mainly in form of *tuo zaafi*, a pulp-like dough ball, in the northern parts of Ghana. Furthermore, they are extensively used for brewery and less frequent for animal fodder. So, Guinness Ghana Breweries established relationships with out-growers to facilitate sufficient domestic supply [Angelucci, 2013].

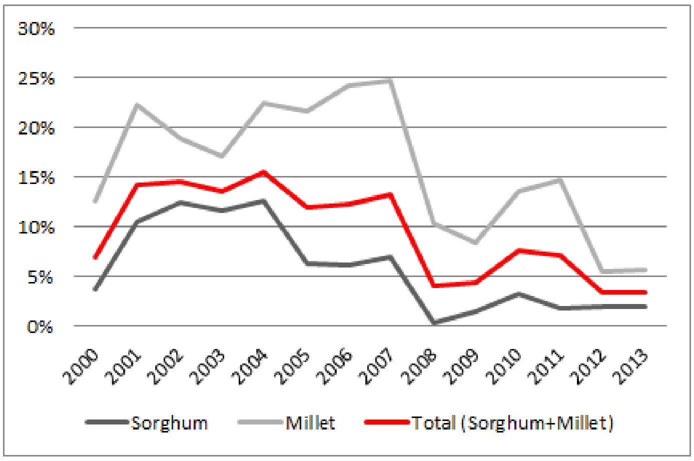

FIGURE 5.2: Stock-to-use ratio of sorghum and millet

Source: FAO CBS [2014]

Annual stock levels have been stable until 2007, and decreased afterwards (Figure 5.2). Stock-to-use ratios for sorghum and millet below 15 percent are not surprising considering the low share of production marketed.

Rice

According to Chapoto et al. [2014], rice is grown by about eight percent of small and medium scale farmers, but 15 percent of large scale farmers. Production is mostly rainfed with a few irrigation schemes in the Volta Region and northern Ghana. Consequently, these regions constitute the largest share to national production. Rainfed rice has similar harvesting patterns as millet and sorghum. With irrigation, two or three harvests per year are possible.

The contribution of national production to domestic consumption is roughly 30 percent [FAO CBS, 2014]. Most imports originate from Thailand followed by Vietnam and the United States [EAT, 2012]. Regional rice trade is limited since all countries of the region are net-importers. There have been several attempts to increase national rice production in order to achieve self sufficiency. The 2009 National Rice Development Strategy of MoFA aims at doubling domestic rice production by 2018. This shall be achieved through private sector investments and an expansion of irrigated areas. The quality of domestically grown varieties is reported to improve and local rice is considered to be able to compete with imports [ZEF-ISSER Trader Survey, 2013]. Larger companies see the potential and invest in milling factories.[3]

Rice consumption is estimated to continue growing at high levels [EAT, 2012]. International imports arrive in ready for sale bags at any available sizes. In contrast, local rice needs to be cleaned and milled before packaging. Therefore, formal traders prefer international products. Generally, the rice sector appears to be more formal than trading in maize, sorghum, and millet. It is dominated by large importing firms and wholesale companies that engage in a variety of products. This fact seems to be driven by the high demand for rice in the country.

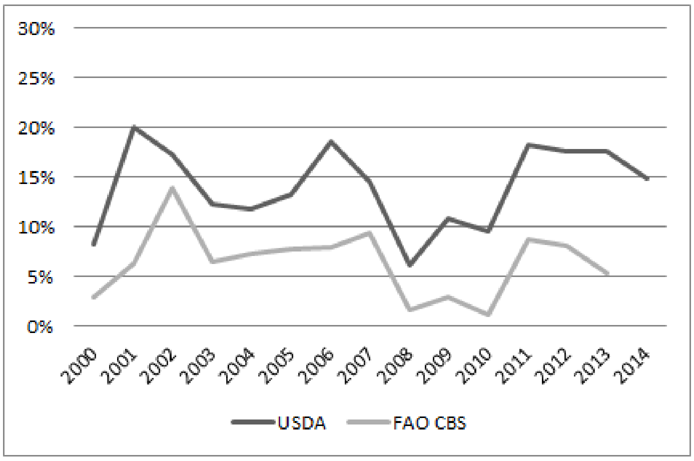

Figure 5.3: Stock-to-use ratio of rice by source

Source: USDA [2014]; FAO CBS [2014].

[3]For instance, Prairie Volta Limited and Avnash Industries Ghana Limited.

Stock-to-use ratios for rice according to FAO CBS [2014] and USDA [2014] are given in Figure 5.3. Stock data for rice should be substantially better than for other crops due to the formality the sector. The stock-to-use ratio of rice is only around five to 10 percent for most of the observation period looking at the data by FAO CBS [2014]. Estimates from USDA suggest stocks to be substantially higher with a stock-to-use ratio of averagely 15 percent. Both sources suggest very similar trends over the course of the last 15 years.

5.2.2 Macroeconomic and policy environment

As outlined above, the political situation in Ghana is very stable as compared to many African countries. Due to the membership in the regional free trade zone ECOWAS, commodity trade with neighboring countries is free of duties on paper. However, in reality, intra-regional trade is still associated with large transaction costs [Annequin and Eshun, 2010; Bromley and Foltz, 2011]. The common external tariff regime is not yet implemented causing large price differentials for imported rice between countries which promote cross border smuggeling. In Ghana, food commodities are charged with 20 percent import tax (10 percent for wheat), while the duty was suspended for rice in 2008 and 2009. In addition to that, port charges further increase the price of imports. Importation at required quantities is secured through sufficiently stable foreign reserves due to exports of oil, gold, timber, and cocoa.

Historically, Ghana's agricultural sector has been characterized by large state involvement.[4] The Ghana Food Distribution Corporation (GFDC) and Grain Warehousing Company (GWC) were established in 1971 and 1975 respectively [Sijm, 1997]. The main objective was to enhance storage and overcome deficiencies in the distribution system. The structural adjustment program, launched in 1983, involved liberalization of trade policies and foreign exchange, as well as a massive reduction of public market distortions. Thereby, the operations of GFDC were not touched on and its budget even increased [Coulter and Poulton, 2000]. However, GFDC has never substantially impacted on market prices due to its low market shares [Alderman, 1992a; Onumah and Coulter, 2000] and went essentially bankrupt in the early 2000s.

After a short period of market liberalization, NAFCO was founded in 2010 to manage the country's emergency and buffer stock. Before the beginning of the marketing year, NAFCO

[4]See Sijm [1997] for a comprehensive overview.

announces minimum prices for farmers and sets prices at which it buys from traders considering a specified margin. In case of interventions, purchases can be made at government storage facilities at subsidized prices. At the moment NAFCO reports following targets which cannot be verified by actual data:

Table 5.3: NAFCO stock levels

crop	intervention stocks	emergency stocks
maize	30,000 mt	10,000 mt
rice	15,000 mt	10,000 mt
soyabeans	1,000 mt	1,000 mt

Source: MoFA [2014].

Benin et al. [2012] review the operations of NAFCO without being able to assess its impacts on price dynamics. The main problem is the non-transparency of operational decisions by NAFCO. However, target stock levels represent a small portion of annual production, and thus NAFCO's purchase and release decisions are unlikely to influence markets. Unlike, the determination of the minimum guaranteed price has an impact on markets. So, farmers refused to sell early in the 2011/2012 marketing year since minimum prices exceeded the prevailing market prices [ZEF-ISSER Trader Survey, 2013]. Yet NAFCO warehouses were filled by that time and no purchases were undertaken. For this reason, farmers sat on their stocks refusing to sell them for lower prices to traders.

National policy interventions are specified in the strategic governmental document Food and Agricultural Sector Development Policy (FASDEP) and its revised version FASDEP II. The document serves to harmonize objectives and policy instruments and emphasizes the value chain approach to agricultural development. Besides the implementation of NAFCO, this includes a huge fertilizer program, mechanization of agriculture, and publicly owned block farms that cultivate food crops to satisfy public demand in prisons, schools, hospitals, and for the army. Both mechanization and fertilizer program are designed to improve agricultural productivity. Therefore, the impacts on trade and storage are limited.

In 2010, the Ghana Grains Council (GGC) was initiated by the private sector and donor organizations. Its aim is to improve the functioning of grain markets by granting market access to small scale farmers and implementing quality standards to foster industrialization of the food sector. Apart from poor physical infrastructure, both remain major obstacles to agricultural market development.

5.2.3 Trade patterns - the role of the traders

An extensive literature exists that comprehensively analyzes trade patterns and value chains in developing country grain markets (also in Ghana) including conceptualizing relationships between market actors in framework diagrams [Ruijs, 2002; Boone et al., 2008; EAT, 2012]. In brief, producers often face the challenge to access markets in order to sell their produce. From a recently conducted survey by IFPRI, it is evident that between 80 and 90 percent of all farmers sell to traders (Table 5.4). For small and medium size farmers, rural assemblers act as collectors who aggregate surpluses and sell on those to wholesalers in larger towns. Then, wholesale traders sell to processors, millers, retail traders, but also directly to consumers. In contrast, larger farmers tend to sell directly to wholesale traders. Since no value is added to the commodity in having multiple agents involved in the value chain, farmers earn higher profits when selling to wholesale trader directly [Sitko and Jayne, 2014].

Table 5.4: Total sales by buyer type (in %)

	Farmer category					
	small		medium		large	
	maize	rice	maize	rice	maize	rice
Small-scale trader	39.2	33.9	52.9	35.9	15.1	19.2
Large-scale trader/wholesaler	16.5	6.4	19.3	35.6	35.4	41.5
Retailer/marketer	36.4	44.9	22.3	22.7	26.9	31.7
Other households for consumption	0.2	0.5	0.1	0.0	0.0	1.4
Direct sale to NAFCO	1.7	1.1	0.2	0.0	0.5	0.0
Sale to NAFCO through an agent	0.3	0.0	0.2	0.1	4.9	0.0
Out grower	4.7	4.1	3.1	0.0	11.3	0.0
Processors	0.1	9.2	0.1	4.4	4.8	5.6
All other buyers	1.0	0.0	1.9	1.3	1.0	0.5

Source: Chapoto et al. [2014].

The literature acknowledges the role traders play to the functioning of markets in providing inputs and credits [Antons, 2010; Sitko and Jayne, 2014]. There is also little evidence for uncompetitive market structure in domestic grain trading in Ghana and other African countries [Alderman, 1992a; Abdulai, 2000; Swinnen et al., 2010; ACET, 2014]. It is to note that retailers in urban centers usually organize themselves into associations. In doing so market queens, the elected heads of this female retail trader groups, have manifested an influential contra-part to wholesale traders [Langyintuo, 2010].

The major challenge for long distance traders is to ship commodities from surplus regions in the middle belt and northern part of the country to consumption and industrial centers. High transportation costs have been identified as a major barrier to market integration [Badiane and Shively, 1998; Abdulai, 2000]. Table 5.5 summarizes distance between major wholesale markets, which are also discussed in Box 3, in terms of road distance and transportation time. Bad road infrastructure is indicated by long travel time for relatively short distance.

Table 5.5: Distance between wholesale markets in Ghana:

km/time	Accra	Kumasi	Mankesim	Techiman	Ejura	Tamale	Wa
Accra	-	4h14min	2h8min	6h38min	7h10min	11h58h	18h15min
Kumasi	248	-	5h9min	2h27min	3h35min	7h46min	13h57min
Mankesim	103	249	-	7h36min	8h44min	12h55min	19h6min
Techiman	365	118	367	-	1h34min	5h19min	11h30min
Ejura	322	91	340	81	-	6h54min	13h4min
Tamale	621	375	623	256	337	-	n.a.
Wa	648	439	687	321	402	n.a.	-

Source: Author's illustration using `http://www.viamichelin.de/web/Routenplaner`.

Against the well understood structure of the value chain, it is less researched how marketing and trade flows change in the course of the year. In other words, it is clear how grain finds its way from producers to consumers, however, little is known on how the grain gets from harvest to lean season. Precisely, who stores what amount at which time is unknown. Furthermore, the heterogeneity among wholesale traders is not well considered. For instance, Boone et al. [2008] classifies them into semi-wholesalers, wholesalers, and large-scale wholesalers. Instead, a classification according to their type of business activity into spatial and inter-temporal arbitragers appears to be more consistent. Thus, in this work it is preferred to use the terms aggregator, distributor, and speculator.

Box 3: Important wholesale markets in Ghana:

- Accra is the capital and the main consumption center in Ghana. It is located in the south close to the sea harbor in Tema.
- Kumasi is the second largest city in the country and capital of the most populous region Ashanti. Kumasi is just in the center of Ghana and accommodates milling industry. Most big trading companies own warehouses or run outlets in Kumasi.
- Mankesim lies on the important Accra-Cape Coast road in the Central Region. It is more or less a wholesale market for the surrounding high yield areas.
- Techiman is the main wholesale market for maize. It is located in Brong-Ahafo that produces most cereals and food crops. The main south-north road also passes Techiman.
- Ejura is the most important assembly market in the Ashanti Region and also close to Techiman.
- Tamale is the third largest city in the country and the economic center of the north. It is an important market for maize and the most important wholesale market for local rice, sorghum, and millet.
- Wa is the capital of the Upper West region. The roads towards Wa are bad and traveling time is immense. Therefore, the whole region is isolated from main trading activities.

To understand both spatial distribution and seasonal patterns of storage behavior, it is crucial to also examine the marketing behavior of farmers. The Ghana Living Standard Survey (GLSS) reveals valuable information on this. Without giving exact figures with regard to proportions, Figure 5.4 presents seasonality of farmers' maize sales according to the main sales month. From this, seasonality of sales is a prevailing pattern for all crops being smallest for maize. Knowing the time of harvest from Figure 5.5-5.7 (lower panel), the months after harvest are the time when most surpluses enter the market. From previous surveys [Armah and Asante, 2006; GSS, 2007; EAT, 2012] it is well known that only a portion of production is formally traded. Interestingly, the estimate that 50 percent of maize produce is formally traded by Alderman [1992b] from 1992 is still a reasonable figure in contemporaneous grain marketing [ACET, 2014]. Therefore, the share of stocks actually held by traders is presumed to be low [Jones, 1972; Alderman, 1992a]. In contrast, the increment of market purchase of farmers (upper panel: Figure 5.5-5.7) indicates that commodities must be stored somewhere to be sold back to farmers at the end of the marketing year.

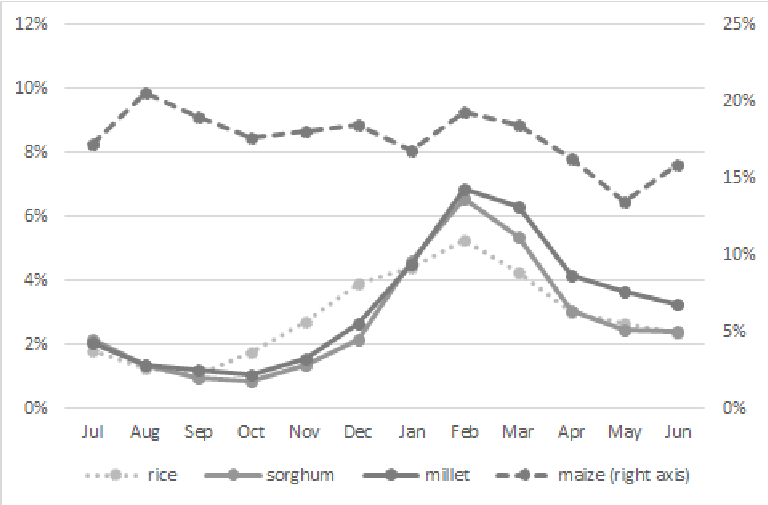

FIGURE 5.4: Main sales month of farmers (% of respondents)

Source: GSS [2007].

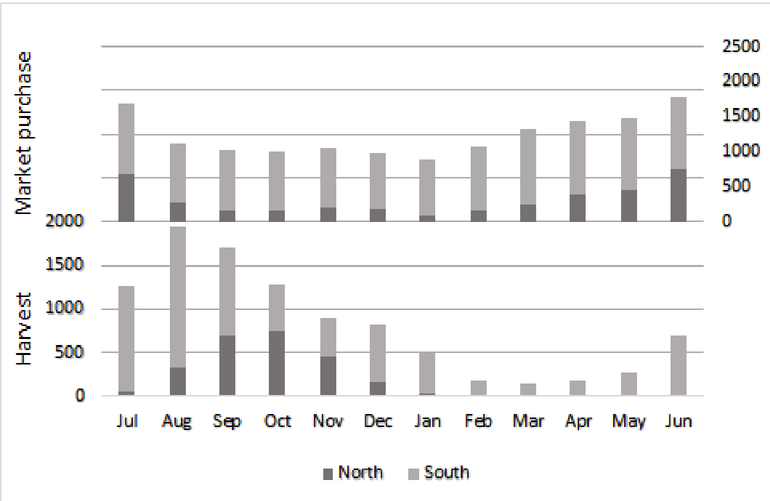

FIGURE 5.5: Seasonality of maize production and consumption (# of respondents)

Source: GSS [2007].

The distribution of imported rice differs substantially from marketing of locally produced

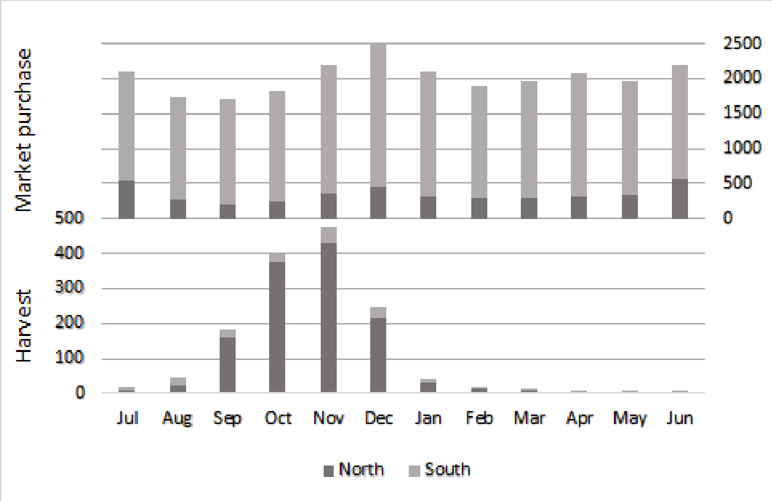

FIGURE 5.6: Seasonality of rice production and consumption (# of respondents)

Source: GSS [2007].

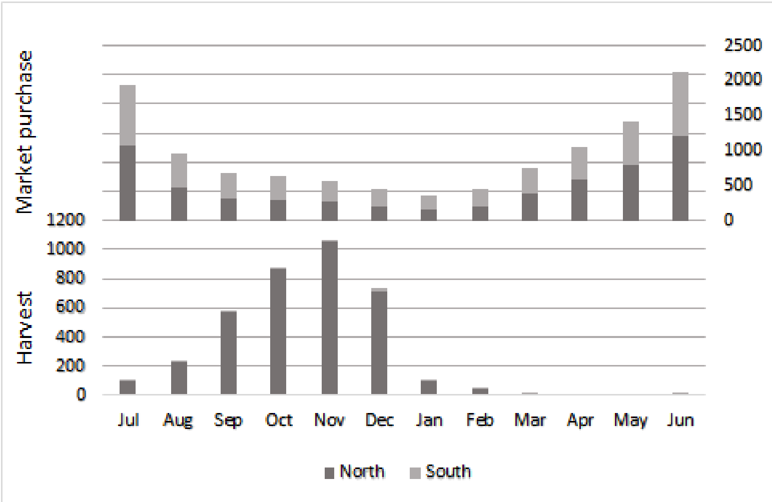

FIGURE 5.7: Seasonality of sorghum/millet production and consumption (# of respondents)

Source: GSS [2007].

crops. There are a few large importing companies who divide the majority of the market among themselves [Kula and Dormon, 2009]. They sell to wholesale traders and supermarkets around the country, but also run own outlet stores. Wholesalers in turn have a wide local distribution network.

Albeit the high relevance and great significance of research works from the beginning of the 1990s [Alderman and Shively, 1991; Alderman, 1992b,a], there are also massive changes happening. On the one hand, the introduction of modern telecommunication technologies strongly reduces transaction costs [Overa, 2006; Tack and Aker, 2014] and eases market access for farmers and small traders. On the other hand, food markets in Africa are becoming more and more industrialized. Supermarkets start to rise and request supply of processed final consumer goods. For this reason, processing companies increase their volume and take larger shares of marketed production. This has wide-ranging consequences for grain marketing. First, the industrialized sector prefers to realize purchases in large quantities in order to reduce transaction costs. Second, quality standards gain importance which presents challenges to proper handling by value chain actors. The trading sector is compelled to adjust to these developments.

5.3 Staple food price trends

Inflation is considered to be the major challenge to macroeconomic stability. After a short period of single-digit inflation, the growth rate of the consumer price index has returned to a level of above 10. In accordance with this, the Ghana Cedi (GHS) has depreciated greatly since 2013. The exchange rate is free-floating since 2006, while a redenomination was implemented in 2007 by canceling four digits (1 GHS = 10,000 Cedis). For this reason, the analysis of staple food price trends employs real prices deflated by the national consumer price index (CPI)(base year 2000). Due to data availability, wholesale prices from 2000 to 2014 are considered.

Maize

Figure 5.8 depicts relative wholesale prices of four major markets since 2000. Prices in all markets follow similar trends, while they are lowest in production areas and highest in the consumption centers Accra and Kumasi. Interestingly, only prices in Accra and Kumasi seem to follow an upward trend since the middle of the decade. Wholesale prices exhibit at least three major price spikes during the 14 year period (2005, 2008, and 2012). However, all spikes are only of transitory nature and persist for only one or two months. This hints at stock-outs at the end of the marketing year [Shively, 2001]. Furthermore, volatility decomposition by UCM as described in chapter two reveals strong seasonality with a range up to 60 per cent as illustrated in Figure 5.9. Strong seasonal price increases indicate insufficient storage to satisfy demand at the end of the marketing year.

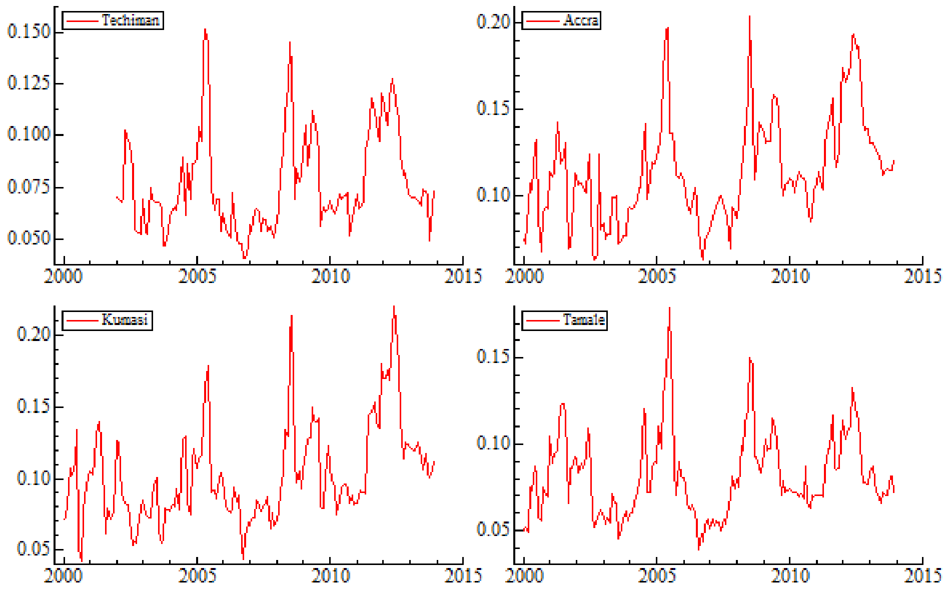

FIGURE 5.8: Deflated maize wholesale prices across markets (1kg)

Source: SRID [2014]; GSS [2014].

Apart from seasonality, prices are driven by annual domestic production levels and the prospect of speculative exports to neighboring countries [Shively, 1996]. Shively [1996] and Alderman and Shively [1996] analyze the impact of economic reforms on wholesale price levels and variability. Accordingly, price levels and volatility decreased after market reform in accordance with the structural adjustment programs in the 1980s.

The correlation between markets is above 0.8 with the exemption of Wa (0.6). Similar to this, regional market integration is considered to be quite high, but not complete [Abdulai, 2000; Cudjoe et al., 2010; Ankamah-Yeboah, 2012]. Abdulai [2000] extents conventional co-integration analysis by accounting for asymmetric price adjustment and finds evidence for faster price adjustment following price increases in the central market. Market integration also affects price variability with less integrated markets experiencing higher price variability [Badiane and Shively, 1998].

Less evidence exists on the relationship between international and domestic maize prices. Conforti [2004] finds no co-integration with the national wholesale price within the period from 1967 to 2001. In contrast, threshold co-integration results by Cudjoe et al. [2010] suggest transmission of world prices to domestic maize prices at small margins.

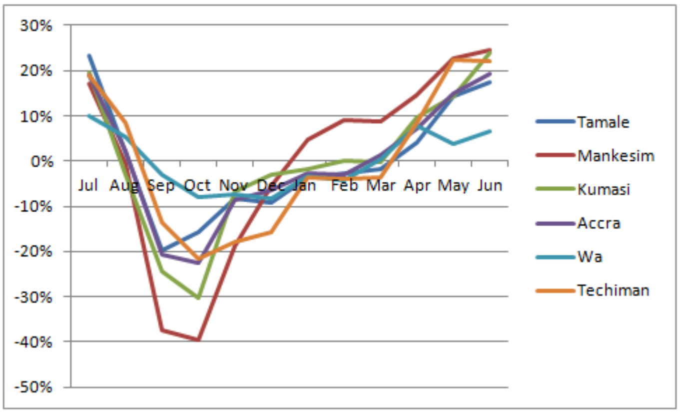

FIGURE 5.9: Seasonality of maize wholesale prices

Source: Author's computation based on SRID [2014].

Rice

Deflated wholesale prices of imported and local rice are illustrated in Figure 5.10. Per kilogram rice prices are substantially higher than for maize, sorghum, and millet. With rare exemptions, imported rice is more expensive than locally produced rice. The gap is smallest for the Accra market that is closest to the sea harbor in Tema, and thus exhibits the lowest share of transportation costs. Generally, the price of imported rice was stable until mid 2011 and has sharply increased afterwards. Conversely, local rice prices follow this trend only in Accra. The reason for the price surge is not a priori clear.[5] A couple of market conditions may have fueled the price development. First, increasing demand for both imported and domestic rice may have created under-supply in the market. Furthermore, an unexpected bad harvest at the end of 2010 and an increase of national petroleum prices in the course of 2011 [WFP, 2014] combined with a rapid depreciation of the Ghana Cedi. Alternatively, it is possible that the reinstatement of the import duty, which was abolished in 2008 and 2009, was only implemented in 2011. This, together with high market concentration among importing firms, may allow wholesale companies to pass price increases 1:1 to consumers [ACET, 2014].

Both prices of local and imported rice offers little indication for seasonal price patterns. This is caused by the dominating influence of imported rice prices on local rice price dynamics [Amanor-Boadu, 2012; Amikuzuno et al., 2013]. In this way, no annual price cycles, due to limited storage, are observable. Amikuzuno et al. [2013] argue that is not driven by direct transmission of price signals but by indirect effects on production decisions of farmers.

[5]Alternatively, Fearon [2013] argues that the 2012 general election may be responsible for misreporting of national inflation figures. So, nominal rather than relative prices raised.

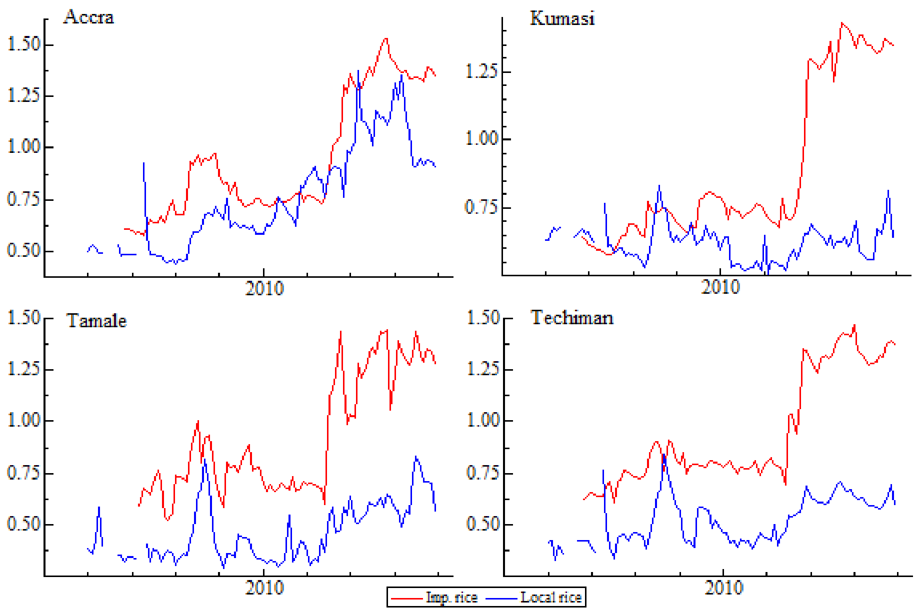

FIGURE 5.10: Deflated rice wholesale prices across markets (1kg)

Source: SRID [2014]; GSS [2014].

WFP [2014] finds correlation of local rice prices across markets to be less than for maize and cassava. Alderman and Shively [1991] argue that the reason is the high concentration of production areas. Against this, prices of imported rice are highly connected between markets ensuing from the south. Due to the high import dependency in rice, domestic markets are likely to be well integrated into world markets. Nevertheless, Minot [2011] establishes co-integration only for one out of seven market pairs, the only one being even local rice. Using threshold co-integration models, Cudjoe et al. [2010] find evidence for transmission of international prices. The mismatch of the result may be explained by a difference in the period of examination. Looking at the 2007/2008 food crisis, Ghana successfully protected domestic consumers through the suspension of the import duty.

Millet/Sorghum

Sorghum and millet prices follow very similar price patterns in all wholesale markets (see Figure 5.12). Real prices also show a positive trend throughout all markets, in particular after 2008. The reason could be increasing demand by the brewery industries within recent years. During the observation period, several price spikes can be identified, yet none of them being as sharp as spikes observed in maize prices. In addition, wholesale prices are at similar size in all markets. Interestingly, volatility decomposition for both sorghum and millet yields strong seasonal pattern only for Tamale, the market in the production area. In contrast, the seasonal range in the remaining markets varies between five and 10 percent. Although the harvesting season starts only in September, prices tend to increase in June already. Alderman [1993] finds this to be caused by cross commodity transmission. In this way, seasonality in rice and maize prices spill-over to sorghum and millet.

Empirical research on integration in millet and sorghum markets is limited. Simple correlation of prices shows very large coefficients across markets for millet (0.85-0.92) and slightly lower coefficients for sorghum (0.62-0.82). Strong market integration for sorghum is also confirmed by the analysis of Quaye and Ameleke [2008]. Due to limited international trade of sorghum and millet, price transmission from international markets is not likely.

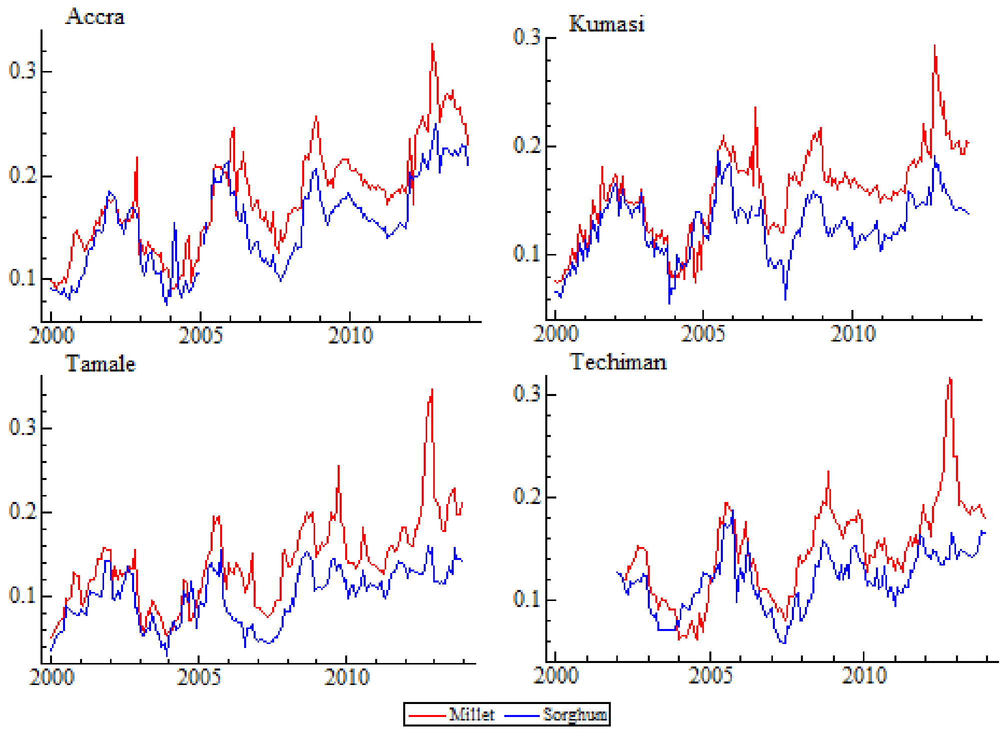

FIGURE 5.11: Deflated sorghum and millet wholesale prices across markets (1kg)

Source: SRID [2014]; GSS [2014].

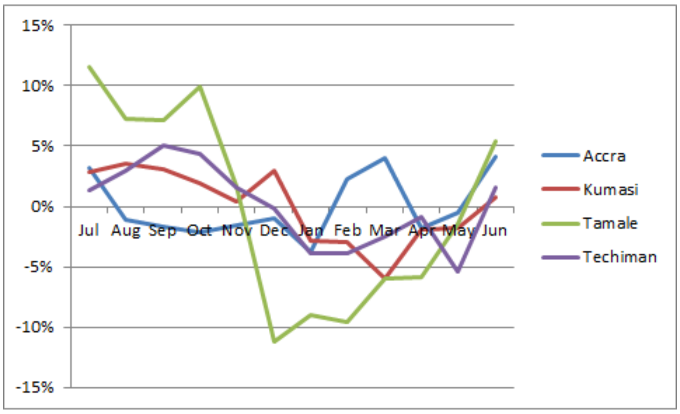

FIGURE 5.12: Seasonality of sorghum wholesale prices

Source: Author's computation based on SRID [2014].

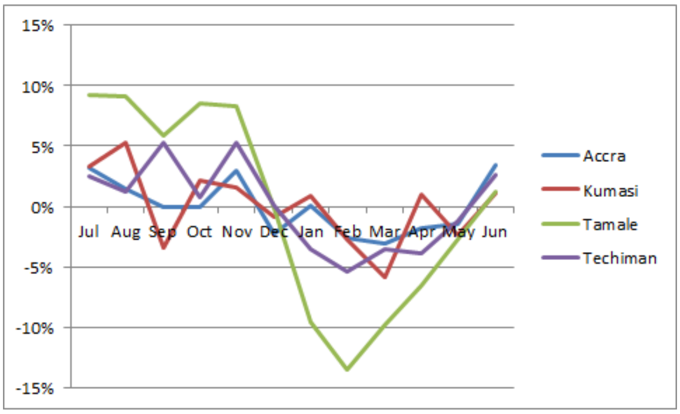

FIGURE 5.13: Seasonality of millet wholesale prices

Source: Author's computation based on SRID [2014].

5.4 Storage behavior

5.4.1 Description of the data

The analysis of storage behavior in Ghana is largely based on a trader survey which provides quantitative data on grain storage and trade. The survey was undertaken as a joint research between the Center for Development Research (ZEF) and the Institute for Statistical, Social and Economic Research (ISSER) at University of Ghana, Legon and was held at major market sites in Ghana between August and November 2013. Subsequent to the survey, follow up telephone interviews were conducted in April and May 2014.

Prior to the main data collection, a qualitative survey was carried out at selected market sites in Ghana and Burkina Faso in November 2012. This survey provided important input to the design of the questionnaire. In addition to that, qualitative information from the first survey in 2012 and from expert consultations during August and November 2013 enrich and underpin the quantitative data.

There is no such thing as a business directory for traders in Ghana. Lists of traders that have been identified during the research stay contain entries with invalid phone numbers or no longer existing companies. Therefore, a sampling technique based on randomization is obsolete. Secondly, the total population of inter-temporal arbitrageurs is not large and the sample is to be considered the larger the better. For this reason, the sampling is purposive with the intention to create a sample that is representative with respect to the size of enterprise and type of business.[6] Traders are identified through two unofficial lists. The first is a list of contractors of NAFCO published on their webpage. And second, the business directory of GhanaWeb an online news platform.[7] Contact information of traders was also found in governmental publications and other publicly available documents. Furthermore, snowball sampling was used in order to increase the number of respondents. Generally, traders were contacted by phone and asked about their willingness to participate in the survey. In this way, the response rate was close to 100 percent. For the follow-up telephone interviews, respondents of the first survey were contacted.

The interviews were structured as follows. At the beginning, general information on the enterprise was collected. Then, part two aimed at obtaining a general overview about grain trading activities. The heart of the questionnaire is the section on storage activities. Here, respondents were asked to state purchases and stock levels during the last marketing year that is 2012/2013. Further, perceptions on risk associated with storage were deduced by asking for the assessment of specific statements. The interview closes with expectations for future price changes and an assessment of traders' market knowledge on tariff rate, rainfall, and geographical production patterns. The telephone interview demanded the evaluation of specific factors that influence price dynamics and induce market risk. In addition to that, it was attempted to obtain information on different cost components. The questionnaires can be found in Appendix D and Appendix E.

In total, 36 traders were surveyed in the first round. Only 20 traders replied to the telephone questionnaire. In addition to that, several qualitative interviews were accomplished. Most notably are interviews with processing companies and practitioners. Since substantial amounts of stocks are held by farmers, it is essential to incorporate this into the analysis.

[6]The representativity of the sample cannot be perfect since information on respondents is not given prior to the interview.

[7]Available at `http://www.ghanaweb.com/GhanaHomePage/telephone_directory/`.

The Ghana Living Standard Survey (GLSS) contains an exhaustive section on agriculture. Nevertheless, a couple of qualitative interviews with farmers and farmer associations were conducted.

The ZEF-ISSER Trader Survey is different to most existing traders surveys in two respects. First, the focus is to interview traders that engage in inter-temporal rather than spatial arbitrage. Second, and related to this, inter-temporal arbitrageurs who own or rent warehouses are large companies who sometimes also involve in other businesses.

Qualitative and quantitative data collected can be analyzed in two respects, in aggregation and separately. Aggregation of results give insights on trends in national storage and aggregated market behavior. Separated analysis allows the analysis of individual storage behavior. Both are important to understand price dynamics and to design adequate and efficient food policies. Therefore, the discussion and interpretation of the data will be in two parts.

5.4.2 Motives for storage

In the course of the field study it became apparent that stocking commodities is subject to multiple motives. Therefore, this section discusses the most common rationales behind stock building in the context of Ghana which is likely to be applicable to other sub-Saharan African countries. Naturally, these motives also differ across different market actors in the value chain. This is of particular relevance for agrarian-oriented economies with a large share of subsistence farmers and low share of production that is formally traded.

5.4.2.1 Speculative storage

The most prominent motive for storage predicted by economic theory is speculation for an increase in future prices. Speculation is defined as the engagement in risky transactions to benefit from fluctuation in market values. The model is thoroughly described in the theory of storage in chapter three. In brief, storers choose to provide additional storage as long as the marginal costs of storage do not exceed the expected return from storage in the subsequent period. Generally, it is possible to hedge any risk associated with storage at futures exchanges or likewise through informal forward contracting. In this way, the price risk is transferred to another institution. Yet commodity exchanges and forward contracting are uncommon in most developing countries.

A special variant of speculative stocks are anticipated stocks. They are not held speculating for higher prices, but in anticipation of changes in demand [Minner, 2000]. Anticipated stocks are reported by rice traders in Ghana who increase their stocks before Christmas and Easter to satisfy the increment in demand [ZEF-ISSER Trader Survey, 2013].

Speculative storage must not be confused with hoarding for what food traders are often accused in times of scarcity in the market. The literature defines it as *excessive speculation.* By theory hoarding can only arise from imperfect competition [Osborne, 2005] or overestimation of price changes [Ravallion, 1985].

By the inter-temporal arbitrage condition (3.6) provided in chapter three, major determinants for the quantity stored are price expectations and storage costs. Storage costs are large in many developing countries due to high interest rates. Ghana is no exemption in this respect [Armah and Asante, 2006]. Therefore, the amount of stocks is likely to be substantially lower than in industrialized countries. Commodity prices in Ghana remain to be largely driven by seasonality (with exemption of rice) as discussed in the previous section. For this reason, speculative returns are unlikely to be realized from inter-annual storage. Based on the intra-annual storage model by Peterson and Tomek [2005], uncertainty about the timing of the harvest may be the only justification for speculative stocks at the end of the marketing year. In contrast, high seasonal variation in prices generates a great opportunity for benefit from intra-annual price changes.

In general, everyone who possesses stocks can speculate. In reality, speculations bind capital for a longer period, and thus mostly larger and highly liquid enterprises are capable of speculative storage. Indeed, the survey revealed that traders who speculate also diversify their risks by involving in spatial trading to realize low risk profits. Respondents also noted the need to deplete stocks before the end of the marketing year in anticipation of a decline in market prices [ZEF-ISSER Trader Survey, 2013]. Likewise traders, producers may also store in expectation of higher prices.

As a result of the discussion, speculative stocks are expected to be close to zero at the end of the marketing year for maize, sorghum, and millet which show strong seasonality. Furthermore, in a typical marketing year, one expects speculative stocks to be highest when prices are lowest. However, traders prefer to store at lower levels of moisture. For this reason, maize harvested in August/September in the southern parts is usually not kept for long and existing stocks are depleted again before the next harvest comes in.

5.4.2.2 Safety stocks

Safety stocks are mainly known from the logistic and supply chain management literature. They describe extra stocks that are carried to moderate the risk of stockouts and associated incapability to satisfy demand. The need for safety stocks arises from uncertainty in demand and supply [Guide and Srivastava, 2000]. Since inventory holding is costly, safety stocks should be kept at a minimum. Optimal safety stocks are chosen dependent on uncertainty in demand, supply, and processing time [Minner, 2000]. In contrast to speculative stocks, they are not related to expected future prices, but to the quantity demanded from the enterprise.

In the context of Ghana, two types of market participants are likely carry safety stocks: on the one hand, processors and animal feed manufacturers; on the other hand, traders especially retailers. A trader survey conducted by WFP during October 2013 found replenishment time of retailers and wholesale traders to be below one week for the vast majority of respondents [WFP, 2014].[8] This indicates the attempt to possess sufficient stocks at all times. The explanation may be the high importance of continuous business relationships to foster confidence in short term deliveries. Similarly, 19 out of 36 respondents ranked “the risk of losing business partners when stopping to supply for three month” as a high risk (28/36 as medium or high risk) in the ZEF-ISSER Trader Survey, in particular those traders who are less likely to hold speculative stocks. Retailers hold safety stocks to foster long-term relationship with costumers. Consumers who find retail shops empty will presumably seek their fortune elsewhere and may not return to the shop in expectation to be confronted with empty shelves again.

Fafchamps [2004] emphasizes contractual risk in many African countries as the cause of large inventories. The risk of late delivery and deficient quality demands firms to hold more than double the stocks of firms that do not encounter late deliveries. Processing firms in Ghana stated their inventories to make up for the production of one to two months [ZEF-ISSER Trader Survey, 2013]. The rise of supermarkets in many African countries within the past years has changed the agrofood system dramatically towards a greater variety of products. In consequence, van Donk [2001] projects safety stocks to increase in order to satisfy demand of multiple food products at the same time.

By their nature, safety stocks are roughly constant throughout the whole year and never fall to zero. Yet, when incorporating uncertainty in supply and demand into the optimal

[8] In detail, 89.2 percent (retailers) and 95.5 percent (wholesalers).

amount of safety stocks carried, stocks are likely to increase by the end of the marketing year.

5.4.2.3 Aggregation stocks

The literature on grain marketing in developing countries emphasizes the importance of small scale traders at village and town level. They have an important role when access to markets for many farmers is not given or costs of traveling to the market are prohibitively high [Sitko and Jayne, 2014].

As described above, these assembly traders sell to larger wholesale traders who ship commodities across the country. Wholesale traders are likely to collect only larger quantities from village and town level markets. Thus, assembly traders aggregate in order to ensure an efficient transaction process with their trading partners. Therefore, aggregation stocks are an artefact of the characteristics of the value chain. They can also appear at central markets when wholesale traders are asked to collect large quantities (several 1,000 mt) for industrial consumption or purchases from NAFCO and WFP as reported in the survey.[9] These stocks are usually built only when their purchase is guaranteed or even pre-financed. By nature, stocks will be totally depleted when the target quantity is reached and delivered to the contractee. There is no reason to not repeat the procedure several times in the course of the marketing year, yet traders make sure to deplete before the next harvest comes in.

5.4.2.4 Consumption smoothing and precautionary savings

As briefly outlined in chapter two, households are producers and consumers at the same time and their decision making with respect to production, consumption, labor, and storage is likely to be non-separable. For this reason, on-farm storage is considered as the outcome of an optimization process within the household [Saha, 1994; Park, 2006]. Taking into account future consumption needs, it can be optimal to store food items to smooth consumption across the whole year [Saha and Stroud, 1994; Michler and Balagtas, 2013].

The reason for this is clear. Due to seasonality prices steadily increase towards the end of the marketing year. If households sell after harvest, they will be required to purchase at higher prices during the lean season [Stephens and Barrett, 2011]. So risk averse households choose to prevent this from happening by stocking sufficient quantities on farm.

[9] NAFCO and WFP hold auctions for the delivery of a certain quantity.

5.4.3 Operational costs

The profitability of storage, and thus the level of stocks, depends on the margins farmers and traders realize as well as the costs of storage up to the time the sale is undertaken. For farmers, after the harvest costs arise from handling and storing of the commodity. In contrast, the costs which affect traders directly are marketing, transport, and storage costs [Angelucci, 2012]. Eventually, these costs are a main determinant for the seasonal variation in prices [Peterson and Tomek, 2005].

Handling costs usually comprise post-harvest losses and expenditures that are necessary to properly store or sell the farm produce. This often involves cleaning, drying, and packaging. The main challenge of proper handling is to reduce the moisture content of fresh maize for storage to decrease the incident of discoloration [Armah and Asante, 2006]. In some instances, traders support farmers in this process by providing drying facilities or bags for adequate storage [Antons, 2010]. In total, estimate of post-harvest losses occurring through pests and insect infestation in sub-Saharan Africa largely deviate between 10-40 percent and 50–70 percent [Affognon et al., 2015]. In Ghana, experts assume total losses to be around 20 percent for maize and half of this for rice, millet, and sorghum.[10]

Post-harvest losses of traders are substantially lower as compared to losses in on-farm storage since traders usually dispose of proper storage facilities and have information about appropriate handling. On the other hand, storage in warehouses and the treatment of stored commodities are costly. In addition, opportunity costs emerge. They are classified as storage costs since other investment opportunities could be seized with the same capital that is used to purchase commodities. Last, traders usually bear the costs of transportation to their storage facilities and after storage to their customers. This includes the loading at point of departure. Exact estimates for transport and storage costs are difficult to obtain and also depend on quantity and quality of the grain. The additional costs are eventually passed on to consumers.

Table 5.6 presents surveyed transport costs for frequently used destinations in Ghana from 2011. Accordingly, short distances are relatively expensive as compared to standard trade routes between Tamale, Kumasi, and Accra. Generally, transport costs are sizeable measured against the price of a mini bag (50 kg; 30-35 GHS) and maxi bag (130 kg; 50 GHS) at harvest time. During the field survey loading costs were reported to be 1 GHS for a maxi

[10] `http://www.aphlis.net/?form=losses_estimates`.

Table 5.6: Transport costs on selected roads in May-June 2011

route	bag in kg	price/bag	price/mt	distance	cost mt/km
Kumasi-Accra	50	2.31	46.28	272	0.17
Kumasi-Tamale	50	2.90	57.83	382	0.16
Kumasi-Ejura	50	3.00	60.16	98	0.61
Kumasi-Nkoranza	50	3.00	60.16	150	0.40
Kumasi-Wenchi	50	2.31	46.28	155	0.29
Accra-Tamale	50	4.04	80.98	654	0.12
Wenchi-Sunyani	130	6.94	53.39	97	0.56
Wenchi-Techiman	130	4.63	35.59	29	1.23
Wenchi-Accra	130	11.57	88.98	427	0.21

Source: World Bank [2012].

Note: Prices converted to GHS with the market exchange rate of 1.74 GHS/USD.

bag. Storage costs are more difficult to obtain. In the interview, traders were asked how much they need to add to the purchase price in order to not make any loses if they buy and immediately sell as well as if they buy and store for three months and sell (Q.4a and Q.4b in Appendix E.). The amount reported for the latter case should yield the sole costs of storage without trader mark-up, while the first captures mainly transport costs but also fixed costs of administration and marketing. The results are reported in Table 5.7.

Table 5.7: Transportation and storage costs in March 2014

description	reported cost
large firms in urban centers	storage costs: 12-18 GHS per ton
	transport & admin costs: 25-30 GHS per ton
traders Brong-Ahafo	storage costs: 1-1.5 GHS per 50 kg
	transport & admin costs: 1-2 GHS per 50 kg
traders Northern Region	storage costs: 2-8 GHS per 100 kg
	transport & admin costs: 5-12 GHS per 100 kg

Source: ZEF-ISSER Trader Survey [2013].

Note: Differences across crops could not be observed, but the sample size for rice and soybeans was small; Traders choose their preferred unit to report the costs.

Two main observation can be made. On the one hand, large firms in Accra and Kumasi reported the smallest amount of storage costs. Second, with the exemption of the Brong-Ahafo region, transport and admin costs are much higher than the costs for three months of storage. The figures should be interpreted cautiously with respect to the total size of the cost reported. More importantly, they can be analyzed relative to each other. Nevertheless, transport and administrative costs reported are in gross accordance with the costs estimated by World Bank [2012]. A comparable proportional relationship between transport and storage costs can also be found in other studies [e.g. Angelucci, 2012; Angelucci et al., 2013]. From this, a total of operational costs between five and 50 percent of the purchase price can be deduced.

It is a general observation in Ghana and elsewhere that storage facilities are built to exploit economies of scale [Monterosso et al., 1985] or the proximity to processing companies in urban centers [EAT, 2012]. Benirschka and Binkley [1995] explain this phenomena by the presence of opportunity costs that decrease with distance to the producing market. In consequence, market supply takes place in a sequential manner. Thus, firms far from the market supply only after those firms that reside closer to market have fully released their stocks. This implies, as soon as supply at producing regions is exhausted, grains are shipped back from urban centers to rural markets. In this way, transport costs are incurred twice; when grain is shipped from rural to urban ares after harvest and reverse in the hunger season [Barrett, 1996]. Taking into account the high costs of transport, traders need to increase the sales price in order to break even. In this light, seasonal price changes of around 50 percent in selected years appear quite reasonable. Conversely, costs of storage alone without transportation cannot account for the strong seasonality in prices.

5.4.4 Aggregated results - seasonality in storage and trade

The objective of this section is to discuss aggregated national storage behavior deduced from the trader survey, producer data from the GLSS V, and qualitative interviews conducted.

On-farm stocks

Before turning to results of the trader survey, lets reconsider Figure 5.4-5.7 from the section above and its implication for on-farm storage. Purchases from the market and sales seem to be good indicators to derive some seasonal variation of these stocks. When farmers are forced to buy at the market, it is likely, their stocks are exhausted. Similarly, as long as they are able to sell to the market, on-farm stocks still prevail. Looking at the GLSS V data, local rice, sorghum, and millet sales reduce strongly at the end of the marketing year. Market purchases of farmers spike during this time. This gives indication that on-farm stocks are usually exhausted several months before the next harvest comes in. As opposed to this, both maize sales and consumption are less exposed to seasonality. This could imply that maize is stored longer on-farm than other grains. High levels of market purchases of maize around and shortly after the harvest could be motivated by speculative storage since prices are lower during this period. So, farmer could choose to store in order to wait for the price to increase. Conversely, storage could be caused by the risk of food insecurity.

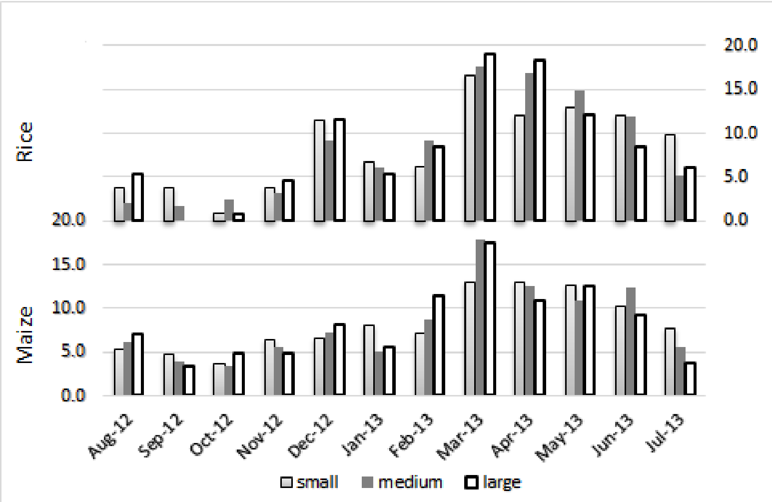

FIGURE 5.14: Share of farmers selling by month in 2012/2013 (in %)

Source: Chapoto et al. [2014].

In contrast to the GLSS, the Ghana Agriculture Production Survey (GAPS) by IFPRI compiled data on the share of farm sales by month. The numbers indicate that most of the sales of rice and maize take place between March and June (Figure 5.14). This would hint at relative high levels of on-farm storage up to the end of the marketing year. However, data for the 2012/2013 crop year needs to be interpreted cautiously due to the extraordinary market situation as a result of the bumper harvest. Net sellers may be more likely to speculate since a portion of their total produce satisfies their consumption demands. Yet the breakdown of farmers' sales by size of the farm in Figure 5.14 reveals no significant difference in marketing behavior. In summary, it is hard to say whether stocks are carried for speculative purposes or to smooth consumption without more in-depth research.

In earlier studies, farmers were under suspicion to hold the majority of stocks [Jones, 1972; Alderman, 1992a]. This cannot be assessed without better information on their marketing behavior and storage motives. A shift of storage activities from farmers to traders can have the potential to raise total availability as on-farm storage is still associated with highest losses from deterioration in consequence of insufficient handling and inadequate storage.

Trader stocks

The results from the trader survey are more enlightening since stock levels at a particular time of the year are explicitly inquired. The survey can be considered as representative for rice and maize as the aggregated turnover of the respondents represents a significant portion of the total quantity marketed.

Table 5.8 summarizes stylized facts of markets for maize, rice, sorghum/millet, and soya. The estimates for the number of traders rest on experiences during the survey which include requests for references to other wholesalers at the end of the interview. By doing so, most of the large wholesale traders should be known to the author. This may not hold for imported rice which is a newly emerging business with several trading companies that keep rice as only one of their products.

TABLE 5.8: Stylized facts of grain markets

	Maize	Rice	Sorghum/ Millet	Soya
National consumption in 2013 (mt)	1,700,000	950,000	450,000	130,000
No. traders in sample	29(+2)	14(+8)	3	11
fraction marketed (%)	50	>80	<20	>90
Industrial use (%)*	20	n.a.	n.a.	n.a.
No. traders whole population (est.)				
Wholesalers	10-15	10	5-7	3-5
Large companies	2	4-6	1	1
Turnover of survey (mt)	94,000	377,000	-	7,400

Note: * Animal feed use 150,000 + 200,000 food processing (Premium Foods, Nestle, Yedent Agro Food Processing); () indicate number of yellow maize and imported rice traders.

Respondents of the survey purchase and sell commodities to different market actors. A large majority buys from farmers or aggregators (Figure 5.15).[11] However, still half of

[11] Multiple responses are possible.

the respondents also buy from other wholesale traders. With respect to sales, only seven respondents sell to consumers directly. In contrast, the large majority interacts with other wholesalers, processing companies, and retail traders (Figure 5.15).

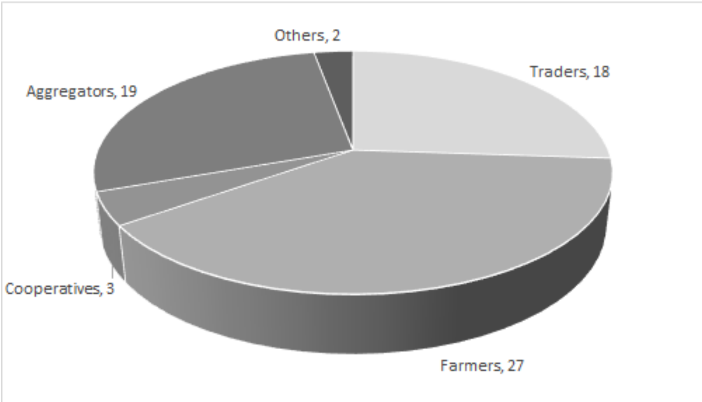

FIGURE 5.15: Sources of commodities traded (# of respondents)

Source: ZEF-ISSER Trader Survey [2013].

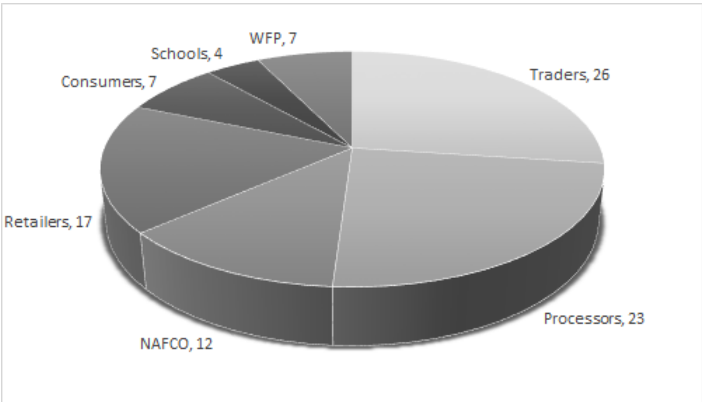

FIGURE 5.16: Buyers of commodities traded (# of respondents)

Source: ZEF-ISSER Trader Survey [2013].

Besides, the average storage capacity is more than 10,000 metric tons with a percentage distribution as shown in Table 5.9. From this, it can be concluded that the sample differs from usual traders surveys, such as WFP [2014], and therefore allows to draw inferences about national storage behavior.

A first indication on seasonal variability of stocks is provided by Figure 5.17 and Figure 5.18 that illustrate the best time to stock-in and release stocks as specified by the respondents of the survey. For maize, stocking-in takes mostly place in August/September and November

TABLE 5.9: Share of traders' storage capacity

Quantity of stocks (in tons)	
x ≥ 15,000	15.15
15,000 > x ≥ 5,000	15.15
5,000 > x ≥ 500	27.27
x < 500	42.42

Source: ZEF-ISSER Trader Survey [2013].

to January. This largely corresponds with harvesting time, and thus with the time of the year with lowest prices. Interestingly, some traders continue to build stocks in the course of the whole year. In line with this, stock releases also occur throughout the whole year. Albeit, most traders prefer to sell in April to June in order to benefit from increasing prices.

Results for rice are different. Stocks of imported rice exhibit less intra-annual variation apart from the fact that stocks are built before Christmas to satisfy increasing demand. In contrast, stockbuilding of local rice takes place from November to January with the intention to sell it from March to June which displays the seasonality of prices.

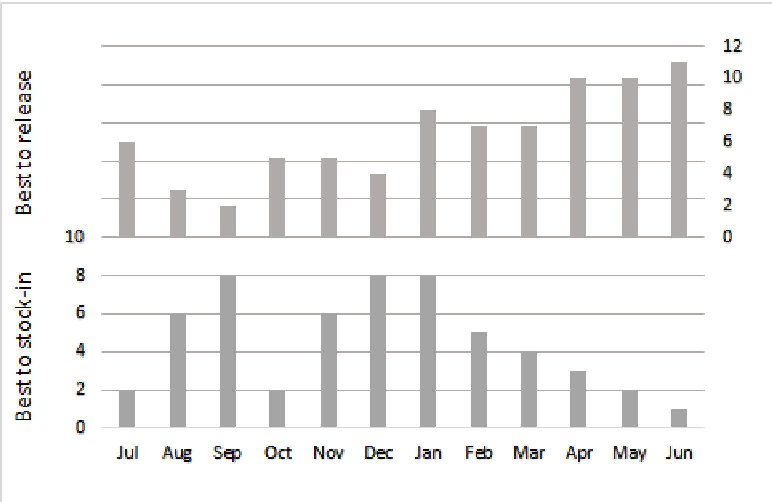

FIGURE 5.17: Best time to stock-in and stock-out maize (# of respondents)

Source: ZEF-ISSER Trader Survey [2013].

Seasonal variation of actual stocks can be deduced from the survey in the following way. First, stock levels of respondents are interpolated in order to fill gaps in the questionnaire. Second, estimated stock levels are aggregated by commodity. Surely, in doing so, large

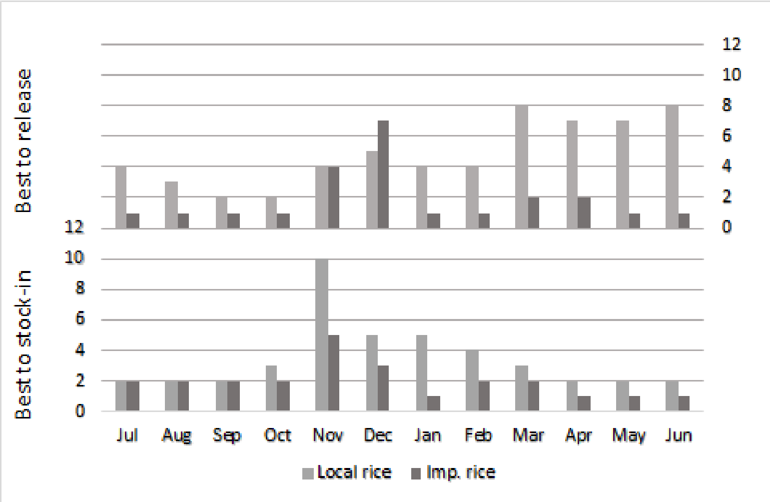

FIGURE 5.18: Best time to stock-in and stock-out rice (# of respondents)

Source: ZEF-ISSER Trader Survey [2013].

wholesale traders carry over-proportional weight and stocks of smaller traders hardly change aggregated stock level.

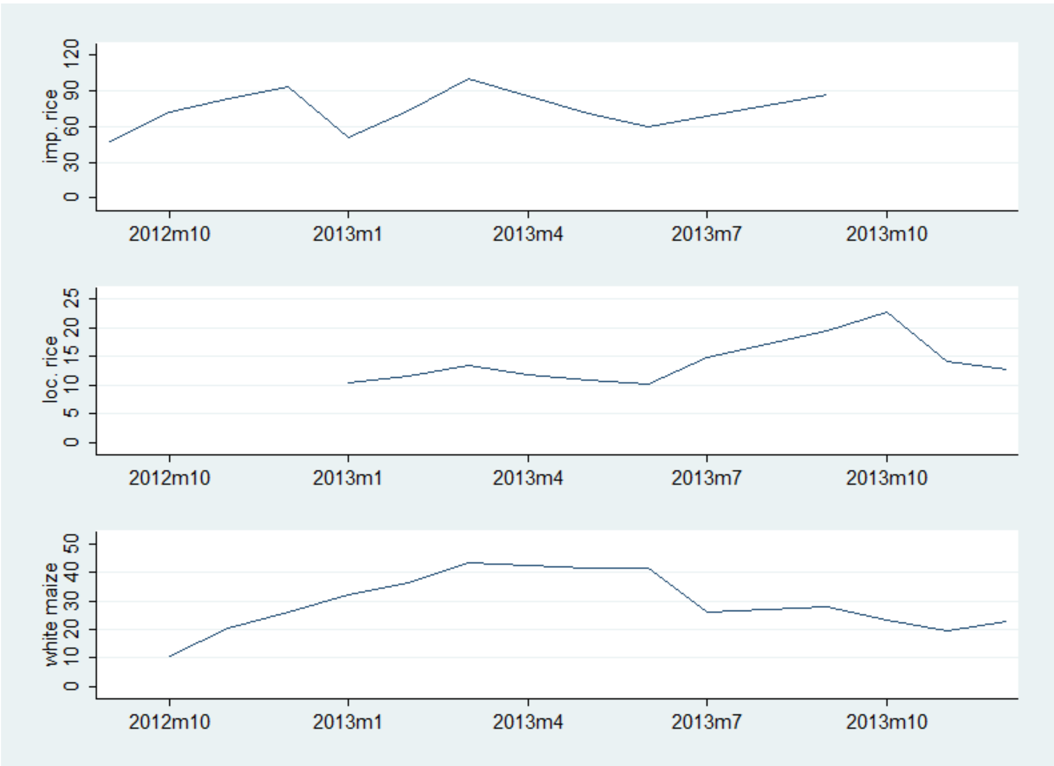

FIGURE 5.19: Aggregated trader stock trends (in 1,000 mt)

Source: ZEF-ISSER Trader Survey [2013].

Figure 5.19 shows the seasonality of observed stocks within the period surveyed. The estimates are in accordance with the preferred time of stocking-in and stocking-out. This is an increasing function until February/March. So, maize stocks are accumulated in the course of a year and distributed toward the new harvest season. It seems evident that on-farm stocks dominate at the beginning of a marketing year and trader stocks take over only within the last few months before the next harvest. Stocks for imported rice are built up before Christmas and Easter and decline as a result of releases during festival time. Local rice stocks do not exhibit similar peaks around Christmas and Easter. On the contrary, the bottom level is reached in June, before they are constantly accumulated. Over the survey period, maize stocks vary significantly from 10,000 to 45,000 tons. Unlike, rice stocks do not show a similar strong pattern. It is to note, that a more precise estimate can be achieved by weighing traders in the survey according to their weight in the survey. So, smaller traders, of which many exits, are under-represented in the survey. Conversely, most of larger wholesale traders are covered.

Taking these figures allow to make projections for total national stocks. This is achieved by dividing the total turnover of respondents of the survey by portion of annual trade volume covered by the survey (Table 5.10).[12] From qualitative interviews, safety stocks of maize processing companies are around 1-2 months of total production. In the knowledge that 20 percent of total national consumption is used for industrial use, the level of stocks can be projected. The estimates are summarized in Table 5.10 including estimates by USDA, FAO CBS, and the Ministry of Food and Agriculture (MoFA).

TABLE 5.10: Estimated opening stocks 2013/2014

	Maize	Rice	Sorghum	Millet
USDA	247,000	172,000	0	0
FAO GIEWS	250,000	50,000	5,000	10,000
MoFA	161,000	82,000	25,000	16,000
Survey	30,000	85,000	-	-
Proj. trader stocks	270,000	220,000	-	-
Industrial stocks	40,000	-	-	-
Total estimate	310,000	220,000	-	-

Source: USDA [2014]; FAO CBS [2014]; MoFA [2014].

Note: Industrial stocks are computed as 1.5 months of industrial produce.

[12] The shares are: 11 percent maize, 50 percent imported rice, 25 percent local rice.

Accordingly, estimates from the survey are well in the range of what is provided by other sources. Generally, safety stocks are a very important component of the annual carry-over stocks of maize. Due to the bumper maize crop in 2012, the level of speculative stocks carried at the end of the marketing year was much higher than in previous years. Therefore, historic carry-over stocks by USDA may have overestimated actual stocks. Figures provided by FAO CBS appear more reasonable. For rice, the estimates by FAO CBS seem to underestimate actual stocks. As elaborated above, USDA is likely to be well informed about the market situation of importing countries, and thus their estimates can be considered to be close to reality.

Apart from aggregated storage patterns, it is interesting to see what respondents consider to be drivers of market prices in Ghana and whether changes of market conditions represent a risk for their business activity. Figure 5.20 presents the average score for each possible driver of market prices given by the respondents. Demand and supply patterns stand out with average scores above three which is associated with a medium risk. On the other side, international and sub-regional price changes as well as market intervention by NAFCO are rated to have the lowest impact on market prices. All other factors are assessed to have a medium impact on prices. Surely, there is heterogeneity among respondents. Most notably, international prices are rated high among rice traders.

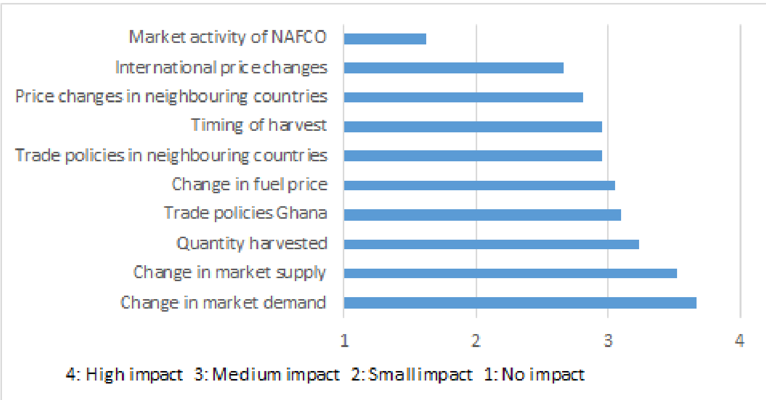

Figure 5.20: Factors that influence market prices (mean of respondents)

Source: ZEF-ISSER Trader Survey [2013].

With respect to risk for stockholding, Figure 5.21 presents average scores. Again, market activity of NAFCO is rated lowest equivalent to low risk associated with market activity of NAFCO. In contrast, trade policy changes are the major source of business risk, while changes in import duties are substantially worse than export regulations. This is in line with the finding from chapter four that trade policy unpredictability enhances market volatility. Thereby, adverse effects of policy unpredictability on investment could be the explanation for the rise in price instability. Furthermore, an increment of fuel and energy prices that boost transportation and storage costs is also characterized as high risk. Notably, a bad harvest is considered to be a medium to high risk for profits, while bumper harvests are only small to medium risk.

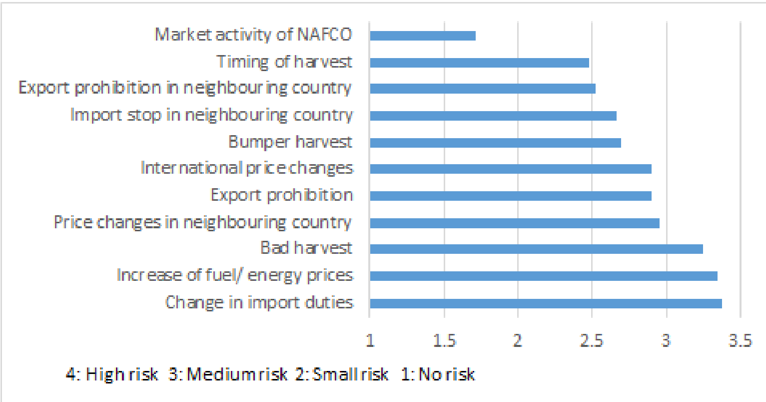

FIGURE 5.21: Risk for profits from stockholding (mean of respondents)

Source: ZEF-ISSER Trader Survey [2013].

In summary, the responses of the traders are in line with the observed storage behavior. Respondents attempt to deplete their stocks before the next harvest in anticipation of a price decline after harvesting. For this reason, bad harvests are riskier than bumper harvests. In addition to that, an increase in storage costs and uncertainty about policy changes endanger profits from stockholding.[13]

5.4.5 Micro results

Aggregated seasonal patterns of storage are quite distinct. On the other hand, the heterogeneity among traders with regard to storage motives and strategy is hypothesized in the literature, but also earlier in this Chapter. Tables 5.22-5.24 depict seasonal variation in individual stock levels by traders interviewed in the survey.

In contrast to aggregated results, common patterns amongst all traders are difficult to identify for individual maize stocks. With respect to imported rice, more similarities can be observed. So, none of the traders for imported rice has depleted stocks entirely in the

[13]Generally, policy changes are motivated to stabilize/reduce market prices.

course of the observation period. Furthermore, all traders increased their stocks toward the end of 2013. Alike maize, for local rice similar patterns are hardly observable, apart from an increase of stocks in the time between September and December 2013.

From the discussion on storage motives, two distinct types of traders can be identified. First, distributors and aggregators who hold stocks only to accumulate predetermined quantities to deliver at predetermined dates. Second, speculators who hold stocks to benefit from seasonal variation in prices. However, it is difficult to extrapolate on the strategy by looking at the seasonal variation of stocks only. Besides, a strategy is difficult to deduce from the stocking trends. A simple approach is to distinguish stock trends into U-shape and reverse U-shape. For maize and local rice, the reserve U-shape represents the holding of stocks until mid of 2013 which hints at a speculative strategy. A U-shape of stock trend implies purchases in late 2012 including more or less immediate sales and re-stocking in late 2013. This is a more likely stocking pattern of an aggregator.

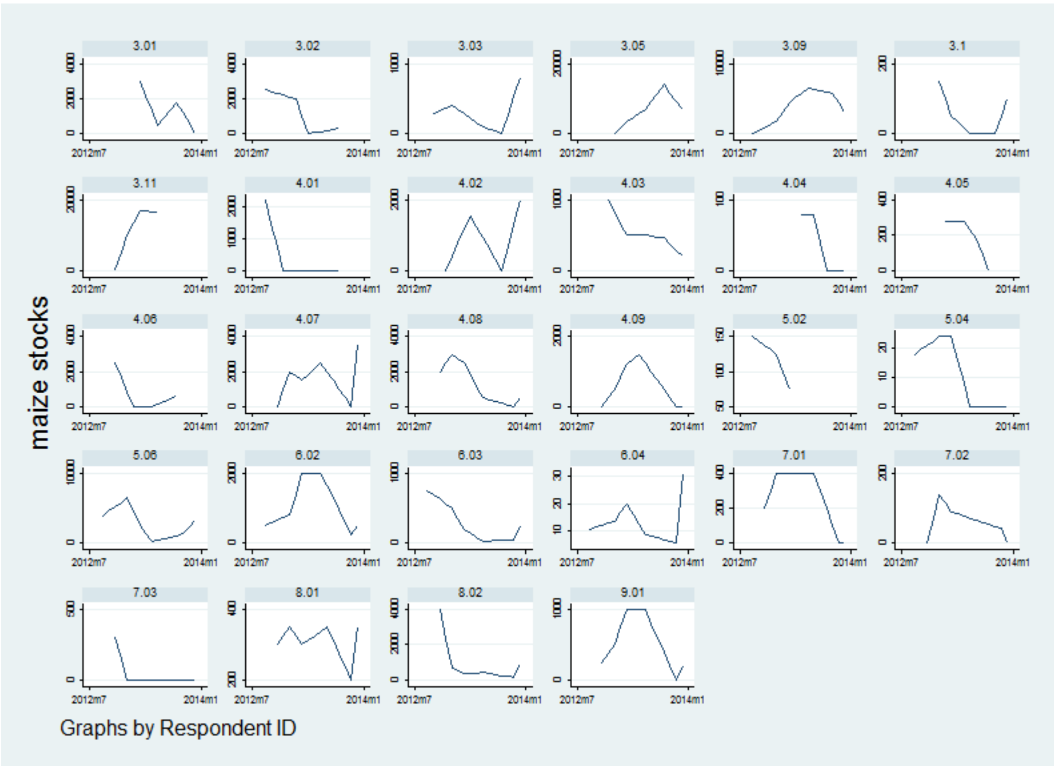

FIGURE 5.22: Stocks by respondent (white maize)

Source: ZEF-ISSER Trader Survey [2013].

In particular two variables of the questionnaire seem capable of helping to identify the storage motive. First, the question regarding the best time of stock release. Speculative

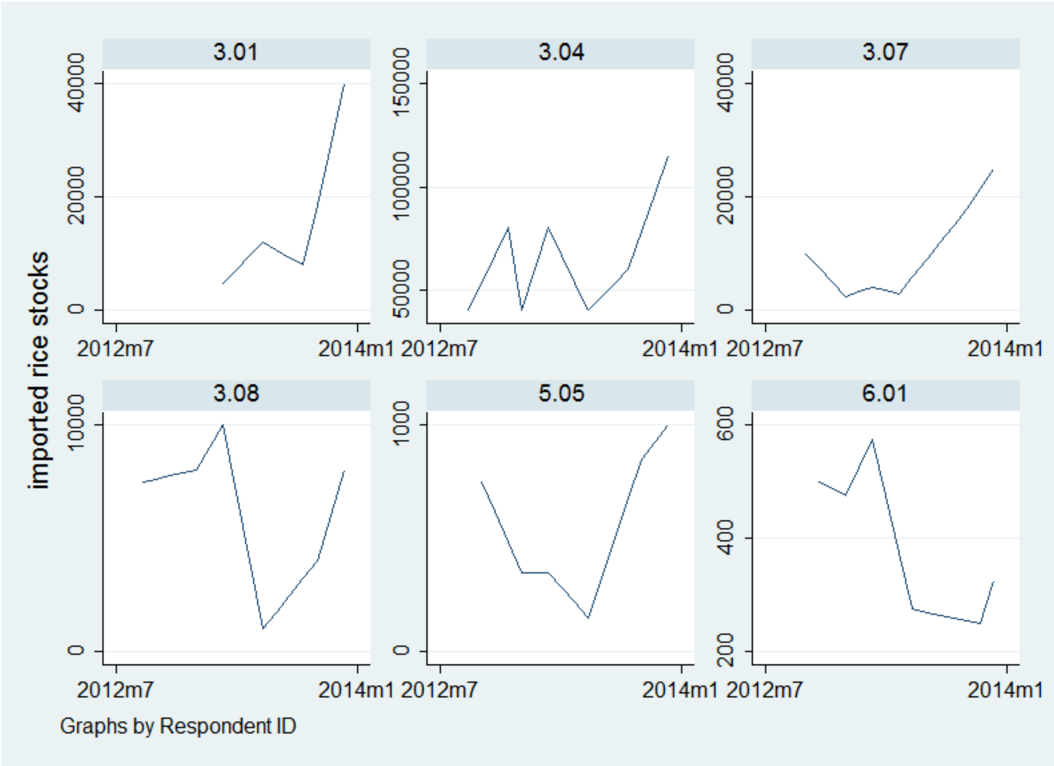

Figure 5.23: Stocks by respondent (imported rice)

Source: ZEF-ISSER Trader Survey [2013].

storage is more likely in case fewer months are considered to be best for releasing. Second, two related questions that ask the respondents to rate risk and advantages of storage for more than three months (see Q22a and Q22b in Appendix D). From the difference of Q22b and Q22a, a respondent's relative risk-chance ratio from long-term storage can be obtained. A positive difference indicates respondents see a greater advantage than risk in holding stocks for a longer period. Table 5.11 summarizes these variables. However, the indicators do not seem to be related to the shape of the stocking trend.

What drives the difference in stocking strategies? More precisely, what makes a trader a speculator and what makes him/her an aggregator or long-distance trader. The speculative storage model presented in chapter three gives some indications what variables influence the decision to keep stocks for some time. First, the costs to carry commodities from t to $t+1$. Second, the expected price spread between two points in time. Last, the extension of the model to risk averse stockholders relates the level of stocks to risk attitudes.

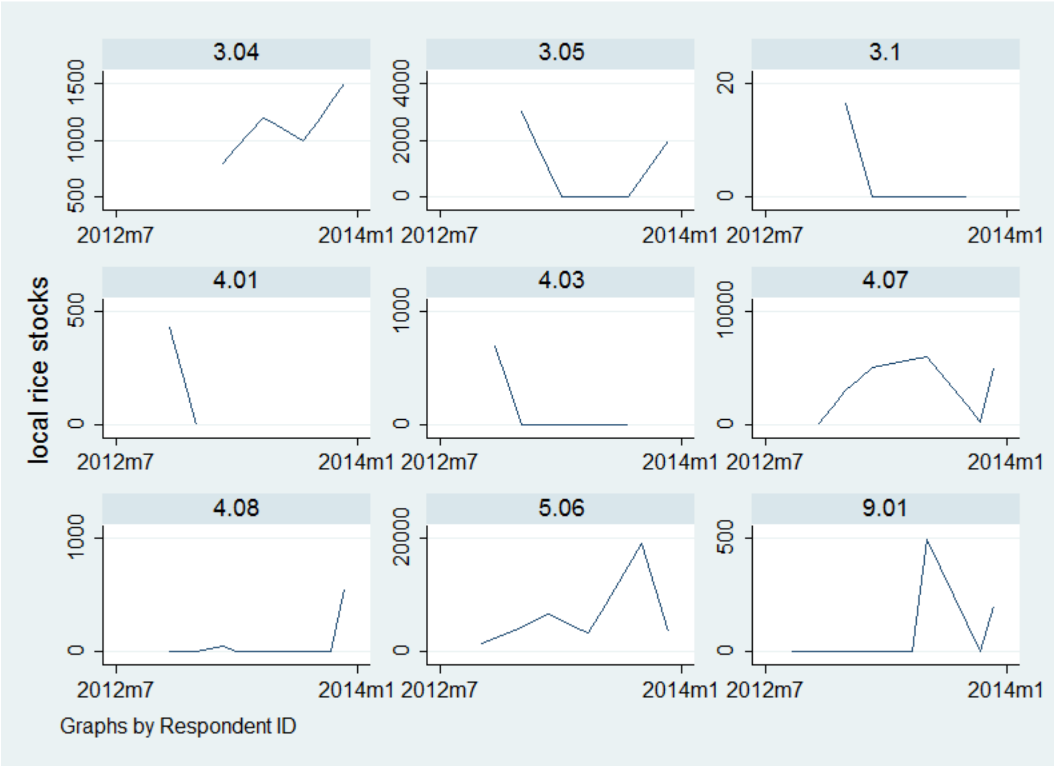

FIGURE 5.24: Stocks by respondent (local rice)

Source: ZEF-ISSER Trader Survey [2013].

TABLE 5.11: Indicators of stocking strategy

	U-shape	
	yes	no
U-shape (maize)	9	15
U-shape (rice)	5	3
U-shape (soya)	8	1
chance/risk (mean)	1.58	1.49
% best release months (mean)	0.22	0.20

Source: ZEF-ISSER Trader Survey [2013].

Lets look at the costs of storage first. Most notable are costs of physical storage and deterioration whilst stocking.[14] The first is much related to the rent paid for storage facilities. With respect to costs, the interviews did not provide much information.[15] Total cost of operation can be divided into transportation and storage costs. Then, one would expect aggregators to have a comparative advantage regarding loading and transportation costs.

[14]Electricity costs should not deviate much across traders.

[15]Questions on cost components were included in the questionnaire and removed after pre-testing the questionnaire in order to cut the time of the interview.

On the other hand, speculators should face lesser costs in storage activities including capital. The telephone interview included questions on relative costs as compared to close competitors in the market (Q3 in Appendix E). However, there is no significant correlation observable with one of the three strategy variables from above.

Most definitely, risk attitude also plays a prominent role. Stocking commodities over a longer time period with uncertainty about future prices is more risky than spatial trading and risk aversion will reduce the level of storage. Conversely, risk lovers are more likely to take the risk of storage without having full certainty about future prices. Risk attitudes of wholesale traders have not been subject to extensive discussions in the literature which mainly focuses on farmers and small-scale traders. An argument against the presence of risk aversion may be the registration of most trading businesses as Limited Liabilities which prevents obligees to demand private property of the company owner or manager.

Lastly, price expectations and expected profits influence the decision whether and how much to store. The competitive storage model is built on the rational expectation hypothesis [Gustafson, 1958; Muth, 1961]. It implies that market actors utilize all available information that are relevant for price formation. All associated errors in prediction are therefore random. This also means all traders have homogeneous expectations. If this is valid, price expectations do not cause heterogeneity of storage decisions among traders.

Some studies stress the reaction of traders to new information [Ravallion, 1985; Osborne, 2004]. Ravallion [1985] finds price expectation of traders in Bangladesh to be correlated with forecasting errors. This implies a systematic under- and overestimation of price changes. The bias explains suboptimal storage. And heterogeneity in the forecasting bias could explain different storage strategies.

Alternatively, the forecasting bias can emerge from difficulties to access information on supply and demand which is often not easily available in developing countries. Therefore, searching for market information is costly [Aker, 2010]. These costs are most likely to be subject to variation across traders in compliance with their individual ability to process information and a trader's inter-connectivity and inter-linkage with the marketing system. In his seminal work, Stigler [1961] relates market information gained from search with price dispersion. He predicts consumers with better information to have a more favorable distribution of minimum prices which makes them better off. The model has been also applied to traders in the context of developing countries [Jensen, 2007; Aker, 2010; Tack and Aker, 2014]. Additional market information through search across markets guarantees traders higher revenues. In the model by Tack and Aker [2014], the reservation price is the threshold value for which additional search is not anymore profitable.[16] The model predicts lower search costs to increase a trader's investment in search. This lifts the reservation price, and thus increases profits.

It is possible to transfer this model to a situation in which traders search for prices in future periods, instead of across markets. In this instance, better market information offers higher expected prices in $t + 1$, and thus returns from storage, vis-à-vis baseline market information. Since inter-temporal arbitrage requires positive returns from storage, a higher expected price in $t + 1$ makes storage profitable even for higher price levels in t. Hence, price information can make a difference in whether arbitrage is profitable or not.[17] In this way, heterogeneous cost of information cause differences in storage patterns across agents.

If the search-costs-hypothesis explains differences in the storage strategy, we would expect to observe heterogeneity in the knowledgeability or information status across traders. This was indeed encountered during the survey. About 70 percent of the traders receive price information from business partners. Less than half of the traders mentioned multiple sources for price information.[18] Yet several traders could not name the main production area of the products they are trading (see Table 5.12). Similarly, the NAFCO minimum price was not known to more than half of the traders. The results are surprising as one would a priori believe traders should possess this information. Certainly, it is also possible that the information asked for is rather unimportant. More predictive power could be realized through the evaluation of long term price forecasting.

Table 5.12: Correctness of survey answers

	correct	wrong or don't know
main production area: maize	15	10
main production area: soya	8	1
main production area: rice	10	3
NAFCO minimum price: maize	10	13

Source: ZEF-ISSER Trader Survey [2013].

Note: Small deviations are accepted for the NAFCO minimum price.

[16] Diminishing returns from information search commonly accepted by the literature.

[17] Again, the level of market information is a function of price information and unobservable search costs.

[18] Other important sources of information are agricultural information system (22.8 percent) and other traders and cooperatives (31.4 percent).

5.5 Discussion and policy implications

Frequent price spikes in consequence of stock-outs are not unusual to many developing countries. Transitory food insecurity adversely impacts on welfare and can cause income related health shocks. National food security policies often involve expensive and distortive price stabilization programs with direct market intervention through purchase and sales of staple food items. This is not different in Ghana where prices of maize, sorghum, and millet exhibit large seasonal fluctuations. In contrast, the rice market is more formalized and dominated by imports and prices are stable throughout the year.

In this chapter, inter-temporal storage behavior of wholesale traders is the subject-matter. Unlike earlier studies, traders are found to hold the substantial amount grain stocks, especially towards the end of the marketing year. For all crops but imported rice, most of these stocks are carried to speculate for the seasonal increase in prices. Other wholesalers accumulate stocks for sale in large quantities to industrial clients. Due to the likely decline in prices with the incoming harvest in July/August, traders attempt to deplete their stocks before prices drop. In a bumper crop year this is often not possible, then taking stocks to the next marketing year is usually associated with losses. Thus, annual carry-over stocks are kept at minimal. On the contrary to maize and local rice, stocks for imported rice exhibit less variation throughout the year. These stocks are built up in anticipation of demand peaks. Apart from trader storage, safety stocks are carried by industrial producers to guarantee the maintenance of their production even under delivery problems.

An additional finding of the survey is the heterogeneity among traders with regard to their storage strategy. In other words, individual stocking trends do not show a uniform pattern across respondents. Several explanations are discussed based on the theory of storage. First, differences in costs of storage and transportation. Second, the importance of a trader's risk attitude implying that risk averse traders prefer not to speculate. Last, the possible relevance of heterogeneous price information and search costs. Improved price information may increase purchase prices at which traders still profit from inter-temporal arbitrage [Tack and Aker, 2014]. The relevance of the explanations given cannot be assessed by the survey data. However, future research could combine these findings with existing methods that address and estimate heterogeneity in price expectations [e.g. Chavas, 1999; Frechette and Weaver, 2001].

It is not within the scope of the study to give a definite answer why price dynamics are characterized by strong seasonal variation and occasional price spikes. According to the narratives of the traders this is much related to the quantity in the system. The price spikes at the end of the marketing year may be attributed to trader stock-outs induced by the risk to lose when carrying stocks into the next year. High seasonal price increases often reflect large real transactions costs that are related to the physical infrastructure and explain price dispersion across space and time. In particular, storage locations distant to production markets induce the transport of commodities when filling as well as when releasing stocks [Barrett, 1996].

Public storage by NAFCO is not likely to significantly impact on market prices which is also supported by low relevance of their market activities for wholesale trading. Against this, trade policy regulations negatively affect business activities creating disincentives for investment [EAT, 2012]. Furthermore, in the past the announcement of minimum farm gate prices has created wrong incentives for farmers to keep their produce.

This does not imply that there is no room for governmental intervention. But unlike direct interference in the bargaining process between farmers and traders, methods exist to raise farm gate prices in a market friendly way. For instance, by providing improved knowledge about prevailing market prices to strengthen the position of farmers in negotiations with aggregators and wholesale traders [Svensson and Yanagizawa, 2009; Courtois and Subervie, 2014; Mitra et al., 2015]. Another options is to facilitate direct market access for farmers in form of physical linkage to assembly markets [Mitra et al., 2015] via infrastructural investment or the provision of warehouse receipt systems that enable farmers to wait for seasonal price increases instead of immediate post-harvest sales to realize badly needed earnings. The relevance of agricultural market institutions to contribute to market stability is also identified in the cross-country panel regression in the previous chapter.

It appears challenging to effectively mitigate seasonal price variability. In particular, it is important to bear in mind that seasonal price increases are also necessary to make storage profitable. Thus, removing seasonality is hardly the solution, given the high costs of storage and transportation, inter-temporal arbitrage would become unprofitable. More importantly, public intervention should address price spikes. This could be done by a strategic reserve without permanent market intervention, a task NAFCO could take up. However, for this purpose stock levels of the strategic reserve should be increased from the current equivalent of seven days of consumption to 28 days which is the duration of overseas shipping. The possibility and feasibility of regional cooperation in storage is discussed in the next chapter. Apart from public storage, there may be other ways to create incentives for traders to carry stocks in the next marketing year and to prevent stock-outs. For instance, the government could invest in infrastructure and storage facilities close to production areas. By providing a warehouse receipt system, traders and farmers could store relatively small quantities without the risk of deterioration. Furthermore, better access to market information and possibility to hedge trading risk potentially incentivize investments commodity storage. The question to what extent additional storage, better price information and infrastructure in production areas could help to reduce price variability is substantive and should be addressed by future research. Last, models that explicitly account for trader heterogeneity and interaction, like Grosche and Heckelei [2014], could be extended to integrate possible market intervention in order to simulate the reaction of the market. This would allow to deduce more specific policy recommendations.

Chapter 6

Regional storage cooperation to enhance food security

6.1 Introduction

Despite widespread skepticism towards public intervention in food markets, many governments in sub-Saharan Africa and elsewhere responded to the 2007/2008 global food crisis by implementing or enhancing public stockholding. These interventions are criticized due to their distortive effects on private trading and high cost of operation [Newbery and Stiglitz, 1981; Miranda and Helmberger, 1988; Tschirley and Jayne, 2010]. On the other hand, the crisis also showed that international trade is incapable of dampening supply and price shocks when exporters insulate their domestic markets from international price development [Martin and Anderson, 2012; Porteous, 2012].

Child mortality and general food insecurity in West Africa are among the highest in the world [FAO et al., 2013; von Grebmer et al., 2013]. The region is a major rice importer and is dependent on these imports to meet food consumption targets. International food aid has been an important factor to offset fluctuations in national production, but has decreased rapidly since the middle of the last decade [FAO, 2014]. For these reasons, the ECOWAS community decided to make plans for a regional emergency reserve.

Regional food reserves are a viable and comparably cheap means, as an alternative to national reserves [FAO et al., 2011; Wright and Cafiero, 2011]. This is not a new idea. International risk sharing and multinational insurance schemes were heavily discussed in the

1970s [Johnson, 1976; Konandreas et al., 1978; Reutlinger et al., 1976]. By the concept of any insurance, pooling national supplies stabilizes regional food availability due to the imperfect correlation of national production shocks [Koester, 1986]. However, potential benefits from cooperation can only be realized when countries agree on a common understanding on contributions and release policies. This requires all countries to benefit from cooperation vis-à-vis without cooperation.

Academic literature on regional storage cooperation is scant. Existing studies underline the potential of risk sharing without explicitly conceptualizing the link to storage. This study aims at closing the gap by providing a methodology to evaluate potential benefits from regional storage cooperation. The main objective is to examine whether storage cooperation could enhance food security in West Africa. Specifically, various possible storage policies are tested and an efficient load distribution among participating countries is discussed. Generally, the methodology is applicable to any group of countries and not limited to West Africa.

The remainder of the chapter is structured as follows. First, section two discusses food security and storage as well as trade as means to increase food availability and introduces the concept of regional cooperation. Then, section three makes the reader familiar with the political and economic environment in West Africa and briefly talks about the proposed regional emergency reserve. Section four derives optimal levels of storage in the presence of stochastic supply in order to stabilize national consumption. It also sketches on a way to assess costs and benefits from cooperation. Results of the study, including sensitivity analysis, are presented in section five. Section six concludes and discuses policy implications.

6.2 Agricultural intervention and food security

6.2.1 The concept of national food security

Food security is a major driver of development and poverty alleviation and is therefore in great focus of national and international politics and organizations. There are numerous definitions of the term food security in the literature. One of the most widely accepted resulted from the World Food Summit in 1996:

> "Food security [is reached] when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" [FAO, 1996]

Generally, it is consensus to examine food security with respect to four dimensions: availability, accessibility, utilization, and stability [e.g. FAO et al., 2013]. In this way, food security involves not only supply and demand patterns, but also the ability for all people to access food distribution channels as well as the persistence of an adequate food security status. In addition, utilization goes beyond food security in form of total caloric quantity and extends it to all micro-nutrients.

National food security in developing countries focuses mainly on availability and accessibility at moderate prices [Dorosh, 2001; Pinstrup-Anderson, 2009]. Badiane [1988, p.1] specifies national food security as the "ability of food deficient countries, [...], to meet target consumption levels on a year-to-year basis". Similarly, von Braun et al. [1992] argue that effective food security policy should be designed to ensure sufficient food consumption of all households without excessive risks. This asks governments to guarantee sufficient food supply beyond the market demand at prevailing prices.

In the past, food security was often used synonymously to self-sufficiency. This is only partially correct. Due to climatic and economic conditions and diverse endowment of arable land, some countries have comparative advantages in producing food as in a classical Ricardian sense. Therefore, imports can be economic and efficient to reach food supply goals. At national level, food security is measured by total availability vis-à-vis needs [von Braun et al., 1992; Sijm, 1997]. Total availability is given by production, imports, and carryover stocks from the previous periods. Against this, demand arises not only from consumption but also from exports and demand for carryover stocks to the next year. Annual production is subject to great fluctuation and consequently not sufficient to meet stable consumption needs in non-exporting economies. Food imports and stocks can offset these fluctuations. National food security policies must aim at controlling trade flows and incentivizing stock building.

Several food deficient countries considerably rely on food aid shipment to reach their minimum consumption needs. In particular, severe political and economic crises increase the need of assistance. However, there is serious doubt that food aid can stabilize availability in an effective manner [Barrett, 2001; del Ninno et al., 2007].

Adequate food supply is a necessary, but not sufficient condition for accessibility. Ideally, national agricultural policies involve management of market prices or social safety net programs that support the most vulnerable when prices are too high. However, agriculture price policies are distortive and can involve disincentives for producers and traders. Flexible import duties are an effective measure to control imported quantities and to manipulate market prices.

6.2.2 Trade integration versus food reserves

In a market economy, private storage is hardly to ban and market forces will always create an incentive for stock building. So, policy makers are left with the decision to further enhance consumption stability by trade integration or additional storage through public reserves. Yet there are reasons to believe that free market stock levels in many developing countries are not sufficiently high or optimal [Newbery and Stiglitz, 1981; Gilbert, 2011a]. The empirical literature emphasizes the interchangeability of trade and storage to offset unstable production [Williams and Wright, 1991; Makki et al., 1996, 2001]. Gouel and Jean [2015] solve the standard rational expectation storage model for a small open economy. Welfare is highest when governments use an optimal mix of storage and trade, while trade is particularly effective in mitigating price spikes. Gilbert [2011a] suggests considering a country's specific characteristics to determine the right policy. So, exporters can easily regulate domestic food availability by flexible export quantities. Trade is also advantageous if supply shocks between countries are independent or negatively correlated [Koester, 1984]. In contrast, importers and countries that switch between net-importer and net-exporter can successfully insure themselves against high international prices through security stocks. Lastly, high transportation costs (e.g. for landlocked countries) and/or long periods of shipment make public reserves favorable to trade.

In reality, countries use both reserves and trade with varying degree of success. Broadly, two types of reserves can be distinguished: first, emergency and strategic reserves, and second, buffer stocks. The former is established to overcome food supply shortfalls as consequence of weather related shocks such as droughts or floods, pests, and political instability. In the event of a crisis, additional food is brought into the system via targeted food subsidies (e.g. food stamps, food-for-work, school feeding programs etc.) [Lynton-Evans, 1997]. In contrast, buffer stocks operate to generally stabilize commodity prices at both ends of the distribution. In doing so, public institutions buy and sell in order to increase market supply or demand. The objective of the buffer stock is to keep prices within a band of predetermined floor and ceiling prices [Newbery and Stiglitz, 1981]. Purchases and sales can be realized in the open market, but also through contract farming and subsidized sales to public and private entities. The main danger persists in the need to operate permanently which implies to intervene in markets permanently. Intervention levels of existing national reserves and buffer stocks do vary significantly.[1]

Similarly to public storage, trade is extensively used to stabilize food supply and commodity prices. In fact, worldwide countries heavily rely on food imports to meet national consumption demand. Indeed, these countries would be plunged into deep hunger crises without trade. Trade policies are effectively used by many countries, in particular in Asia, to buffer price volatility [Thomas, 2006; Dorosh, 2008]. Bezuneh and Yiheyis [2009] provide empirical evidence on the positive impact of trade liberalization on food security for developing countries. This is in line with the findings from chapter four. Notably, purchases at international markets require sufficient foreign reserves by importers to settle the food import bill.

Yet trade can also transmit market instability from partner countries into domestic markets [Makki et al., 2001]. Reliance on imports to manage food availability can be problematic when partner countries are non-cooperative and restrict exports at times [Gouel and Jean, 2015]. This was observed during the price surges in 2007/2008 [Martin and Anderson, 2012; Porteous, 2012]. Public storage also involves major shortcomings. First, stockholding is expensive and buffer operation tie up fiscal resources that could be used for other policies. Second, and more importantly, public interventions cause market distortions provoking responses by private market participants [Miranda and Helmberger, 1988; Tschirley and Jayne, 2010].

6.2.3 Aims and scope of a multinational reserve

The idea of a regional response to increasing international market volatility rests on the possibility of cost sharing and capability of timely intervention [Wright and Cafiero, 2011; FAO et al., 2011]. Wright and Cafiero [2011] discuss the role of regional reserve to increase a country's commitment to refrain from export regulation in times of a food crisis. These

[1] Agricultural markets in India, Zambia, and Indonesia are dominated by stated owned enterprises that buy, stock, and sell a very large share of marketed grains. As opposed to this, several countries maintain public stockholding that is unlikely to affect market prices due to its small size. In an ideal world, buffer stocks should be large enough to influence prices, but small enough to not crowd out private investment and to distort markets.

commitments seem unfeasible under the common WTO discipline. At the same time, governments dispose of ways to impede exportation through over-bureaucratizing of the legal process. Hence, it is more conceivable to combine storage and trade cooperation. In doing so, participating countries provide a share of their production to be exported (if harvests are sufficiently high) and receive the entitlement to receive stock releases at periods of crisis in return. Furthermore, an independent multinational institution is granted higher reputation than national food agencies in pursuing its goals.

The main function of the reserve is to provide additional supply in an emergency or abnormal market situation. The emergency situation is to be defined by the member countries or the respective body that is leading the operations of the reserve. Storage cooperation requires an agreement on strict rules with respect to a country's contribution and entitlement to receive releases from the stock. The trigger will play a key role to the success of the reserve. In buffer stock regimes, stock releases occur when prices exceed a threshold level. In line with this, stock building is undertaken when market prices fall below the floor price. Unlike buffer rules, rules for interventions are less obvious for security stocks. Generally, it is also possible to link release policy to market prices. Alternatively, scholars and policy makers propose to use a mix between international and local triggers. At the international level, the excessive food price variability early warning system by IFPRI detects periods of excessive volatility in the US futures markets [Martins-Filho et al., 2012].[2]. At the local level, early warning systems like the Famine Early Warning System (FEWS), WFP's Humanitarian Early Warning Service, and FAO's Global Famine Early Warning System (GIEWS) collect more in depth information from the field such as rainfall and temperature patterns, local supply and demand, and commodity prices.[3]

A multinational reserve involving a buffer stock scheme, with market purchase and release, seems very challenging to realize. If the regional reserve operates at national levels separately, trade between countries undermines the principles of operation and can lead to complete inefficacy. On the contrary, if the region is considered as one market, intervention prices are extremely difficult to determine since price levels naturally differ among member countries, especially without a common currency. Therefore, strategic humanitarian reserves should be preferred. Their optimal level is often targeted on the basis of consumption requirements of the (vulnerable) population. Accordingly, most commonly used

[2] http://www.foodsecurityportal.org/policy-analysis-tools/excessive-food-price-variability-early-warning-system

[3] http://www.fao.org/giews/food-prices/en/, http://www.hewsweb.org/hp/, and http://www.fews.net/.

are figures between 17-18 percent of annual consumption needs (FAO benchmark) and 25 percent (equivalent to 90 days) [Lynton-Evans, 1997].[4] In response to the world food crisis in 2007/2008, von Braun and Torero [2009] advocate a small physical reserve (e.g. 30 days of consumption requirements) in combination with a virtual reserve that holds options to purchase grains at predetermined prices. Alternatively, Briones [2011] proposes to adjust stock levels to historic food gaps (peak deficit minus usual import requirement). In this way, a regional approach to food reserves would benefit from risk pooling in case national supply levels are not perfectly correlated. In consequence, reserves carried could be significantly lower.

From a functional perspective, it seems also plausible to concentrate on few major commodities in order to limit operational costs and to make use of stabilizing effects of cross price transmission [Alderman, 1993]. Moreover, common food stocks need to be located at strategic points that are easily accessible for all member countries. At first, the location of stocks will be dictated by main production areas and existing available storage facilities [Lynton-Evans, 1997]. Furthermore, new reserve locations should be set up in accordance with existing road and railway networks that minimize transportation costs to food deficit regions.

6.2.4 Experience from existing regional reserves

The idea of international risk sharing and multilateral commodity agreements is far from new. As early as in 1933 and again in the post-war period, major exporting countries agreed on cooperation to ensure stable supply in the International Wheat Agreement (IWA). After the establishment of the United Nations Conference on Trade and Development (UNCTAD) negotiations became increasingly political and the focus moved to tropical commodities (coffee, tin, rubber) [Gilbert, 2011b]. After the global food crisis in the 1970s, the idea of regional and international grain reserves was widely discussed [Johnson, 1976; Konandreas et al., 1978; Reutlinger et al., 1976]. In the wake of the 1974 World Food Conference, WFP was endowed with 500,000 metric tons of grain to distribute in food crises situations [Shaw, 2007]. Over the last decades, the role of WFP has been enlarged.

[4] For more details, see Briones [2011].

Enhanced regional trade and market integration in the following decades benefited attempts to regional food policy cooperation. The Common Agricultural Policy (CAP) of the European Union (EU) is the most prominent and successful model for regional integration.[5] Economic and political integration was always less advanced in Africa and Asia including some notable exemptions. Since 1988 the South Asian Association for Regional Cooperation (SAARC) has maintained an emergency reserve that has been expanded from 200,000 to 480,000 metric tons of rice in 2012 [Prasad Pant, 2014].[6] In addition, member countries made efforts to enhance harmonization of trade and taxation policies.[7]

The ASEAN Emergency Rice Reserve (AERR) was established by Southeast Asian countries in 1979.[8] The objective is to hold regional stocks complementary to national buffer stocks and reserves. In 2011, China, Japan, and Republic of Korea joined the initiative that morphed into the ASEAN Plus Three Emergency Rice Reserve (APTERR). Total earmarked stocks are enlarged to 787,000 metric tons, while the bulk of contributions comes from China, Japan, and Korea. Earmarked reserves maintain under national control but are legally owned by the community [APTERR, 2014]. Decisions on stock releases are made by the APTERR Council. In an emergency situation, national governments request the release of stocks which needs to be cleared by the Council [Briones, 2011]. Before 2011, the AERR reserve has not been in operation as countries preferred to seek at help from international donors directly [Lines, 2011].

Nevertheless, several countries operate their own national stabilization programs including the maintenance of large stocks (China, India, Pakistan, Bangladesh, the Philippines, Indonesia). In fact, China and India are unlikely to participate in regional arrangements with the intention to benefit from releases. The regional stock level is just too small to have any impact on these enormous economies. Instead, they rather provide assistance to their smaller neighbors [Torero and von Braun, 2010]. Therefore, regional reserves in Asia are a promising attempt to multilateral food assistance and south-south cooperation, but do not serve as an example for regional risk sharing.

In contrast to Asian countries, regional policy initiatives with respect to food security in Africa have not yielded into a common food reserve. Among these regional organizations the

[5] Food security has been achieved through rigorous production subsidization, market liberalization, and risk sharing through welfare transfers [Koester, 1986]. However, a common food reserve was never created.

[6] SAARC members are India, Pakistan, Bangladesh, Nepal, Sri Lanka, Bhutan, the Maldive Islands, and Afghanistan.

[7] `http://www.saarc-sec.org/Agreements/69/`.

[8] AERR members are Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam.

Southern African Development Community (SADC) is the most advanced one. The implementation of a regional grain reserve was planned multiple times, but never realized [Maunder, 2013]. At the same time, agricultural products can move freely, a common external tariff was implemented, and a regional food security early warning system established.[9] Against this, attempts towards a regional reserve of the Intergovernmental Authority on Drought and Development (IGADD), Inter-State Committee on Drought in the Sahel (CILSS), and in the Middle East and North Africa (MENA) region never advanced from a planning stage and are limited to scientific cooperation.

6.3 Institutional environment and the PREPARE initiative

The methodology applied in this work is indeed applicable to any group of countries. Here, West Africa is selected as a case since the proposal for policy cooperation is part of the current political agenda. The region also accommodates a number of severely food insecure countries, namely Liberia, Sierra Leone, Niger, and in particular Chad [von Grebmer et al., 2013]. Moreover, West Africa as a region is the largest importer of rice and has been particularly affected by transmission of international price levels and volatility to domestic markets [Aker et al., 2011; Kornher and Kalkuhl, 2013; Kalkuhl, 2014]. This section serves to introduce the current institutional environment and the PREPARE initiative for common regional stockholding to the reader.

Regional economic and political integration in Africa is puzzling, but more distinct in West Africa as compared to other regions [Keane et al., 2010].[10] It is dominated by two major political and economic communities. On the one hand, ECOWAS which is the most populous economic zone in Africa and was founded in 1975 to promote economic and political integration in “all fields”. On the other hand, the West African Economic and Monetary Union (UMEAO) originally formed for former French colonies.[11] The ECOWAS treaty is the heart of agreement between the member states. It specifies the ECOWAS Trade Liberalisation Scheme (ETLS) that guarantees movement of goods and services between member countries free of duties. This includes both import and export duties as well as non-tariff trade

[9] `http://www.sadc.int/about-sadc/integration-milestones/`.

[10] In Central Africa several competing communities exist without strong economic integration. Cameroon and Chad are geographically in West Africa but not part of ECOWAS. Mauritania left ECOWAS in 2011. Here, they are counted as potential member countries of a regional reserve.

[11] UMEAO members are Benin, Burkina Faso, Cote d’Ivoire, Guinea, Mali, Niger, Senegal, and Togo. Chad and Cameroon are not part of the UMEAO but of the Economic Community of Central African States (CEMAC). Both CEMAC and UMEAO shares the CFA that is pegged to the Euro.

barriers (NTB). In addition to that, all ECOWAS countries joined the UEMOA Common External Tariff (CET) in 2006 which is not implemented in all countries, yet.

Table 6.1: Share of intra-regional grain trade in West Africa

	share of regional trade in total grain trade		
	imports	exports	imports+exports
Benin	0.87%	100%	55.88%
Burkina Faso	1.14%	100%	8.32%
Cameroon	0.00%	51.09%	0.11%
Cape Verde	5.09%	100%	5.12%
Chad	n.a.	n.a.	n.a.
Cote d'Ivoire	0.03%	100%	8.32%
Gambia, the	0.09%	100%	1.14%
Ghana	0.64%	97.5%	1.56%
Guinea	n.a.	n.a.	n.a.
Guinea-Bissau	n.a.	n.a.	n.a.
Liberia	n.a.	n.a.	n.a.
Mali	4.28%	94.74%	6.25%
Mauritania	3.19%	n.a.	n.a.
Niger	12.29%	1.09%	11.17%
Nigeria	0.0%	n.a.	n.a.
Senegal	0.02%	82.73%	5.52%
Sierra Leone	n.a.	n.a.	n.a.
Togo	1.08%	100%	9.5%

Source: Author's calculation based on UN Comtrade [2014]

Note: Average of 2010-2013 is used when available. Benin's large share of exports is likely to be explained by re-exports to Nigeria.

In official statistics the reality in West Africa indeed is different and intra-regional trade seems limited (see Table 6.1). Column one presents the share of grain imports originated from the region. So, only 0.64 percent of Ghana's grain imports come from other West African countries. In contrast, grain exports go predominantly to the region (except for

Niger and Cameroon that share border with non West African countries). It also becomes apparent that imports account for the majority of trade and regional trade alone cannot compensate for supply shocks.[12] However, there are serious doubts in the precision of official statistics. A survey on intra-regional grain trade from 2012 finds a significant understatement of regional cross-border trade.[13] Informal trade is encouraged through high informal costs at border crossing [Josserand, 2013].[14] Chambers et al. [2012] list within-ECOWAS NTBs by member countries in recent years. NTBs span from seasonal trade restrictions to unofficial ad hoc violations of the ETLS by customs officers. Furthermore, they note unawareness of private traders about the actual scope of the free trade arrangement. Similarly, the USAID Agricultural Trade Promotion (ATP) project is concerned with high unofficial costs of cross border (but also within country) transportation [e.g. Annequin and Eshun, 2010]. External tariffs for rice remain divergent being highest in Ghana and Nigeria and lowest in UMEAO countries and Gambia [de Roquefeuil et al., 2014]. This results into cross border smuggling via Cote d'Ivoire and Benin.

Traditionally, West Africa is a main recipient of international food aid. However, the amount has been significantly reduced after 2006 [FAO, 2014]. In the wake of the global food crisis in 2007/2008, the idea of a regional food reserve in West Africa was pushed on with by ECOWAS, which sees regional food security as one of its primary objectives. The RESOGEST approach intends to strengthen cooperation and solidarity among member countries to mitigate food crisis effectively.[15] In 2011, the G20 decided to support this initiative financially as a pilot program with the aim to replicate a successful project to other food deficient regions.[16] The idea of the G20 contains an independent multinational body (e.g. WFP) that manages the reserves and releases stocks according to monitored triggers. In contrast, the regional food security strategy is built upon a triad of local, national, and regional stocks and aims at embedding regional stocks into national organizations and structures that manage national reserves. According to the proposal [ECOWAS Commission et al., 2012], only 33 percent of the required stocks are covered by the regional reserve of which only 33 percent are physical stocks. The level of required stocks is computed as a portion of a country's total annual needs. Stocks shall cover enough to compensate affected people n_t

[12]This can be seen by the small share of total trade (imports+exports) with the region which is closer to the share of imports than to the share of exports to the region.

[13]Arbitrage opportunities through different currencies and flexible exchange rate are a major driver of cross-border trade.

[14]Formerly, informal trade was stimulated by the inconvertibility of several currencies in the region which were traded in parallel markets [e.g. Azam, 1991; Shively, 1996].

[15]`http://www.westafricagateway.org/topic/regional-food-reserve`.

[16]`http://www.foodsecurityportal.org/g20-lends-support-international-emergency-food-reserve-system?print`.

for shocks arising from natural disaster or international food price hikes over the period from 2000 to 2012.[17] Regional stock needs are derived from the sum of affected people in each country i. Finally, the number of affected people is multiplied by their annual requirement as of WFP norm (12× 15kg per month). Expressed in an equation:

$$\text{annual needs} = (\sum_{i=1}^{I}(\max_t[n_{ti}], t \in [2000, 2012]) \times 15\text{kg} \times 12 \text{ (months)} \tag{6.1}$$

It yields total regional stocks between 20 and 26 percent of total annual needs over all member countries.[18] In general, estimating reserve needs on the basis of the vulnerable population is plausible. However, targeted distribution of grains out of the reserve requires readiness for policy responses [Grosh et al., 2011; Tiba, 2011]. Grosh et al. [2011] list important criteria for timely national crisis responses including existing safety net programs, administrative capacity, and a viable targeting mechanism. There is legitimate doubt in the capacity of West African countries to satisfy these requirements. During the 2007/2008 food crisis, only Burkina Faso and Liberia were able to mitigate adverse impacts through safety net intervention [Demeke et al., 2009]. Besides, the existing national reserve programs do not have sufficient coverage.

All in all, West Africa is politically well integrated with structures in place that could facilitate regional cooperation. Intra-regional trade flows appear to be too low to let trade alone equilibrate national production shocks. Moreover, international food aid is decreasing and stockholding enhances regional autonomy. The PREPARE proposal includes reserve levels based on short-term needs of the vulnerable population. Thereby, stocks are carried for an emergency situation in which a shock hits all member countries at the same time. Thus, stock levels would be precisely the same for individual countries without regional storage cooperation. In fact, supply shocks are unlikely to be perfectly correlated. On this account, storage cooperation can reduce the costs of operation. Given the current policy proposal, an assessment of costs and benefits from cooperation contributes significantly to the political debate.

[17]For most countries the 2008 or 2012 food crisis was the most drastic shock.

[18]The percentage of annual needs is derived from the expected duration for intervention of the international community or requested imports. This is 1.5 months to two months for coastal countries and three to four months for landlocked countries.

6.4 Assessment of costs and benefits from cooperation

6.4.1 Optimal stocks and stocking rule

The crunch question is: What is the optimal level of stocks? Gardner [1979] argues that there is no such thing as an optimal stock level. This means, in the retrospect, there was always a better choice for the level of stocks carried from one year to the next.[19] On the other hand, stocks can be chosen optimally conditional on the uncertain distribution of future prices. Thus, an optimal storage rule defines the optimal carry-over from year to year given storage is profitable. First and foremost, the optimal stock level depends on the criterion of desirability (e.g. maximize social welfare function) or directly on the outcome variable to stabilize [e.g. Goletti et al., 1991]. There are two obvious choices: consumption and prices. The first is easier to derive without the conjecture of specific functional relationships of the variables. Limiting food security issues to consumption risk may be too short-sighted. Cereal consumption could remain stable at higher price levels at the costs of reducing consumption of other foodstuffs, medical services, investments, and alike [von Braun and Tadesse, 2012].

Most of the literature on optimal price stability evaluates different levels of stability with respect to the sum of Marshallian surplus of producers and consumers [e.g. Gouel and Jean, 2015]. A major simplification can be achieved if storage costs and the probability distribution of output are assumed to be constant in all years. In this instance, the optimal storage is identical in each year [Gustafson, 1958] and equals:[20]

$$S_t = \theta(S_{t-1}, Q_t) \tag{6.2}$$

where S_{t-1} and S_t are beginning and ending stocks in t and Q_t production in t; θ is a function that describes the storage rule.

[19]Example: two subsequent bumper crops. Ideally, nothing should have been stocked after the first bumper crop in order to stabilize prices over the two periods. However, in expectation of a normal crop in the second period, it was optimal to stock the excess supply leading to medium prices in the first year and very low prices in the subsequent year.

[20]A mathematical illustration of problem and solution is lengthy and complicated and can be found in Gustafson [1958]; Newbery and Stiglitz [1981]; Williams and Wright [1991].

Accordingly, the storage rule is a function that relates ending stocks to total supply in a given period (t). There is no closed form solution for (6.2) with rational expectations and the model can be solved numerically only using iterative approximations. As shown by Gustafson [1958], the exact storage rule can be well approximated by a piecewise linear function. The resulting optimal stock level depends on the shape of the demand function and the costs of storage. Furthermore, social optimal stocks are increasing in total output levels and production variability. In other words, for a country with higher production variability, the optimal carry-over level is higher than for a country with lower production variability. This will be of great significance to the realization of benefits from cooperation.

Modeling of storage in the standard rational expectations framework becomes increasingly complicated the more countries are involved. In order to conceptualize costs and benefits under storage cooperation, standard identity equations are sufficient without including price responses. For this reason, here it is preferred to stay with a simpler approach and to concentrate on consumption stabilization as welfare criterion.

6.4.2 Conceptualizing costs and benefits of cooperation

Conceptualizing costs and benefits from cooperation is crucial to illustrate the incentives for countries to join a common regional reserve. Countries will only join the reserve if benefits from cooperation exceed the costs.

The gains from cooperation rest on the concept of risk pooling. Risk pooling or diversification originates from the insurance and finance literature and is the business concept of every insurance company. Pooling uncertain outcomes of multiple individuals reduces the volatility of their joint outcome. Expected losses remain the same, but insurance companies can reduce accrued liabilities if (and only if) losses of policyholders are not perfectly correlated. On the same account, risk sharing among countries can reduce the likelihood of joint losses. Table 6.2 provides a simple example. Assuming that countries A and B insure themselves against a shortfall from their expected profits ($E[\pi]$), they will be required to put a total of 20 aside. In case they share the risk, their joint expected shortfall is 10 and the countries together would need to put only 10 aside because individual shortfalls are independent. Storage cooperation works exactly in this manner.

TABLE 6.2: Risk pooling and insurance

	state 1	state 2	state 3	$E[\pi]$	shortfall
Country A	110	100	90	100	10
Country B	60	40	50	50	10
Combined	170	140	140	150	10

Source: Adapted from Koester [1984].

Expressed in statistical terms, the key issue is the co-variance of risks among countries. If shocks are idiosyncratic, then risk sharing is feasible. On the contrary, if shocks are highly correlated, benefits from risk sharing will be small [Townsend, 1995]. In his pioneering contribution Koester [1986] analyzes benefits from cooperation for southern African countries. Following his approach, the variance of production in a region is given by:

$$\mathrm{VAR}(\sum_1^n Q^T) = \sum_1^n \mathrm{VAR}(Q_i) + 2\sum_i^n \sum_{i+1}^n \mathrm{COV}(Q_i, Q_{i+1}) \tag{6.3}$$

$$\mathrm{VAR}(\sum_1^n Q^T) = \sum_1^n \mathrm{VAR}(Q_i) + 2\sum_i^n \sum_{i+1}^n r_{i,i+1}\sqrt{\mathrm{VAR}(Q_i)\mathrm{VAR}(Q_{i+1})} \tag{6.4}$$

where $\mathrm{VAR}(\sum_1^n Q^T)$ is the variance of production in the region that is formed with i=1,...,n countries, $\mathrm{VAR}(Q_i)$) variance in production in country i, $\mathrm{COV}(Q_i, Q_{i+1})$ the covariance between country i and j, and $r_{i,i+1}$ the coefficient of correlation between deviations from trend production of country i and $i+1$.

Then, the coefficient of variation of production can be written as:

$$\mathrm{CV}^2(\sum_1^n Q_i) = \sum_1^n s_i^2 \mathrm{CV}(Q_i) + 2\sum_i^n \sum_{i+1}^n s_i s_{i+1} r_{i,i+1} \mathrm{CV}(Q_i)\mathrm{CV}(Q_{i+1}) \tag{6.5}$$

where s_i, is a country's share in regional production.

From this, it is possible to conclude that production instability in the region is lower if national production in cooperating countries is independent or negatively correlated [Koester, 1984]. Since production variability is the reason why stocks are required, smaller production variability implies lower stocks. In consequence, the costs of public intervention diminish.

Against this, heterogeneity between countries explains disagreements about common regional policies. In regional integration, states hand over voluntarily decision making power to supernational entities and create a political power that overrules national policies [Heinonen, 2006]. Countries with similar economic structure lose less in comparison with countries with deviant structures [Alesina et al., 2005]. For instance, only those countries with a common business cycle profit from common counter cyclical policies.

Let public storage be rationalized by a social welfare function that values consumption stability, but negatively accounts for the cost of carrying stocks. Without losing generality, utility is given by:

$$U = H(\mathrm{VAR}(C(\alpha))) - G(\alpha) \tag{6.6}$$

where H is a function decreasing in consumption variability ($\mathrm{Var}(C)$) and G, the costs of interventions that increase with the stock-to-use ratio α; $\alpha \in (0,1)$ reduces consumption variability, and thus increases H in the following manner $H'(\alpha) > 0$ and $H''(\alpha) < 0$.

A government chooses the optimal policy involvement (α) in order to maximize social welfare given by (6.6). Accordingly, there is a clear trade-off when increasing the level of intervention (α). On the one hand, higher consumption stability will increase welfare. On the other hand, budgetary costs reduce welfare. This framework is necessary to evaluate net benefits from joining regional storage cooperation for each member country.

The optimal α maximizes welfare in autarky. In contrast, in case of storage cooperation, the level of consumption variability is not anymore determined by the individual country through welfare optimization, but a common decision among all member countries. Applying a game theoretical approach, the median voter decides on the level of consumption stability for all members countries [Alesina et al., 2005].

In order to assess costs and benefits from regional cooperation, consumption variability and reserve levels are compared under regional cooperation vis-à-vis without cooperation. In other words, a hypothetical food reserve is simulated for each individual country and for specific groups of countries. Under cooperation, countries benefit from risk sharing, and thus reduced costs of intervention for a given level of consumption variability. On the other hand, the level of consumption stabilization which determines the actual costs of intervention, is set by the union and may be different from the optimal level for the individual country. The net benefits (N_i) for each country are given by:

$$N_i = H_i(\mathrm{VAR}(\hat{C}_i)) - H_i(\mathrm{VAR}(C_i^*)) + G_i(\alpha_i^*) - G_i(\hat{\alpha}_i) \tag{6.7}$$

where $\mathrm{VAR}(C_i^*)$ is consumption variability resulting from an optimal α_i^* for an individual country without cooperation or the optimal level of target consumption chosen by the country. Analog, $\mathrm{VAR}(\hat{C}_i)$ is consumption variability under cooperation determined by α_i which is jointly selected by the member countries. So it is to note, that α_i are the same for all member countries. In the stabilization reserve, $\mathrm{VAR}(\hat{C}_i)$ is also the same for each member country.

There are four possible outcomes as a result of storage cooperation (summarized in the Box 2. Without specifying the functions H and G, in two instances the welfare impact is certain. Yet in the two remaining cases a specific functional form of H and G is required to assess costs and benefits.

Box 2: Possible welfare effects of cooperation:

1. $\mathrm{VAR}C_i^* > \mathrm{VAR}\hat{C}_i \ \& \ \alpha_i^* > \hat{\alpha}_i$ +
2. $\mathrm{VAR}C_i^* > \mathrm{VAR}\hat{C}_i \ \& \ \alpha_i^* < \hat{\alpha}_i$?
3. $\mathrm{VAR}C_i^* < \mathrm{VAR}\hat{C}_i \ \& \ \alpha_i^* > \hat{\alpha}_i$ -
4. $\mathrm{VAR}C_i^* < \mathrm{VAR}\hat{C}_i \ \& \ \alpha_i^* < \hat{\alpha}_i$?

In words, if consumption variability and costs of intervention are both lower under cooperation, then countries unambiguously gain from cooperation. In contrast, if consumption variability is larger and costs of intervention are higher, then cooperation is associated with losses.

6.4.3 Stocking norms

The cost-benefit framework introduced requires the definition of optimal stocking norms or stock-to-use ratios that are applied by each country. This implies stocks need to be sufficiently high to cover stock releases to achieve the desired level of consumption stability. At the same, the release policy from the reserve must be strictly defined. Within regional storage cooperation, the member countries must endow the regional reserve through contributions. These contributions could be proportionally equal. In this case, all countries have identical stock-to-use ratios. Alternatively, Koester [1986] proposes to organize contributions according to a country's individual stock needs. In doing so, countries with greater supply instability are asked to contribute relatively more than countries with stable supply. Again, the releases from the reserve must make sure that the desired consumption stability is given for each member country. This means, whenever supply falls short of its target level (specified in the rules of the reserve), countries receive stocks from the regional reserve to guarantee national consumption. As opposed to this, if domestic supply is sufficiently high in a particular year, countries do not receive anything from the regional reserve. In this analysis, two possible reserves are considered. First, an emergency reserve that releases stocks whenever supply falls short of a predetermined level. And second, a buffer stock which stabilizes supply in both directions.[21]

6.4.3.1 Emergency reserve

In line with the existing literature, the optimal reserve level shall absorb historic production shocks by a predetermined probability or margin [Johnson, 1976; Konandreas et al., 1978; Koester, 1986]. Let the market identity for country be given by:

$$C_t = Q_t + IM_t - EX_t \tag{6.8}$$

$$C_t = X_t \tag{6.9}$$

where total consumption (C_t) equals production (Q_t) plus imports (IM_t) minus exports (EX_t). Imports and exports are assumed to be from international markets only. National production and net imports constitute total national supply (X_t).

[21]This implies stocks are built up when supply is over high and released when supply is low.

In case production falls short of a desired level of minimum consumption can be achieved through additional imports. However, the experience, not only from West Africa, shows availability varies drastically from year to year despite food imports. There may be multiple explanations, some of them are noted above. Furthermore, international prices fluctuate and make the food import bill unpredictable [Sarris et al., 2011]. In such a situation, the emergency reserve steps in to lift consumption to the desired minimum level. Following Konandreas et al. [1978], the desired minimum level is referred to as target consumption level c^* (e.g. 95 percent of long-term trend). Then, consumption in a given year is:

$$C_t = \max[X_t, c^* E[C_t]] \tag{6.10}$$

where X_t, is actual supply in t and $c^* E[C_t]$ is the target consumption based on expected supply that is calculated from historical values. By definition $c^* \in [0, 1]$.

In words, when national supply is higher than the target level, consumption just equals total supply. In contrast, whenever supply is lower than the target level, the reserve releases whatever is necessary to close the gap to satisfy at least $c^* \times$ 100 percent of the expected consumption. In expectation, consumption always equals supply. In order to satisfy (6.10), stocks need to compensate for supply shortfalls of more than $(1 - c) \times$ 100 percent. This is defined as the stocking norms for each country. Subsequently, the ratio of consumption to be stored (α) is defined as the ratio between stocks and expected consumption:

$$S^*_{t_n} = \max_t [0, c^* E[X_t] - (X_t)] \text{ for } t = t_1, .., t_n \tag{6.11}$$

$$\alpha^*_{t_n} = \frac{S^*_{t_n}}{E[C_{t_n}]} \tag{6.12}$$

where $\max_t[c^* E[X_t] - (X_t)]$ is the largest historic shortfall in supply over the period t_1 to t_n. If supply never falls below $c^* E[X_t]$, no stocks shall be carried. α^* is the optimal stock-to-use ratio at present time.

Accordingly, the individual national reserves carry total regional stocks which are the sum of national stocks:

$$S_{R,t_n} = \sum_i S^*_{i,t_n} = \sum_i^I \max_t[0, c^* E[X_t] - (X_t)] \text{ for } t = t_1, .., t_n \tag{6.13}$$

where S_R are regional stocks and all other parameters are described as above.

In regional cooperation, the reserve must carry sufficiently large stocks to satisfy the sum of supply shortfalls in all member countries, so that regional consumption is given by:

$$\hat{C}_{R,t} = \sum_i^I C_{i,t} \tag{6.14}$$

where $\hat{C}_t$ is regional consumption which is the sum of the consumption in each of the I member country given by (6.10).

If national supply shortfalls are not perfectly correlated, then the common regional reserve must carry only:

$$\hat{S}_{R,t_n} = \max_t[\sum_i^I \max[0, (\hat{c}E[X_{i,t}] - (X_{i,t}))] \text{ for } t = t_1, .., t_n \tag{6.15}$$

where $\max_t[\sum_i^I(\hat{c}E[X_{i,t}] - (X_{i,t}))]$ is the largest historic shortfall in the region within the period from t_1 to t_n. $\hat{c}$ is the consumption target under regional cooperation which does not vary across country i. If supply never falls below $\hat{c}E[X_t]$, no stocks shall be carried.

The regional reserve shall be endowed with stocks by contributions from its member countries. Then, the regional stocking norm is:

$$\hat{S}_{i,t} = s_{i,t}\hat{S}_{R,t} = \hat{\alpha}E[X_{i,t}] \tag{6.16}$$

$$\text{with } \hat{\alpha} = \frac{\hat{S}_R}{E[C_{R,t}]} \tag{6.17}$$

$$\tilde{S}_{i,t} = \frac{S^*_{i,t}}{\sum_i^I S^*_{i,t}} \hat{S}_{R,t} \tag{6.18}$$

where s_i is a country's share in regional consumption; $\hat{S}_i$ and $\tilde{S}_i$ are national contributions to the regional reserve under equal and relative contributions. Under equal contributions all countries have the same stock-to-use ratio $\hat{\alpha}$. Under relative contributions $\tilde{\alpha}_i$ varies across countries by the extent to which national stocks vary across countries without regional cooperation. Be reminded: $E[C_{R,t}] = \sum_i^I E[X_{i,t}]$; $\hat{S}_{R,t}$ and $\tilde{S}_{R,t}$ are the same.

However, it is also possible to combine regional storage cooperation with intra-regional trade cooperation. For instance, it is conceivable to assume that supply surpluses are exported to the region. Hence, supply shortfalls in neighboring countries can be balances through trade first, before the regional reserve releases stocks. Storage cooperation could also increase the commitment to such arrangements [Wright and Cafiero, 2011].

A reasonable assumption may be to approve a country's excess surplus ($ES_{it} = X_{it} - E[X_{it}]$) for export. Thus, intra-regional trade and regional stocking norms are given by:

$$T_{R,t} = \sum_i^I \max[0, X_{it} - E[X_{it}]] \tag{6.19}$$

$$S_{R,t_n} = \max_t [\sum_i^I (\hat{c}E[X_i, t] - (X_i, t)) - T_{R,t}] \text{ for } t = t_1, .., t_n \tag{6.20}$$

where $T_{R,t}$ is the total quantity traded within the region in a particular year which is computed as the sum of excess surpluses over all member countries. Regional trade reduces regional stocks which are necessary to balance supply shocks. Therefore, historic shortfalls to be balanced diminish by the amount of intra-regional trade. Contributions of member countries and stock-to-use ratios can be computed analogous to the case without intra-regional trade which are presented in (6.16) to (6.18).

6.4.3.2 Stabilization reserve

As opposed to the emergency reserve described in the previous section, the stabilization reserve is derived from the classical storage literature [Gustafson, 1958]. This implies that stocks are part of national supply and demand. In each year a constant portion (γ) of total available supply is stocked in, which is a linear approximation of Gustafson's pioneering stocking rule. In this way, stocks change over time. After years with good harvests, stocks are higher and lower after bad harvests. In doing so, the market identity from above (6.9), changes to:[22]

[22] This model has been developed with Matthias Kalkuhl.

$$C_t = X_t - \Delta S_t \tag{6.21}$$

$$\Delta S_t = S_{t+1} - S_t \tag{6.22}$$

$$S_{t+1} = \gamma(S_t + X_t) \tag{6.23}$$

where all parameters are the same as above. S_t are the opening stocks available for consumption in t and S_{t+1} are the stocks carried to the next period. ΔS_t is the change in ending stocks from $t-1$ to t. γ is the constant portion of total available supply that is carried to the next period.

Inserting (6.23) in (6.22) allows to write consumption as:[23]

$$C_t = (1-\gamma)(X_t) + (1-\gamma)S_t \tag{6.24}$$

Since supply naturally fluctuates, we want to know the expected level of stocks. This can be easily derived since $E[S_t] = E[S_{t+1}]$.[24] Thus,

$$S_t^* = \frac{\gamma E[X_t]}{(1-\gamma)} \tag{6.25}$$

$$\alpha^* = \frac{\gamma}{(1-\gamma)} \tag{6.26}$$

where S_t^* is the optimal stock level and α^* the corresponding optimal stock-to-use ratio.

The objective of the stabilization reserve is to stabilize consumption. Hence, eventually the interest is to see how consumption variability depends on the stocking parameter (γ). Taking the variance of (6.24) yields:

$$\text{VAR } C = \frac{(1-\gamma)}{(1+\gamma)} \text{VAR } (X) \tag{6.27}$$

[23]For an analytical derivation: see Appendix F.

[24]This requires supply to be stationary.

$$\text{CV } C = \sqrt{\frac{(1-\gamma)}{(1+\gamma)}} \text{ CV } (X) \tag{6.28}$$

where VAR (C) and VAR (X) are variance of consumption and supply; CV (C) and CV (X) are the respective coefficients of variation.

Consequently, consumption variability is a function of variability in supply (production plus international imports) and the stocking parameter (γ). The larger the supply variability, the larger is consumption variability. On the contrary, increasing γ stabilizes consumption. It is important to note, the stabilization reserve under regional storage cooperation works only if markets are fully integrated and demand and supply adjust perfectly between countries. In this case, regional supply and consumption variability is equal to national supply and consumption variability for each individual member country.

6.5 Results for West Africa

6.5.1 Supply patterns

Table 6.3 provides economic and agricultural statistics on West African countries involved in this analysis. Heterogeneity between countries exists with respect to income level and food security status. While Ghana and Cape Verde have relatively low prevalence of hunger and malnutrition, still 12 percent of the total population are undernourished with alarmingly high figures in the Sahel zone. With the exemption of Mali and to some extent Burkina Faso, all countries depend on imports to guarantee sufficient supply of grain. In general, it is observed that coastal countries have larger import-to-production ratios with a ratio above one in Cape Verde, Cote d'Ivoire, Liberia, Senegal, and Mauritania. Overall Nigeria's prominent role in the region is to note. Due to its population, more than 40 percent of regional production originates from Nigeria, and thus the country would take a leading role in any regional cooperation agreement.

Table 6.3: Key statistics: ECOWAS

	population (in 100,000)	GDP per capita PPP	% of under-nourished^{+}	total production (in 1,000 mt)	import/pro-duction (in %)
Benin	10,323	1,791	8.1	1,667	21
Burkina Faso	16,934	1,634	25.9	4,949	9
Cape Verde	498	6,412	-	7	2.86
Cote d'Ivoire	20,316	3,012	21.4	1,276	116
Gambia, The	1,849	1,666	14.4	214	58
Ghana	25,904	3,974	3.4	2,645	44
Guinea	11,745	1,255	17.3	2,292	21
Guinea-Bissau	1,704	1,242	8.7	175	74
Liberia	4,294	878	31.4	150	227
Mali	15,301	1,641	7.9	5,032	3
Niger	17,831	913	12.6	4,308	13
Nigeria	173,615	5,863	8.5	22,042	32
Senegal	14,133	2,269	20.5	1,182	150
Sierra Leone	6,092	1,927	28.8	897	28
Togo	6,816	1,390	16.5	1,142	23
Total ECOWAS	327,355	4,123	12	47,978	30
Cameroon	22,253	2,711	15.7	3,047	37
Chad	12,825	2,081	33.4	1,647	18
Mauritania	3,889	3,042	9.3	222	207

Source: AFDB [2013]; $^{+}$von Grebmer et al. [2013] (http://www.ifpri.org/ghi/2013), USDA [2014].

Note: Mauritania withdrew from ECOWAS in 2000; CFA countries are: Benin, Burkina Faso, Cameroon, Chad, Cote d'Ivoire, Guinea-Bissau, Mali, Mauritania, Niger, and Senegal; all other countries use their own free floating currency.

The analysis is based on fluctuations of food production and supply. So, stocking norms are computed for shortfalls in production as well as supply. Supply is calculated as production plus imports. In this way, extreme fluctuations in production of many import dependent countries are extenuated. All imports are considered to be from international markets. In the analysis with intra-regional trade, these international imports are considered to be part of the national supply.

Since production increases with agricultural productivity and population growth, unadjusted measures of variability as variance and coefficient of variation become inappropriate measures of variability [Cuddy and Della Valle, 1978]. One possibility is to correct coefficient of variation and variance by the fitness of a trend function [Koester, 1984]. Alternatively, variability can be measured after de-trending the time series. Thus, variability in production and supply is given as the variation around a trend. A linear trend clearly does not fit to production and supply data of several countries in the region, therefore it is opted for de-trending by the Hodrick-Prescott-filter (HP-filter).[25]

An example is given in Figure 6.1 for Ghana. Actual production quantities are depicted by the blue line, while the red line indicates HP-filter trend values for a smoothing parameter of 6.25. The deviation of actual production from trend production becomes stationary and variability can be computed by (6.29). Figures G.1-G.35 in Appendix G show cereal supply and production for the remaining countries (including supply for Ghana). Clearly, production and supply trends are very diverse across countries. Further, with few exemptions, a linear trend is inappropriate to capture fluctuations in production and supply, and thus the use of the HP-filter is validated.

The validity of the calculations for the stabilization reserve requires data to be stationary. More precisely, expected values need to be constant over time. This is achieved by dividing production and supply by their HP-trend value. Hence, the coefficient of variation is given by:[26]

$$\mathrm{CV} = \frac{\sqrt{1/n \sum (\mu - Q_t/\overline{Q}_t)^2}}{\mu} \tag{6.29}$$

where Q_t is production in t and $\overline{Q}_t$ the trend value of production determined by the HP-filter. By definition μ equals 1.

[25]The HP-filter is widely used to de-trend macroeconomic time series data that exhibits cyclical fluctuations. The estimated trend value is given by the minimization of quadratic deviations in due consideration of a smooth trend. As recommended for annual data, the smoothing parameter is chosen to be 6.25 [Gabler Wirtschatfslexikon, 2014].

[26]Alternatively, the coefficient of variation could be calculated as the variance of residuals divided by the mean trend value. The results only deviate marginally.

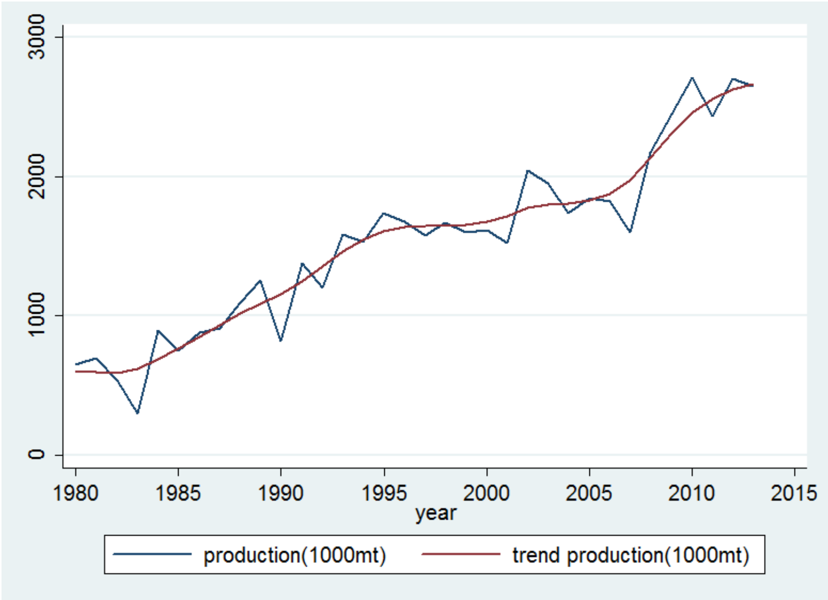

FIGURE 6.1: Grain production in Ghana 1980-2014.

Source: Author's illustration based on USDA PSD.

Table 6.4 displays each country's contribution to total regional grain production and grain supply in 2014 as well as the coefficient of variation over the period from 1980 to 2014. In brief, there are two general observations. First, supply variability is substantially lower than production variability, in particular for countries with high import-production ratio. Second, no country exhibits production and supply variability that is lower than the figure for the region as a whole. Therefore, the basic grounds for benefits from cooperation, as illustrated in the previous section, seem factual.

In more detail, production variability is highest for Cape Verde, Mauritania, Senegal, the Gambia, and Chad. All countries largely depend on import. However, for all of these countries supply variability is significantly lower. This implies, imports are successfully utilized to stabilize domestic consumption, but still higher than in countries with greater self-sufficiency. In general, coastal countries show higher production and supply stability which can be explained by more favorable climatic conditions in the humid and semi-humid tropical zone compared to the Sahel zone [HarvestChoice, 2014]. Interestingly, these findings with regard to instability are quite similar to the ones of Koester [1984] who looks at the period from 1960 to 1980. According to his analysis of UEMOA countries, Burkina Faso, Cote d'Ivoire, and Mali have more stable production than Senegal, Mauritania, and Niger. It seems that this pattern is very persistent over time.

Table 6.4: Production and supply instability across West Africa

	Production		Supply	
	s_i	CV	s_i	CV
Benin	2.9	7.6	2.7	7.6
Burkina Faso	8.9	10.3	7.5	9.1
Cameroon	5.7	7.2	6.0	6.0
Cape Verde	0.0	43.8	0.0	30.3
Chad	3.4	15.7	3.0	13.3
Cote d'Ivoire	2.4	5.5	4.0	5.7
Gambia, the	0.4	16.1	0.5	14.4
Ghana	5.0	14.0	5.6	10.2
Guinea	4.2	5.5	3.9	5.6
Guinea-Bissau	0.3	9.8	0.4	10.3
Liberia	0.3	16.1	0.7	14.8
Mali	10.4	9.7	8.1	9.4
Mauritania	0.4	27.6	1.0	9.6
Niger	8.7	13.5	7.4	12.0
Nigeria	40.6	5.8	41.2	5.4
Senegal	2.4	18.0	4.3	8.3
Sierra Leone	1.5	13.8	1.6	11.1
Togo	2.1	10.2	2.0	8.1
Region	100.0	4.5	100.0	3.4

Source: Author's computation based on USDA [2014].

6.5.2 Emergency reserve

This subsection discusses optimal stocking norms for an emergency reserve as defined earlier. The critical parameter to choose is the target consumption level. A target consumption level of j percent can be represented by j percent of annual production (red line in Figure 6.1).[27] The green line in Figure 6.2 illustrates this for a target consumption level of 95 percent. Then, the deviation of actual supply from target consumption is computed and

[27]Recall that production/supply = consumption.

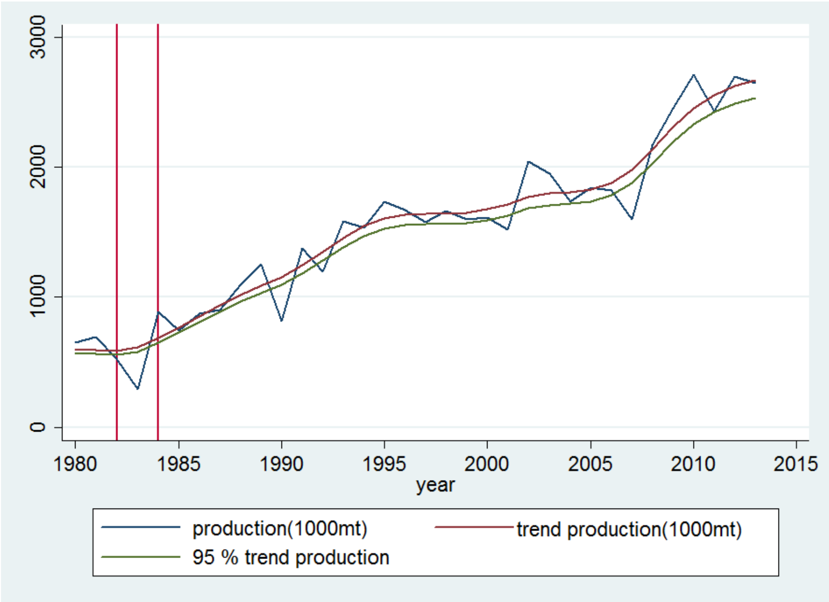

FIGURE 6.2: Grain production and 95 % target consumption in Ghana 1980-2014.

Source: Author's illustration based on USDA [2014].

the maximum historic shortfall identified. In the instance of Ghana, the maximum shortfall happened in 1983. The size of the shortfall depends on the target consumption chosen.

Target consumption levels of individual countries are hypothetical and cannot be observed. A possible way to determine target consumption levels is to assume that each country uses the reserve to mitigate the x percent largest supply shocks. From the standard deviation of supply shocks of each country, the target consumption level with respect to any quantile can be computed. Normalized standard deviations are equal to the coefficient of variation displayed in Table 6.3. Assuming a normal distribution of supply shocks, target consumption levels across countries for the one, five, and 10 percent quantile are illustrated in Table 6.5.

TABLE 6.5: Target consumption levels based on extreme supply shocks

	1 percent	5 percent	10 percent
Benin	82%	88%	90%
Burkina Faso	78%	85%	88%
Cameroon	86%	90%	92%
Cape Verde	29%	51%	62%
Chad	69%	78%	83%
Cote d'Ivoire	87%	91%	93%

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... Table 6.5 continued

	1 percent	5 percent	10 percent
Gambia, the	66%	76%	82%
Ghana	77%	83%	87%
Guinea	87%	91%	93%
Guinea-Bissau	76%	83%	87%
Liberia	65%	76%	81%
Mali	78%	84%	88%
Mauritania	78%	84%	88%
Niger	72%	80%	84%
Nigeria	88%	91%	93%
Senegal	80%	86%	89%
Sierra Leone	75%	82%	86%
Togo	81%	87%	90%
Median	78%	84%	88%

Source: Author's computation based on USDA [2014].

Table 6.5 contains important information. Intuitively, the larger the tail of the distribution (the greater the quintile), the lower target consumption will be. As elaborated above, higher target consumption levels also require larger stocking norms. Second, target consumption levels vary significantly across countries being highest for Nigeria, Cote d'Ivoire, and Guinea and lowest for Cape Verde. Third, the lower national supply variability, the higher are target consumption levels given a particular quintile. This is also intuitive, the more stable national supply is, the higher target consumption must be to balance relatively moderate supply shocks. In the following, median values will serve as possible target consumption levels for the region. In addition, reserve levels for a target consumption of 99 percent, 97 percent, 95 percent, and 90 percent are considered in the simulation.

6.5.2.1 Emergency reserve without intra-regional trade

The stocking norm is defined as the maximum historic shortfall from target consumption over the past 35 years. The respective stocking norms for all countries and various levels of target consumption are summarized in Table 6.6. Intuitively, optimal stocking norms are highest for large countries. The corresponding stock-to-use ratios show the relative level of the stocking norms. All countries that are characterized by high supply variability also have the largest optimal stocking norms within an emergency reserve. Generally, total regional stocks according to the maximum historic shortfall rule (target consumption 95 and 99 percent) are between 1.7 million and 6.2 million tons and well in the range of actual stock levels according to USDA and FAO CBS. Yet optimal emergency stocks are expected to be smaller than actual stocks since total stocks also include speculative and working stocks. In this respect, lower levels of target consumption seem to be more reasonable.

On the other hand, several countries with low supply variability hardly stock anything at target consumption levels below 95 percent. Table 6.7 presents stock levels for target consumption levels of 78 percent, 84 percent, and 88 percent. Column two, five, and eight contain stocking norms without cooperation, whereas the remaining columns show stocking norms under equal and relative contributions to the reserve. In most of the cases, stocking norms under regional cooperation are lower than without cooperation. In contrast, Nigeria and Guinea would not store anything, and thus would not benefit from regional storage under all stocking norms in Table 6.7. With a target consumption level of 84 percent, Cote d'Ivoire and Senegal would also quit the regional reserve, followed by Benin, Burkina Faso, Cameroon, Guinea-Bissau, Mali, and Togo. Hence, target consumption needs to be chosen sufficiently high in order to enable benefits from cooperation for all West African countries. For this reason, the subsequent presentation of simulation results in the text is limited to target consumption of 95 percent, the remaining results are presented in tables in Appendix G (Table G.1-G.3). The difference in stock levels between USDA and FAO CBS is explained by the issues with regard to USDA data and small countries as well as less-traded crops as sorghum and millet that comprise a significant share of total grain consumption in the region.

Table 6.6: Optimal stocking norms vs. actual stocks in 2014

	Optimal reserve levels: supply														Actual stocks	
	99%		97%		95%		90%		88%		84%		78%		USDA	FAO CBS
	S_i^*	α_i^*	S_i^*	α_i^*	S_i^*	α_i^*	S_i^*	α_i^*	S_i^*	α_i^*	S_i^*	α_i^*	S_i^*	α_i^*	S_i^*	S_i^*
BEN	152,677	8%	127.936	7%	103,195	5%	42.379	2%	32,037	2%	11.354	1%	-	-	107,000	162,000
BFA	593,667	11%	500,825	9%	407,983	8%	203,667	4%	140,506	3%	55,756	1%	-	-	364,000	495,000
CMR	203,148	5%	170,363	4%	148,788	4%	94,852	2%	73,277	2%	30,128	1%	-	-	148,000	866,000
CPV	15,455	57%	14,800	54%	14,144	52%	12,505	46%	11,849	44%	10,538	39%	8,571	32%	0	7,000
TCD	357,082	17%	317,808	15%	278,533	13%	180,347	9%	141,073	7%	80,930	4%	34,576	2%	106,000	564,000
CIV	181,273	6%	139,631	5%	99,615	4%	35,635	1%	10,043	0%	-	-	-	-	301,000	467,000
GMB	48,382	14%	41,486	12%	34,589	10%	22,209	6%	19,160	6%	13,061	4%	3,914	1%	29,000	48,000
GHA	477,451	12%	422,149	11%	366,847	9%	228,592	6%	173,290	4%	129,889	3%	83,183	2%	476,000	325,000
GIN	124,296	4%	87,947	3%	51,597	2%	10,864	0%	-	-	-	-	-	-	201,000	511,000
GNB	26,092	8%	23,423	7%	20,755	7%	14,084	4%	11,415	4%	6,078	2%	-	-	24,000	69,500
LBR	53,601	10%	48,902	9%	44,203	8%	32,455	6%	27,756	5%	20,446	4%	12,343	2%	53,000	56,000
MLI	417,047	7%	303,936	5%	223,631	4%	78,210	1%	49,735	1%	2,156	0%	-	-	764,000	855,000
MRT	111,038	15%	101,159	14%	91,279	12%	66,580	9%	56,701	8%	36,942	5%	7,303	1%	59,000	95,500
NER	681,052	13%	585,455	11%	503,972	10%	345,241	7%	289,035	6%	176,625	3%	72,619	1%	225,000	522,000
NGA	2167,705	7%	1572,822	5%	977,939	3%	128,646	0%	-	-	-	-	-	-	1539,000	85,0000
SEN	308,029	10%	258,230	8%	208,432	7%	83,935	3%	34,137	1%	-	-	-	-	197,000	492,000

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... *Table 6.6 continued*

	Optimal reserve levels: supply														Actual stocks	
	99%		97%		95%		90%		88%		84%		78%		USDA	FAO CBS
	S_i^*	α_i^*	S_i^*	α_i^*	S_i^*	α_i^*	S_i^*	α_i^*	S_i^*	α_i^*	S_i^*	α_i^*	S_i^*	α_i^*	S_i^*	S_i^*
SLE	149,723	13%	134,597	12%	119,471	11%	81,657	7%	66,531	6%	36,280	3%	8,628	1%	0	87,000
TGO	117,762	8%	105,888	7%	94,014	7%	64,329	5%	52,455	4%	28,707	2%	-	-	95,000	171,000
ALL	6,185,480	9%	4,957,354	7%	3,788,989	5%	1,726,187	2%	1,189,001	2%	638,891	1%	231,137	0 %	4,688,000	6643,000

Source: Author's computation based on USDA [2014].

Note: Stocks in mt; S_i^*, $\hat{S}_i$, and $\tilde{S}_i$ are stocks without cooperation, with equal, and relative contributions.

Table 6.7: Optimal stocking norms in 2014 for various levels of target consumption

	$c = 0.88$			$c = 0.84$			$c = 0.78$		
	S_i	$\hat{S}_i$	$\tilde{S}_i$	S_i	$\hat{S}_i$	$\tilde{S}_i$	S_i	$\hat{S}_i$	$\tilde{S}_i$
BEN	32,037	13,494	13,168	11,354	7,469	4,807	-	2,960	-
BFA	140,506	37,424	57,752	55,756	20,713	23,606	-	8,209	-
CMR	73,277	29,325	30,119	30,128	16,231	12,756	-	6,432	-
CPV	11,849	188	4,870	10,538	104	4,461	8,571	41	3,975
TCD	141,073	14,535	57,985	80,930	8,045	34,264	34,576	3,188	16,035
CIV	10,043	19,555	4,128	-	10,823	-	-	4,289	-
GMB	19,160	2,383	7,875	13,061	1,319	5,530	3,914	0,523	1,815
GHA	173,290	27,258	71,226	129,889	15,087	54,992	83,183	5,979	38,578
GIN	-	19,684	-	-	10,895	-	-	4,318	-
GNB	11,415	2,163	4,692	6,078	1,197	2,573	-	474	-
LBR	27,756	3,699	11,408	20,446	2,047	8,657	12,343	0,811	5,724
MLI	49,735	39,181	20,443	2,156	21,686	0,913	-	8,594	-
MRT	56,701	5,101	23,305	36,942	2,824	15,640	7,303	1,119	3,387
NER	289,035	35,880	118,801	176,625	19,859	74,779	72,619	7,870	33,679
NGA	-	199,916	-	-	110,650	-	-	43,850	-
SEN	34,137	21,349	14,031	-	11,816	-	-	4,683	-
SLE	66,531	7,815	27,346	36,280	4,326	15,360	8,628	1,714	4,001
TGO	52,455	9,762	21,561	28,707	5,403	12,154	-	2,141	-
$\sum$	1,189,001	488,710	488,710	638,891	270,492	270,492	231,137	107,195	107,195

Source: Author's computation based on USDA [2014].

Note: Stocks in mt; S_i^*, $\hat{S}_i$, and $\tilde{S}_i$ are stocks without cooperation, with equal, and relative contributions..

Under storage cooperation, optimal stocking norms can be significantly lower if shortfalls from target consumption levels are independent or not perfectly positively correlated. Setting the shortfall to zero if target consumption is reached, Table 6.8-6.9 yields the correlation matrix of production and supply shortfalls. Clearly, production and supply shortfalls among countries are not perfectly correlated. The highest country-to-country correlation is around 0.8. Notably, Burkina Faso shares relatively high positive shock correlation with six countries. Likewise, Mali, Sierra Leone, and Senegal exhibit positive correlation with a vast majority of countries in the region. As opposed to this, Ghana, Togo, Niger, Benin, and

Cote d'Ivoire show predominantly negative correlation coefficients. These findings underline again potential benefits from storage cooperation.

Finally, results for the region are provided in Table 6.10. The first column reveals the probability of shortfalls in production and supply, respectively.[28] For both production and supply the remaining columns contain the optimal level of stocks for three distinct scenarios. First, optimal stocks without storage cooperation under autarky. Second, stocks for the case of equal contributions to the regional reserve.[29] Lastly, stocks with relative contributions to the regional reserve required under autarky.

The last row contains the total level of stocks for the whole region if countries operate individual reserves, and if they cooperate. Total stocks for individual storage amount to 3,989,905 mt for production only and 3,788,989 mt for supply, respectively. In contrast, under cooperation, regional stocks only need to be 2,342,642 and 2,452,834 mt. This equals a reduction by 41 and 35 percent compared to the initial amount. The effect for individual countries is equally positive regardless of the rule according to which contributions are shared. Benefits from cooperation are relatively lower for higher levels of target consumption. With 99 percent and 97 percent target consumption, regional stocks under cooperation are around 25 percent, respectively 30 percent, lower than without cooperation. Against this, benefits from cooperation are relatively greater with target consumption of 90 percent. Accordingly, regional stocks could be 62 percent lower with regional cooperation vis-à-vis without cooperation. With few exemption (Guinea and Nigeria), countries benefit from cooperation under both equal and relative contributions to the reserve. With relative contributions to the regional reserve, all countries always need to store less than without regional cooperation.

[28] The probability of shortfall is computed from historic shortfalls.

[29] Equal contributions imply, proportionally equal to a country's share in regional consumption.

Table 6.8: Correlation of production shortfalls from 95 % target consumption

	BEN	BFA	CIV	CPV	TCD	SEN	GHA	MLI	GIN	GMB	GNB	NER	NGA	CMR	LBR	SLE	MRT	TGO
BEN	1.00																	
BFA	-0.18	1.00																
CIV	-0.11	-0.15	1.00															
CPV	-0.13	-0.04	-0.10	1.00														
TCD	0.39	-0.02	-0.01	-0.01	1.00													
SEN	0.01	0.47	-0.09	-0.04	0.05	1.00												
GHA	-0.10	0.04	-0.03	0.26	-0.11	-0.13	1.00											
MLI	0.14	0.40	-0.03	0.02	0.18	0.45	-0.01	1.00										
GIN	-0.14	-0.00	0.17	0.30	-0.11	0.39	-0.01	0.25	1.00									
GMB	0.08	0.04	0.30	0.11	0.10	0.12	-0.20	-0.04	0.19	1.00								
GNB	-0.13	0.42	-0.16	-0.04	-0.10	0.37	0.02	0.01	0.07	-0.05	1.00							
NER	0.47	-0.21	0.36	-0.13	0.13	-0.09	-0.16	0.08	-0.07	-0.01	-0.15	1.00						
NGA	-0.13	0.71	-0.16	0.08	-0.10	-0.02	0.30	0.05	-0.20	-0.17	0.20	-0.21	1.00					
CMR	0.16	0.23	-0.09	-0.10	-0.19	0.60	-0.14	0.20	0.26	0.03	0.27	-0.15	-0.04	1.00				
LBR	0.04	0.33	-0.11	0.15	-0.07	0.68	-0.06	0.26	0.28	0.20	0.36	-0.11	-0.05	0.58	1.00			
SLE	-0.12	0.07	-0.03	-0.02	0.12	0.17	0.04	0.05	0.20	-0.13	0.03	-0.05	-0.06	0.13	0.14	1.00		
MRT	-0.18	0.77	-0.14	0.08	0.02	0.13	0.32	0.25	-0.09	-0.05	0.25	-0.18	0.80	-0.04	0.06	-0.04	1.00	
TGO	-0.11	-0.19	-0.04	0.25	-0.02	-0.15	0.03	-0.03	-0.19	0.18	-0.20	-0.04	-0.19	-0.11	0.22	0.06	-0.17	1.00
# +	7	10	3	8	7	11	7	13	9	10	10	4	6	9	12	10	9	5
# -	10	6	14	9	10	6	10	4	7	7	7	13	11	8	5	7	8	12

Source: Author's computation based on [USDA, 2014].

Table 6.9: Correlation of supply shortfalls from 95 % target consumption

	BEN	BFA	CIV	CPV	TCD	SEN	GHA	MLI	GIN	GMB	GNB	NER	NGA	CMR	LBR	SLE	MRT	TGO
BEN	1.00																	
BFA	-0.18	1.00																
CIV	-0.11	-0.15	1.00															
CPV	-0.13	-0.04	-0.10	1.00														
TCD	0.39	-0.02	-0.01	-0.01	1.00													
SEN	0.01	0.47	-0.09	-0.04	0.05	1.00												
GHA	-0.10	0.04	-0.03	0.26	-0.11	-0.13	1.00											
MLI	0.14	0.40	-0.03	0.02	0.18	0.45	-0.01	1.00										
GIN	-0.14	-0.00	0.17	0.30	-0.11	0.39	-0.01	0.25	1.00									
GMB	0.08	0.04	0.30	0.11	0.10	0.12	-0.20	-0.04	0.19	1.00								
GNB	-0.13	0.42	-0.16	-0.04	-0.10	0.37	0.02	0.01	0.07	-0.05	1.00							
NER	0.47	-0.21	0.36	-0.13	0.13	-0.09	-0.16	0.08	-0.07	-0.01	-0.15	1.00						
NGA	-0.13	0.71	-0.16	0.08	-0.10	-0.02	0.30	0.05	-0.20	-0.17	0.20	-0.21	1.00					
CMR	0.16	0.23	-0.09	-0.10	-0.19	0.60	-0.14	0.20	0.26	0.03	0.27	-0.15	-0.04	1.00				
LBR	0.04	0.33	-0.11	0.15	-0.07	0.68	-0.06	0.26	0.28	0.20	0.36	-0.11	-0.05	0.58	1.00			
SLE	-0.12	0.07	-0.03	-0.02	0.12	0.17	0.04	0.05	0.20	-0.13	0.03	-0.05	-0.06	0.13	0.14	1.00		
MRT	-0.18	0.77	-0.14	0.08	0.02	0.13	0.32	0.25	-0.09	-0.05	0.25	-0.18	0.80	-0.04	0.06	-0.04	1.00	
TGO	-0.11	-0.19	-0.04	0.25	-0.02	-0.15	0.03	-0.03	-0.19	0.18	-0.20	-0.04	-0.19	-0.11	0.22	0.06	-0.17	1.00
# +	7	10	3	8	7	11	7	13	9	10	10	4	6	9	12	10	9	5
# -	10	7	14	9	10	6	10	4	8	7	7	13	11	8	5	7	8	12

Source: Author's computation based on [USDA, 2014].

Noteworthy, a regional reserve without integration of markets or transfers between countries is required to act significantly more often than national reserves as the probability of shortfalls increases. Hence, the total quantity needed to compensate for production and supply shortfalls is equal with or without storage cooperation. Benefits from cooperation emerge from the lower levels of stocks carried only. However, these benefits are substantial as countries also require to renew their reserve stocks on a regular base, even if they are not used to offset supply shocks.

TABLE 6.10: Optimal stock levels in 2014 for target consumption of 95 %

	Production				Supply			
	P_i	S_i^*	$\hat{S}_i$	$\tilde{S}_i$	P_i	S_i^*	$\hat{S}_i$	$\tilde{S}_i$
Benin	26%	98,832	68,249	58,004	29%	103,195	66,181	66,804
Burkina Faso	26%	461,771	209,158	271,009	29%	407,983	182,765	264,111
Cameroon	11%	163,986	134,570	96,242	14%	148,788	146,499	96,319
Cape Verde	43%	7,572	298	4,444	40%	14,144	885	9,156
Chad	37%	301,534	79,510	176,968	31%	278,533	73,389	180,311
Cote d'Ivoire	14%	84,520	55,554	49,604	20%	99,615	97,416	64,487
Gambia, the	34%	70,230	9,566	41,217	43%	34,589	12,069	22,391
Ghana	17%	287,853	118,080	168,939	26%	366,847	136,789	237,481
Guinea	17%	57,988	99,377	34,033	14%	51,597	96,782	33,402
Guinea-Bissau	29%	21,528	7,566	12,635	31%	20,755	10,768	13,436
Liberia	31%	20,306	7,941	11,918	31%	44,203	18,083	28,615
Mali	37%	216,774	243,921	127,223	31%	223,631	199,491	144,770
Mauritania	46%	49,666	9552	29,149	29%	91,279	25,604	59,090
Niger	29%	607,626	204,524	356,610	31%	503,972	182,173	326,251
Nigeria	17%	928,445	951,527	544,897	14%	977,939	1,010,583	633,077
Senegal	40%	429,613	56,908	252,136	26%	208,432	106,131	134,930
Sierra Leone	31%	105,992	35,788	62,206	31%	119,471	38,301	77,341
Togo	23%	75,671	49,553	44,411	20%	94,014	48,925	60,861
Region	97%	3,989,905	2,342,642	2,342,642	97%	3,788,989	2,452,834	2,452,834

Source: Author's computation based on USDA [2014].

Note: Stocks in mt. P_i is the probability of intervention when production and supply are below the target consumption (95%). S_i^*, $\hat{S}_i$, and $\tilde{S}_i$ are stocks without cooperation, with equal, and relative contributions.

Last, what are the welfare implication from the simulation results above? First and most importantly, with reasonably high levels of target consumption optimal stocking norms can be selected so that all countries benefit. However, preferences are not homogeneous and low levels of target consumption discriminate countries with low supply variability. Since preferences of countries cannot be observed, net benefits with heterogeneous preferences are possible to judge only in two instances. Firstly, in the case target consumption chosen by the region is lower than for a country without cooperation, while stocking norms are lower in cooperation. Then, a country benefits from cooperation. As opposed to this, net benefits from cooperation are unambiguously negative if target consumption under cooperation is higher than under regional cooperation and stocking norms are higher than without cooperation. Indeed, the latter can be excluded by choosing target consumption levels above 90 percent. Intuitively, countries with large supply variability prefer equal contribution to the regional reserve. Yet it is important to create incentives for all countries to join the reserve in order to utilize full benefits from cooperation.

6.5.2.2 Emergency reserve with intra-regional trade

When allowing intra-regional trade, the analysis is analogous to the scenario without trade. So, maximum historic shortfalls and associated stocking norms in autarky remain unchanged. The only difference is that supply shortfalls in neighboring countries are balanced through trade first, before the reserve releases stocks. Participating countries are committed to export only when actual supply exceeds estimated supply as computed by the HP-filter.

TABLE 6.11: Regional stocks for an emergency reserve with intra-regional trade

	Production				Supply			
	99%	97%	95%	90%	99%	97%	95%	90%
stocks w/o trade	4,122	3,193	2,342	1,074	4,717	3,561	2,453	642
P(shortfall)	100%	100%	97%	89%	100%	97%	97%	89%
stocks w/ trade	4,011	3,082	2,231	963	4,615	3,460	2,352	465
P(shortfall)	43%	34%	26%	17%	37%	26%	20%	6%

Source: Author's computation based on USDA [2014].

Note: In 1,000 mt.

Table 6.11 presents required stocks with intra-regional trade in comparison to the scenario without intra-regional trade. Apparently, trade hardly reduces the level of required stocks. Most notably are gains when stocks are based on a consumption shortfall of 10 percent.

The results of the simulation are explained by the choice of the criterion to determine reserve levels according to historic consumption shortfalls. The historically largest shortfall occurred in 2007, while only very few countries would have been able to export in this year. These exports are not high enough to offset supply shortfalls of other countries.

On the contrary, regional trade would reduce the frequency of stock-outs significantly. So, the probability of shortfall is maximum 43 percent as compared to between 89 and 100 percent across all levels of target consumption for the emergency reserve without intra-regional trade. Allowing for five percent shortfall in consumption, with intra-regional trade the probability of shortfall is only between 20 and 26 percent for supply and production, respectively.

Table 6.12: Annual average intra-regional exports by country

	production		supply	
	$\overline{T_i}$	$\frac{\overline{T_i}}{C_{2014}}$	$\overline{T_i}$	$\frac{\overline{T_i}}{C_{2014}}$
Benin	24,352	1.32%	26,835	1.46%
Burkina Faso	113,461	2.15%	112,928	2.14%
Cameroon	31,839	0.76%	31,904	0.76%
Cape Verde	1,240	4.59%	2,139	7.92%
Chad	59,531	2.92%	56,633	2.78%
Cote d'Ivoire	20,767	0.73%	39,873	1.41%
Gambia, the	9,195	2.55%	11,897	3.30%
Ghana	57,546	1.50%	65,885	1.72%
Guinea	20,894	0.74%	23,943	0.85%
Guinea-Bissau	4,949	1.60%	6,145	1.98%
Liberia	5,814	1.10%	11,604	2.19%
Mali	103,132	1.83%	101,559	1.80%
Mauritania	13,147	1.81%	16,164	2.23%
Niger	145,487	2.80%	141,980	2.74%
Nigeria	405,876	1.38%	414,309	1.41%
Senegal	71,668	2.29%	56,365	1.80%
Sierra Leone	20,098	1.85%	23,255	2.14%

Continued on next page...

... Table 6.12 continued

	production		supply	
	$\overline{T_i}$	$\frac{\overline{T_i}}{C_{2014}}$	$\overline{T_i}$	$\frac{\overline{T_i}}{C_{2014}}$
Togo	19,467	1.43%	20,299	1.49%
Total	1,128,463	1.60%	1,163,716	1.65%

Source: Author's computation based on USDA [2014].

These advantages come from annual exports as presented in Table 6.12. Average annual exports range between 0.7 to 0.9 percent of total supply in 2014 for Guinea and Cameroon and 4.59 and 7.9 percent for Cape Verde. By the formula according to which exports are calculated, countries with higher production and supply fluctuations automatically export more than countries with less variation. This occurs since these countries exhibit greater negative and positive deviations from the trend. Generally, exports are at a realistic magnitude. Net welfare benefits can be computed analogous to the case without intra-regional trade.

6.5.2.3 Transportation costs

It may by naïve to assume costless transportation of grains from surplus to deficiency countries. For this reason, a sensitivity analysis is undertaken by penalizing regional storage cooperation and regional trade in the following way. On the one hand, regional storage cooperation requires coordination among member countries. Thus, it may convincing to assume higher administrative costs to operate the reserve. Therefore, contributed stock levels multiplied by a factor to raise the costs of cooperation. On the other hand, a regional reserve may demand higher transportation costs to ship stocks from ports to the location of the reserve, between the different warehouses of the reserve, and from warehouses to deficient regions.

Lets consider a regional reserve with relative contributions $\tilde{S}_i$ which are proportional to the stocking norms without cooperation. Since stocks under cooperation are 65 percent of regional stocks without cooperation, additional transportation under cooperation costs are allowed to be up to 35 percent in order to make cooperation still beneficial. The problem of high probability of intervention still does not change.

Table 6.13: Optimal regional stock levels with costly trade and contributions

		Production				Supply			
Trade costs		99%	97%	95%	90%	99%	97%	95%	90%
0%	stocks	4,011	3,082	2,231	963	4,615	3,460	2,352	465
	stocks & trade	5,139	4,210	3,359	2,091	5,779	4,624	3,516	1,629
P	stock-outs	43%	34%	26%	17%	37%	26%	20%	6%
10%	stocks	4,022	3,093	2,242	974	4,626	3,470	2,361	474
	stocks & trade	5,150	4,221	3,370	2,102	5,790	4,634	3,525	1,638
P	stock-outs	43%	34%	29%	17%	46%	26%	20%	9%
20%	stocks	4,033	3,104	2,253	985	4,636	3,480	2,371	485
	stocks & trade	5,161	4,232	3,381	2,113	5,800	4,644	3,535	1,649
P	stock-outs	46%	34%	34%	20%	54%	29%	23%	9%
Costly contribution 10%									
0%	stocks	4,412	3,390	2,454	1,059	5,077	3,806	2,587	512
	stocks & trade	5,540	4,518	3,582	2,187	6,241	4,970	3,751	1,676
P	stock-outs	43%	34%	26%	17%	37%	26%	20%	6%
10%	stocks	4,424	3,402	2,466	1,071	5,089	3,817	2,597	521
	stocks & trade	5,553	4,531	3,595	2,200	6,252	4,981	3,761	1,685
P	stock-outs	43%	34%	29%	17%	46%	26%	20%	9%
20%	stocks	4,436	3,414	2,478	1,084	5,100	3,828	2,608	534
	stocks & trade	5,565	4,543	3,607	2,212	6,263	4,992	3,772	1,697
P	stock-outs	46%	34%	34%	20%	54%	29%	23%	9%
Without cooperation		5,816	4,818	3,990	2,582	6,185	4,957	3,789	1,726

Source: Author's computation based on USDA [2014]

Note: In 1,000 mt; Trade is always 1,128 mt (production only) and 1,164 mt (supply); *P* is the probability of stock-out given the respective level of target consumption.

Table 6.13 contains stock levels and probabilities of intervention for coordination costs and additional transportation costs. As expected, assuming higher transport costs has little influence on regional reserves. Besides, the probability of intervention increases substantially for a regional reserve that guarantees target consumption levels of 99 percent. For all remaining levels of target consumption, stock-outs do not change significantly.

Notably, this exercise underlines the benefits from cooperation even if regional storage co-operation is associated with additional costs from coordination and transportation. In fact, transportation costs also arise without regional cooperation. Similarly, it is also reasonable to assume that storage cooperation could be characterized through lower administrative costs using economies of scale. Furthermore, reciprocal monitoring could also impede rent seeking behavior of bureaucrats and general leakage in the system.

6.5.3 Stabilization reserve

The optimal stocking rule under national stockholding can be estimated using actual stock data. For reasons discussed previously, the stock data from FAO GIEWS is preferred and utilized in this analysis. The stocking parameter can be obtained by estimating following equation with OLS:

$$S_{it} = \gamma_i(S_{t-1} + Q_{t-1} + IM_{t-1} + EX_{t-1}) + \epsilon_{it} \tag{6.30}$$

where all variables are as described above.

Notably, the constant is omitted in the estimation. First, storage is non-negative and negative values for stocks are not possible. Second, stocks need to increase with supply starting from zero if supply is zero. The estimation is associated with several problems (non-stationarity, number of observations) and results have to be interpreted with caution. Albeit, the objective is not to establish causality or to compute confidence intervals. Instead, it is attempted to obtain country preferences without storage cooperation. Regression tables are not discussed in the text but appear in the Appendix G (Table G.4). Results are presented in Figure 6.3 which depicts the stocking parameter γ conditional on the level of supply variability estimated by the coefficient of variation around a trend as described above.

The red line represents the overall positive correlation between supply variability and the stocking rule. A slope parameter of 0.30 implies that on average the stocking parameter increases by three percentage points when supply variability is 10 percentage points higher.[30] Yet there are notable exemption of the relationship.[31] Niger, Sierra Leone, and Nigeria store only six percent of its total available supply although supply variability is relatively high. In contrast, the Gambia and Chad experience similar supply variability as Niger, but store

[30]When Cape Verde is excluded the slope parameter changes only marginally.

[31]Be reminded that an increase of 0.1 is quite substantial regarding the range of γ between zero and one.

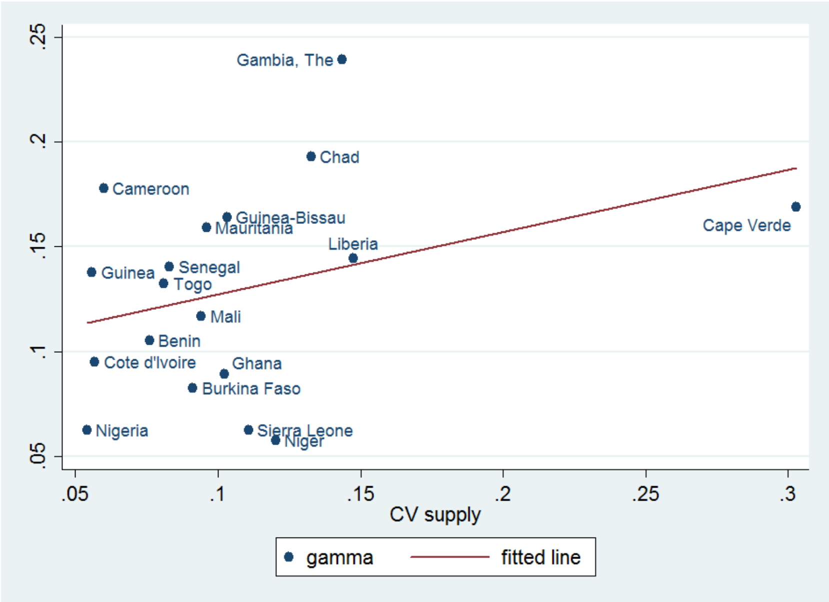

FIGURE 6.3: Stocking parameter and supply variability across study countries.

Source: Author's illustration based on USDA [2014] and FAO CBS [2014].

24 and 19 percent respectively. All other countries in the region store roughly between eight and 17 percent. Taking the sum of individual stocks as optimal choice for the region, it averagely stores around nine percent of its annual supply due to the low value for Nigeria.

Using the policy parameter, it is possible to compute resulting consumption variability as chosen by each country. Figure 6.4 draws consumption and supply variability by country.[32] The red line represents parity of consumption and supply variability, where countries without storage lie. Storage reduces consumption variability, and thus all countries are below the red line. Two observations can be made. Firstly, the larger the stocking parameter γ, the farther away from the parity line are countries. Secondly, with lower supply variability it is less efficient to decrease consumption variability by increasing storage by one unit. Accordingly, Cameroon requires to store 18 percent of its total available supply to reduce consumption variability by one percent. In contrast, Ghana achieves a reduction in consumption instability of 0.8 percent by only storing nine percent of its available supply.

The costs of stabilization are already described by the stocking parameter γ. The full dimension of the costs become more visible when looking at the amount of stocks required to reach a desired level of consumption stability. Table 6.14 presents optimal stocks levels and stock-to-use ratios for γ given by the country-level stock data and compares them to

[32]Due to scaling issues Cape Verde is excluded from the graph. A representation including Cape Verde can be found in the Figure G.36 in Appendix G.

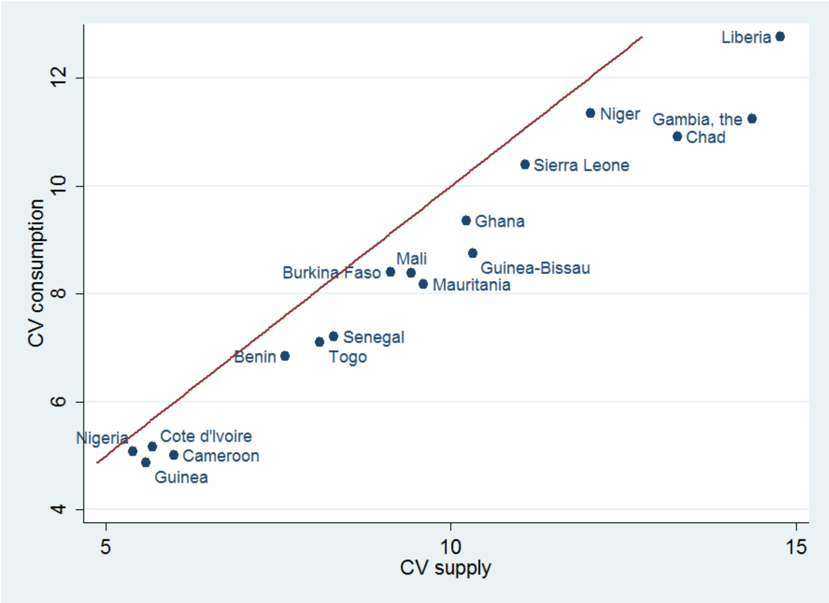

FIGURE 6.4: Consumption and supply variability across study countries.

Source: Author's illustration based on USDA [2014] and FAO CBS [2014].

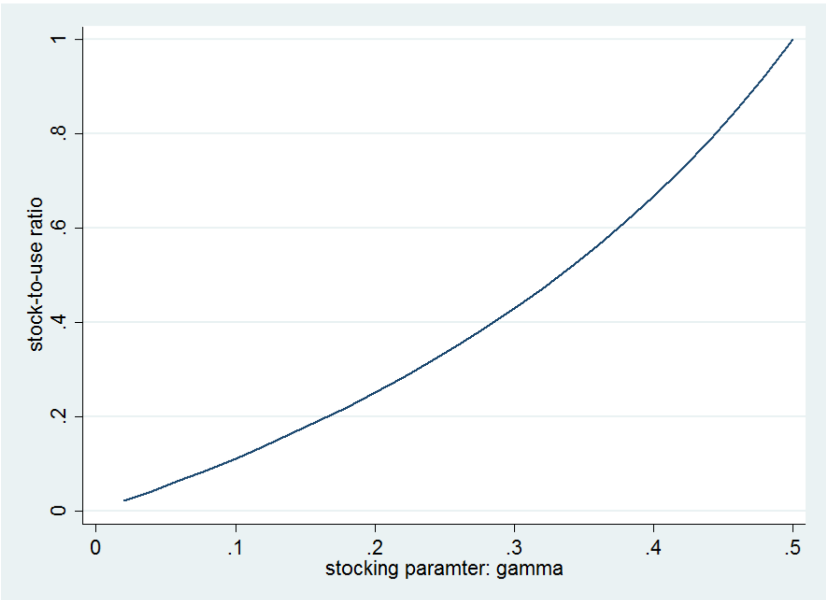

FIGURE 6.5: Relationship between stocking parameter and stock-to-use ratio.

actual levels. The resulting stock-to-use ratio is $\alpha = \frac{\gamma}{1-\gamma}$, and thus just correspond to γ in an exponentially positive way.[33] The relationship is pictured in Figure 6.5. With $\gamma > 0.5$, stocks already amount to expected consumption levels with a stock-to-use ratio greater than one. Generally, the linear stocking predicts actual stocks and stock-to-use ratios quite precisely.

TABLE 6.14: Actual and optimal stock under linear stocking rule

	γ^*	CV_C	S^*	S_{2013}	α^*	α_{2013}
Benin	0.105	6.8	220,802	162,000	11.8	12.8
Burkina Faso	0.083	8.4	466,615	495,000	9.0	8.5
Cameroon	0.178	5.0	899,228	866,000	21.7	16.0
Cape Verde	0.169	25.5	5,089	7,000	20.3	20.3
Chad	0.193	10.9	496,928	564,000	23.9	22.3
Cote d'Ivoire	0.095	5.2	290,463	467,000	10.5	9.3
Gambia, the	0.239	11.2	107,609	48,000	31.5	30.4
Ghana	0.089	9.4	379,520	325,000	9.8	9.2
Guinea	0.138	4.9	438,248	511,000	16.0	14.3
Guinea-Bissau	0.164	8.7	59,828	69,500	19.6	17.3
Liberia	0.144	12.8	86,482	56,000	16.9	14.7
Mali	0.117	8.4	746,375	855,000	13.2	10.1
Mauritania	0.159	8.2	137,177	95,500	18.9	20.7
Niger	0.057	11.4	314,910	522,000	6.1	5.4
Nigeria	0.063	5.1	1,915,352	850,000	6.7	7.0
Senegal	0.140	7.2	491,235	492,000	16.3	16.2
Sierra Leone	0.063	10.4	72,532	87,000	6.7	5.3
Togo	0.132	7.1	211,342	171,000	15.2	14.9
$\sum$ Region	-	3.1	7,063,305	6,643,000	-	10.3

Source: Author's computation based on USDA [2014]. Stock data from FAO CBS [2014].

Note: γ is obtained by the regression (6.30); CV consumption is computed as $\text{CV}_C = \sqrt{\frac{(1-\gamma)}{(1+\gamma)}}\ \text{CV}_(Q+IM)$ (see equation 6.28); the regional γ is unknown.

[33]See Appendix F for a detailed derivation.

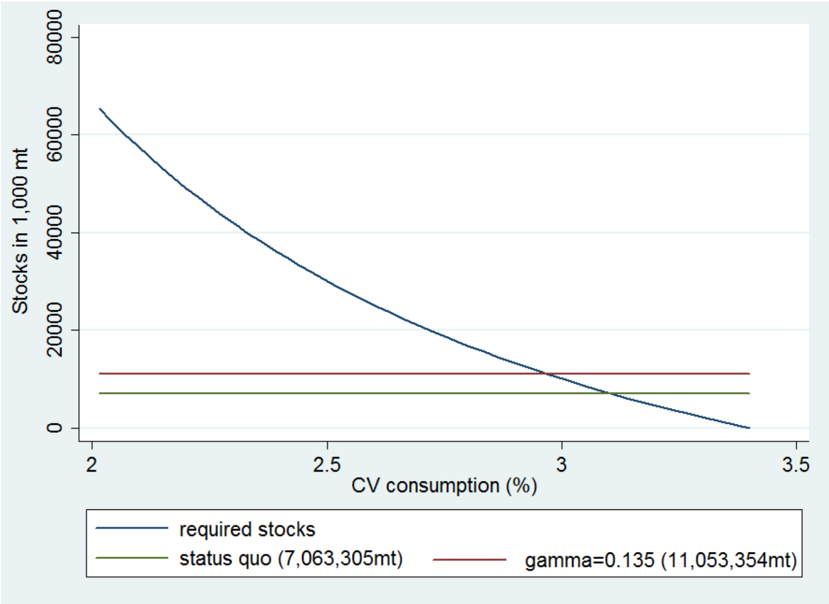

FIGURE 6.6: Regional consumption variability at different stock levels.

Source: Author's illustration based on USDA [2014] and FAO CBS [2014].

The last row of Table 6.14 provides stock figures for the region as a whole. Given the current stock level of around 7 million tons, the regional stocking rule would be nine percent which is associated with a consumption variability of 3.4 percent without storage to 3.1 percent. It is also possible to illustrate the initial optimization problem of the government directly as the trade-off between costs and benefits. More concretely, the trade-off between consumption stability and operational costs. Figure 6.6 pictures the trade-off for the region as a whole. The red line indicates the status quo of roughly seven million tons of stocks associated with a coefficient of variation for consumption of 3.1 percent. The green line represents a stock level of 11.1 million tons resulting from a stocking parameter of 0.135, which is the median parameter across all member countries.

The amount of stocks required increases over-proportionally in the reduction of consumption instability. So, in order to reach consumption stability up to only 2.7 percent, the region would require roughly 20 million tons of stocks. On the other hand, without any stocks required consumption variability through market integration or transfers between countries is only 3.4 percent, two percent less than for Nigeria which has the lowest supply variability. As a result, most gains origin from trade integration and not from storage cooperation. In other words, under regional trade integration consumption stability is massively enhanced, but increasing stocks have only little impact on the level of consumption variability. Benefits from regional trade cooperation are massive. Indeed, individual stabilization reserves by all

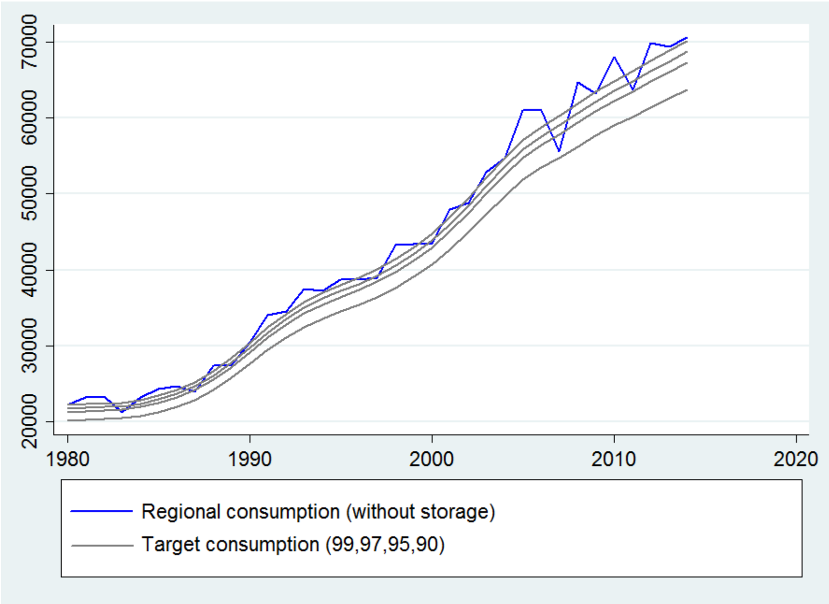

FIGURE 6.7: Regional consumption under trade integration without storage 1980-2014.

Source: Author's illustration based on USDA [2014].

countries would need an unrealistically large amount of stocks to achieve a consumption variability of 3.4 percent.[34]

Costs and benefits of cooperation can be evaluated for a particular level of consumption variability the region desires. Net benefits and costs can be assessed as discussed in the theoretical part. Thus, net benefits are strictly positive for all countries upto a stock-to-use ratio of 6.1 percent for Niger, 6.7 for Nigeria and Sierra Leone, 9.0 for Burkina Faso, 9.8 for Ghana, continuing in the same manner according to α_i^* in Table 6.14.

Lastly, it is possible to test how a linear stocking rule would have performed over the course of the last 35 years. This is illustrated in Figure 6.7 and 6.8 with associated target consumption levels. Despite regional trade integration, target consumption levels of 99 percent, 97 percent, and 95 percent are undershot multiple times.[35] Thus, regional trade integration reduces consumption variability significantly, but is unable to combat severe supply shortfalls. Conversely, a linear stocking rule that guarantees net benefits from cooperation for all countries (α=6.1 percent) would have guaranteed target consumption of 97 percent over the whole period (Figure 6.8).

[34]Table G.5 in Appendix G presents stocking parameters and stock-to-use ratios for all countries if they would attempt to achieve consumption stability as regional trade integration, with and without storage cooperation, does.

[35]To be exact, shortfalls are accordingly: 99 percent - 11 times ,97 percent - 7 times, and 95 percent - 3 times.

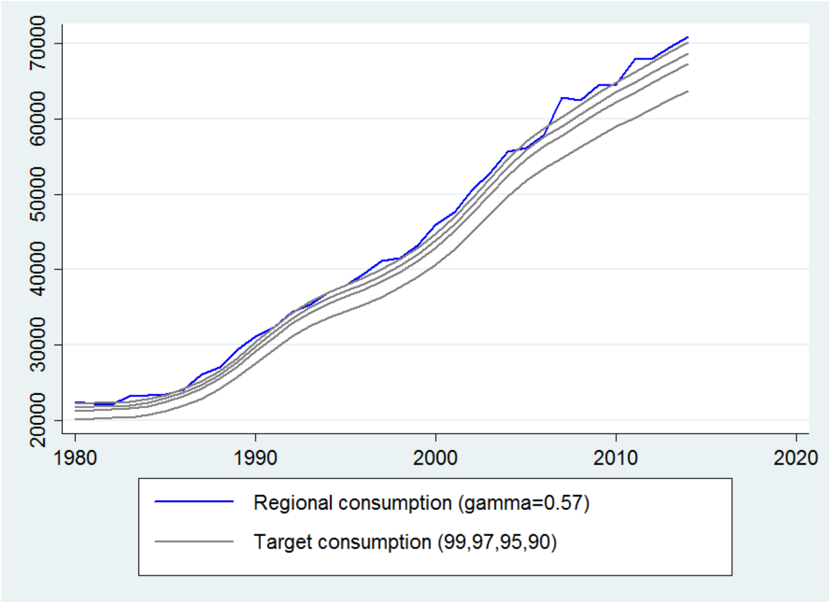

FIGURE 6.8: Regional consumption under a linear stocking rule 1980-2014.

Source: Author's illustration based on USDA [2014].

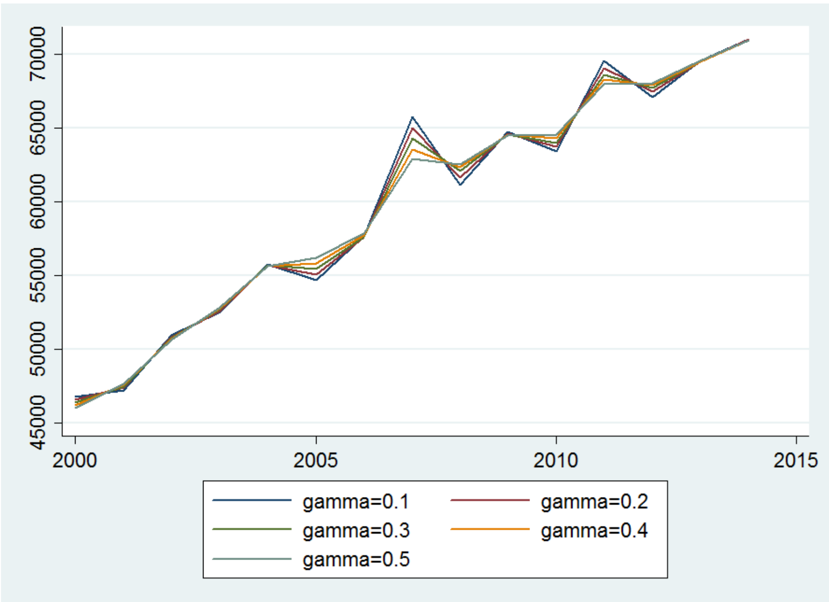

FIGURE 6.9: Regional consumption under different stocking rules 2000-2014.

Source: Author's illustration based on USDA [2014].

Clearly, a linear stocking rule is effective in buffering positive and negative supply shock as pictured in Figure 6.9 for various stocking parameters. However, the effects are rather small as compared to benefits from trade integration within the whole region. This may change if the number of participating countries reduces.

6.6 Conclusion

In this chapter a methodology for the assessment of costs and benefits from regional storage cooperation is outlined and exercised for the West African region. Building on the influential works by Johnson [1976] and Koester [1986], the methodology links supply and consumption variability and accounts for potential benefits from cooperation through imperfect correlation of production and supply shocks among neighboring countries. In doing so, the work complements previous studies by conceptualizing the link to storage.

The principles of risk pooling allow to reduce carry-over stocks, to guarantee at least 95 percent of the expected trend consumption, within West Africa by 35 to 41 percent without welfare transfers or trade between countries. For other levels of minimum consumption, the benefits are between 25 to 60 percent. However, in this way releases from the reserve occur frequently and stocks need to be re-filled on a regular basis. If limited intra-regional trade takes place between surplus and deficiency areas, optimal regional stocks under cooperation hardly change. However, the probability of intervention reduces significantly. So, trade is very effective to smooth consumption when supply fluctuations are moderate. In contrast, reserves are required to dampen large supply shortfalls. These benefits hold when assuming additional costs of transportation for trade and storage. Lastly, complete market integration in West Africa would greatly benefit countries with high supply variability. Without any storage undertaken, regional supply variability is 3.4 percent which is higher for each country included in the analysis. Storage cooperation with perfect market integration would reduce consumption variability only marginally. Furthermore, trade integration without storage is incapable of dampening severe supply shortfalls as an emergency reserve does.

It is also important to discuss incentives for countries to join a regional reserve. Under relative low levels of target consumption in an emergency reserve, countries with low supply variability do not benefit. Yet these countries are of particular importance to utilize the full benefits from regional cooperation. The advantages of cooperation diminish rapidly when countries with limited supply variability or counter-cyclical shock patterns refuse to participate in the alliance. However it should be noted, an regional emergency reserve guaranteeing relative high levels of target consumption needs to carry large amounts of stocks which are associated with high operational costs.

These findings are of great relevance for the ongoing debate on public food storage, trade integration, and regional reserves. Trade liberalization is widely considered as an effective instrument to balance supply variability and production shortfalls. In contrast, public storage is associated with substantial market distortions and comes at high fiscal costs. Nevertheless, a number of developing countries responded to the global food crisis in 2007/2008 by implementing and enhancing public storage to increase food security. This is also driven by the unpredictability of food availability at international markets as exporters attempt to insulate domestic markets. Regional storage cooperation was brought up for discussion as a viable and comparably cheap means and as an alternative to national reserves. Moreover, storage cooperation could enhance commitment of exporters to regional trade agreements [Wright and Cafiero, 2011].

West Africa has taken a pioneering role with the intention to implement a region-wide emergency reserve. Political and economic integration in West Africa is among the most advanced in Africa. However, at present, intra-regional trade is limited partly caused by bad infrastructure and bureaucratic hindrances at national boundaries. The results from this study should be understood as encouragement to regional storage cooperation in the region. Three message can be taken away. First, production and supply patterns in the region facilitate massive benefits from cooperation. Second, trade integration is more effective than storage to smooth supply effectively, but storage is required to dampen extreme supply shortfalls. Last, there is great potential for storage cooperation with regard to an emergency reserve and less with regard to a stabilization reserve. Yet clear rules with regard to national contributions and releases and, if needed, to regional trade management are essential to organize storage with mutual benefits. Therefore, future research should attempt to evaluate costs and benefits for a subset of countries with the attempt to identify countries that are particularly feasible to form a coalition.

Chapter 7

Conclusion

The conclusion completes this dissertation. It has a special function insofar as each analytical chapter already closes with a summary and discussion of its finding. Therefore, the main objective of this last chapter is to draw results together and to take them as a whole further into policy implications. The conclusion concentrates on the chapters four to six which answer the research questions raised in the introduction.

7.1 Summary of the findings

Price volatility and the recent price spikes in agri-food markets have been a prominent subject among scholars and policy makers. Research has focused a lot on causes of international price spikes and volatility as well as the micro-consequences of food crises on the poor. The contribution of this study is to look at markets in developing countries and to examine which factors cause price fluctuations and which factors can contribute to price stabilization and food security. In doing so, the dissertation contributes to the current political debate on food price volatility and possible government responses to reduce market volatility. Thereby, the study makes use of econometric techniques as well as the construction of a theoretical model in which national consumption is stabilized through storage. Furthermore, primary data collection is used in order to gain insights in the trading business in Ghana.

In detail, the dissertation was set out to explore the causes of food price instability in developing countries, the role of stocks and trade to stabilize commodity prices, the storage behavior of private traders in Ghana as well as its implication for policy design, and last to theoretically discuss costs and benefits from regional storage cooperation and to apply the model to West Africa. First, an econometric panel analysis is employed to determine drivers of food price volatility in developing and emerging economies in the period from 2000 to 2013. Then, storage patterns and stockholding strategies of traders in Ghana are analyzed combining existing research and secondary data with primary data collection. Finally, costs and benefits from storage cooperation are examined based on a theoretical model in which countries stabilize national consumption through storage.

Following the introduction, which describes the context and motivation of the dissertation, chapter two and three introduce the reader to volatility modeling and the competitive storage model which is the workhorse to explain price formation of storable commodities. The analysis in chapter two supports the general notion that food price volatility has increased during 2007/2008 but decreased afterwards. Furthermore, volatility deviates across countries and crops. Markets in southern and eastern Africa exhibit the highest price volatility, while markets in Latin America and Asia are more stable. Last, unconditional and conditional food price volatility yield to very similar research results, whereby conditional volatility models are associated with estimation problems in some rare cases. The results of this exercise can be used for vulnerability mapping and extensive cross country analysis.

In chapter three, the competitive storage is introduced. Notably, the literature acknowledges shortcoming of the classical model with respect to the heterogeneity of stockholders in their strategies and risk preferences. However, they have not been sufficiently accounted for in empirical research. Additionally, this part of the dissertation also discusses availability and quality of fundamental agricultural data. In particular stock data is likely to be imprecise due to limited financial resources for data collection. The newly established Agricultural Market Information System (AMIS) aims improving data quality and market information by consolidating existing data.

Chapter four employs a cross-country-cross-commodity panel to investigate the impact of a wide range of explanatory variables on food price volatility in developing countries. The econometric model successfully accounts for persistence of volatility, dynamic panel bias, and takes care of the endogeneity of some of the explanatory variables. Different to many other studies, a strong spillover of international volatility into domestic food markets is identified. The effects are particularly strong for importing countries. Furthermore, stocks are found to be an effective instrument to stabilize prices. Likewise, regional trade integration is associated with fewer volatility. Institutional quality also strongly stabilizes commodity prices. With respect to policies the evidence is mixed. Export restrictions, so called insulation policies, significantly reduce volatility. In contrast, no evidence is found that countries with high market intervention through storage are characterized by lower food price volatility.

The country case study in chapter five sheds light on storage behavior of traders in Ghana. This is of great relevance to policy makers who are concerned with the private sector's reactions to public market interventions. The findings are largely drawn from a survey among 36 wholesale traders conducted by the author at major market sites. The large seasonality in prices of locally produced foodstuffs is often attributed to limited storage. Data on storage and transport costs suggests that storage costs alone can be responsible for existing seasonal price increases. Instead, high transportation costs to the storage facility inflate commodity prices. In contrast to earlier studies, stock data collected from wholesale traders hint at significant stocks held by wholesale traders, in particular towards the end of the marketing year. The risk of price declines in the sequel of the incoming harvest induces traders to deplete their stocks timely. This may cause early stock-outs followed by short and sharp price spikes.

Furthermore, the trader survey revealed significant heterogeneity across traders. On the one hand, several traders act as aggregator and distributor and take limited risk from inter-temporal arbitrage. Instead, they stock exclusively to sell their products in bulk. On the other hand, several traders speculate for an inter-seasonal price increase. By the nature of distinct strategies, seasonal variation in stocks varies significantly across traders. At the same time, traders with resembling seasonal storage pattern can be grouped together. Aggregation stocks increase after harvest and abruptly fall to zero when a deal is settled. Theoretically, afterwards stocks can be built up again. Speculative stocks seem to increase towards the end of the marketing year and drop before the incoming harvest. In contrast, working stocks are constant throughout the year. The drivers of the underlying decision making process cannot definitely be clarified by the data from this survey.

The study on regional storage cooperation in chapter six starts by providing a theoretical model to determine optimal stocking norms for an emergency reserve as well as a stabilization reserve. The former addresses supply shortfalls only, while the latter smoothes both positive and negative deviation from the expected trend in supply. The model conceptualizes the link between supply variability and consumption and explains the possibility to stabilize consumption through stocks. In West Africa, storage cooperation without intra-regional trade reduces required stocks for a common emergency reserve by 25 to 60 percent vis-à-vis without cooperation conditional on the level of target consumption chosen. In case limited intra-regional trade is possible, countries ship excess supply from surplus to deficiency countries, required stocks will hardly change, but the probability of intervention diminishes significantly. Different to an emergency reserve, a regional stabilization reserve requires complete market integration. In this case, regional trade integration alone, without storage, reduces regional consumption variability to 3.4 percent, which is lower than for any individual country in West Africa. Yet trade is incapable of dampening severe supply shortfalls. A regional stabilization reserve in addition to trade has only limited power to further reduce consumption instability.

7.2 Policy implications, limitations, and further research

The results of the cross-country panel provide empirical evidence on a number of explanatory variables. Strikingly, there is clear evidence for volatility transmission from international to domestic food prices. This contradicts conventional wisdom and research findings from price transmission analysis using co-integration and vector-error-correction model techniques. The weaknesses of these models are extensively discussed in the literature [Lütkepohl, 1982; Stern, 2011; Grosche, 2014]. Most importantly, it is difficult to establish true causality due to the omission of relevant variables. Secondly, findings from co-integration based price transmission models in existing studies like Minot [2011], Robles [2011], and Baquedano and Liefert [2014] are greatly inconsistent.

The evidence for the existence of volatility spill-overs from international markets is striking for two reasons; first, they result from a structural model that controls for counterfactuals; and second, they are at a considerable range between 30 to 50 percent. Therefore, they should encourage policy makers to re-direct the interest to control variability of international prices. Unlike multivariate conditional volatility models used by Rapsomanikis and Mugera [2011] and others, the panel model is not able to capture asymmetric behavior. Accounting for heterogeneity of countries as well as trade and storage policies gives indication on the relevance of state dependent models. Thus, future research should focus on possible asymmetries in the transmission mechanism and with respect to public market interventions.

Findings from chapter four are based on a cross-country analysis and estimates represent on average effects. However, the results support economic theory and have strong implications for policy makers. First, the stock-to-use ratio is the major driver of price dynamics as postulated by the competitive storage model. With few exemptions, this relationship has not been identified empirically with actual stock data as explanatory variable in the regression model. Second, institutional quality, compromising infrastructure, economic freedom, mobile penetration, and the presence of a commodity exchange, reduces price instability strongly. Third, regional trade integration has great potential to stabilize markets. Fourth, extensive public storage is not associated with lower price volatility. All of these results go into the same direction. Generally speaking, markets are found to have a strong price stabilizing effect. This should be understood as a main argument against public intervention and for the liberalization of markets.

On the other hand, restrictive trade policies seem to isolate domestic from international markets. Furthermore, storage in many developing countries is not sufficiently high and governments are asked to use public means to increase the overall level of stocks to protect consumers. Yet public storage cannot be introduced at a short notice and for a short time period. Instead, storage structures need to be in place and effectively managed to have the capacity to intervene when needed.

As a limitation of the analysis, the effect of agricultural policies on price volatility may not be adequately measured as restrictive generalization are necessary to incorporate variables into the model. The differences between general price volatility, irregular price changes, and abrupt prices spikes are also not sufficiently explored. Moreover, it should be aimed at gathering short term stock data to test the model in a particular country.

The case study on private trade and storage provides detailed insights on how grain markets in Ghana, and possibly in other comparably countries, actually work. A number of issues seem to be of particular relevance. First, stock-outs of traders at the end of the marketing year are likely responsible for occasional price spikes as hypothesized by the existing literature. However, there may be ways to counteract. On the one hand, creating an incentive for traders to hold on stocks by hedging their risk from losses after price declines in consequence of the incoming harvest. This could be achieved by a commodity exchange or by providing access to international exchanges. On the other hand, public storage to offset absent private stocks at the later time of the marketing year. Currently, the National Food Buffer Company (NAFCO) maintains a total of intervention and emergency stocks of about 40,000 and 25,000 metric tons for maize and rice, respectively. This corresponds to national consumption of approximately one week. By the way of comparison, imports from the United States or Asia require a minimum of three to four weeks of time. Therefore, stocks would need be expanded to at least bridge the time until imports arrive. More significant public intervention will also lead to private sector responses. To avoid a crowding-out of private investment, the government should solely rely on emergency stocks which are not held with the intention to regulate prices unless a severe food crisis is evident.

Then, the cost component of storage and trade should be taken into account. The survey yielded relative low costs of storage as compared to the price of the commodity. Hence, sole costs of storage cannot be responsible for an intra-annual price spread of up to 60 percent. In contrast, transport costs constitute for a relatively large proportion of commodity prices. Storage facilities are often located at urban centers due to the proximity to processing companies and in order to exploit economies of scale. Therefore, costs of storage also involve the transport to the storage facility and from the storage facility to the wholesale market where the commodities are sold. This inflates the cost of storage. The government could reduce these costs by providing storage facilities closer to production areas. This could be in the form of a warehouse receipt system. Thereby, both traders and farmers could store relatively small amounts at relatively low prices. As a side effect, this would also reduce post-harvest losses significantly.

In line with the literature on heterogeneous traders, the data suggests that wholesale traders in Ghana follow distinct stockholding strategies. Roughly three strategies can be identified: firstly, an aggregating strategy which is used to accumulate stocks to sell them in bulk to large wholesale traders, NAFCO, or processing companies; secondly, traditional speculation with the goal to benefit from a seasonal increase in prices; lastly, working stocks in order to be in the position to constantly supply to other traders or retailers. This has important implications for policy making since the reaction to policy intervention varies within the group of traders. At the same time, the heterogeneity can be exploited by encouraging a particular business model.

The country case study is accompanied by several limitations. In particular three aspects are of great relevance. First, on-farm storage is still not well understood. For instance, it is not clear to what extent and for which purposes farmers hold stocks. Shifting storage from farmers to trader would reduce post-harvest loss significantly. Second, what are the underlying motives of traders to follow different stockholding strategies and what role do price expectations and access to market information play? Third, what are the implication of these research findings on the observed price dynamics? If possible all information collected could be utilized within an intra-annual simulation model that acknowledges heterogeneous stockholders. In this way, a set of policies could be tested and evaluated under realistic market conditions.

The simulation conducted in chapter six contains several important implications for regional storage cooperation. First and foremost, it is shown theoretically and empirically that there is a great potential for regional storage cooperation within an emergency reserve in West Africa. Intra-regional trade of excess supply, at realistic margins, from surplus to deficient countries reduces the probability of stock releases, but does not alter the regional stocking norms significantly. A regional stabilization reserve requires full market integration among member countries. In this instance, intra-regional trade stabilizes consumption variability massively. Yet this is very unlikely, given the present economic reality with large differences in price levels and multiple regional currencies.

Thus, it seems politically feasible to initiate regional storage cooperation within an emergency reserve, albeit disagreements could also arise in an emergency reserve setting. Countries with relative stable national supply advocate for an emergency reserve that guarantees high levels of minimum consumption. This is costly for countries characterized by great supply variability which are satisfied with moderately low levels of minimum consumption. Generally, it holds that: the larger the region, the larger the benefits from cooperation. On the other hand, it must be ensured that countries, who carry most of the benefits from cooperation, can be convinced. These countries exhibit a large share in regional supply and low supply variability. As a matter of fact, larger countries are usually also characterized with relatively stable supply patterns. Apart from this, cooperation within an emergency reserve would allow member countries to continue using agricultural policies. Admittedly, countries would have limited reasons to implement price stabilization programs or the enhance international trade if the reserve covers supply shortfalls [Johnson, 1976]. Likely, a multi-national body would be needed to monitor national policy efforts for food security in order to rule out free-riding of member countries who do under-report national supply levels [Konandreas et al., 1978]. On the other hand, storage cooperation may enhance the commitment to regional trade agreements since they are made partly accountable in case of supply shortage in neighboring countries [Wright and Cafiero, 2011].

The concentration of the model on consumption variability, instead of price volatility, is a simplification. In fact, many of the findings are still similar to those of more advanced partial equilibrium modeling which include commodity prices [Larson et al., 2013; Gouel and Jean, 2015]. Nevertheless, it would be interesting to extend the analysis in this respect. Secondly, incentives for countries to participate in regional storage cooperation should be explored more thoroughly also by including the cost of coordination that limits the ideal number of member countries. This exercise should include a grouping of countries according to their reciprocal suitability with regards to supply patterns.

All recommendations made need to be also seen in light of the political economy in a given country. Liberalization of markets was often proposed by economists, yet governments did not have the strength to enforce reforms against the public and influential civil society organizations. Even if this work emphasizes the role of private storage and trade to stabilize prices, it also identifies room for public interventions and policies. For instance, strategic reserves that do not directly impact on market prices, but represent a viable tool to overcome short term supply shortages. At the same time, it is to note that many African countries have used public storage in the past, however with limited success. Therefore, reserves should be set up with highest possible transparency and a clear mandate of operation. On the other side, governments can overcome market imperfections by investing in hard and soft infrastructure. So, national stock levels can also be enhanced by providing incentives for the private sector to invest in warehouses and a better distribution system.

Appendix A

Appendix: Supplementary tables chapter 2

Table A.1: Wheat price volatility by market

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
2.3	Bengkulu	IDN	0.093	3	0.441	1	0.233	1				
2.8	Harare	ZWE	0.146	1	0.382	5	0.192	4	0.311	1		
6.0	Khujand	TJK	0.094	14	0.292	8	0.209	2	0.232	2	0.233	14
6.3	Bandar Lampung	IDN	0.075	16	0.396	3	0.170	7			0.389	4
6.3	Semarang	IDN	0.078	4	0.416	2	0.161	8				
7.8	Khujand	TJK	0.089	22	0.278	10	0.201	3	0.217	3	0.221	16
9.0	Bandung	IDN	0.072	11	0.388	4	0.157	9				
9.3	Aden	YEM	0.107	6	0.237	15	0.151	13	0.207	6		
10.0	Surabaya	IDN	0.073	12	0.363	6	0.154	11				
10.0	Gharm	TJK	0.061	15	0.293	7	0.190	5	0.187	11	0.302	6
10.8	Gharm	TJK	0.060	17	0.288	9	0.187	6	0.183	12	0.311	5
11.0	Al Hudaydah	YEM	0.114	2	0.234	17	0.145	17			0.270	8
15.2	Gharm	TJK	0.075	13	0.236	16	0.148	16	0.176	14	0.188	20
16.6	Khorog	TJK	0.064	36	0.225	18	0.144	18	0.199	7	0.184	23
17.2	Khujand	TJK	0.064	28	0.214	21	0.136	21	0.153	16	0.249	10

Continued on next page...

... Table A.1 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
18.4	Gharm	TJK	0.052	72	0.240	13	0.155	10	0.198	8	0.189	19
18.6	Gharm	TJK	0.068	21	0.224	19	0.142	19	0.162	15	0.174	25
19.4	Khorog	TJK	0.060	43	0.217	20	0.139	20	0.187	10	0.175	24
20.0	Khujand	TJK	0.059	34	0.211	22	0.135	22	0.145	20	0.246	12
20.6	Gharm	TJK	0.049	80	0.238	14	0.154	12	0.195	9	0.187	21
20.8	Bahirdar	ETH	0.091	9	0.187	27	0.106	31	0.179	13	0.161	27
20.8	Khujand	TJK	0.061	31	0.208	23	0.131	25	0.149	18	0.193	18
21.0	Port Sudan	SDN	0.085	7	0.193	25	0.113	30				
21.8	Khorog	TJK	0.057	46	0.189	26	0.122	28			0.454	3
22.8	Gharm	TJK	0.039	114	0.244	11	0.150	14	0.214	4	0.250	9
24.4	Khujand	TJK	0.057	37	0.205	24	0.129	26	0.143	21	0.185	22
25.2	Gharm	TJK	0.036	130	0.241	12	0.149	15	0.212	5	0.248	11
26.6	Jijiga	ETH	0.066	38	0.152	34	0.090	35	0.151	17	0.147	31
26.8	Khujand	TJK	0.054	41	0.187	28	0.135	23	0.146	19	0.157	28
29.8	Khujand	TJK	0.051	51	0.185	29	0.134	24	0.143	22	0.157	29
32.4	Khorog	TJK	0.042	113	0.178	30	0.122	27	0.132	25	0.235	13
33.2	Jijiga	ETH	0.058	63	0.138	36	0.083	39	0.129	27	0.130	39
34.0	Dire Dawa	ETH	0.074	8	0.143	35	0.065	64	0.141	23	0.139	36
34.6	Khorog	TJK	0.041	92	0.170	31	0.117	29	0.130	26	0.224	15
36.0	Kinshasa	COD	0.057	44	0.161	32	0.089	36	0.108	45		
37.4	Kadugli	SDN	0.054	35	0.136	40	0.071	56	0.141	24	0.154	30
40.0	Mota	ETH	0.055	29	0.132	43	0.079	43			0.128	40
40.8	Dushanbe	TJK	0.046	98	0.136	39	0.081	41	0.125	32	0.131	38
42.6	Jaffna	LKA	0.056	33	0.130	46	0.063	72	0.128	29	0.142	34
42.6	Sodo	ETH	0.046	26	0.128	49	0.080	42	0.126	30	0.126	41
43.0	Kano	NGA	0.050	96	0.135	41	0.079	44	0.122	35	0.120	49
43.4	Wekro	ETH	0.054	20	0.130	45	0.079	45	0.119	38	0.120	50
43.6	Khorog	TJK	0.042	97	0.158	33	0.103	32	0.124	33	0.119	52
44.6	Dire Dawa	ETH	0.061	10	0.129	48	0.058	86	0.129	28	0.125	42

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... Table A.1 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
46.0	Cayes	HTI	0.041	65	0.127	50	0.094	33	0.125	31	0.124	43
46.6	Wekro	ETH	0.052	25	0.132	42	0.083	40	0.106	49	0.110	58
47.0	Dhankuta	NPL	0.044	56	0.137	37	0.091	34	0.099	57		
47.2	Sodo	ETH	0.046	23	0.124	55	0.077	47	0.122	36	0.122	45
48.4	Mota	ETH	0.057	24	0.118	59	0.068	60	0.114	41	0.114	54
49.3	Ajeber	ETH	0.058	5	0.113	65	0.064	66	0.115	40		
50.0	Khujand	TJK	0.052	30	0.126	52	0.072	54			0.119	51
51.0	Ajeber	ETH	0.055	18	0.117	60	0.065	65	0.118	39	0.111	56
51.8	Jeremie	HTI	0.052	45	0.126	51	0.064	71			0.122	44
52.2	Yabelo	ETH	0.044	50	0.124	54	0.064	69	0.124	34	0.122	46
52.3	Mbandaka	COD	0.045	87	0.130	47	0.071	55				
54.4	Yabelo	ETH	0.042	48	0.123	56	0.064	68	0.122	37	0.121	47
55.4	Sana'a	YEM	0.049	91	0.115	61	0.064	67	0.107	47	0.117	53
55.8	Ampara	LKA	0.041	53	0.137	38	0.076	48	0.085	85	0.133	37
56.5	Dushanbe	TJK	0.043	106	0.131	44	0.078	46			0.098	74
59.4	Achham	NPL	0.043	61	0.099	91	0.084	37	0.087	80	0.164	26
60.8	Kurgan-Tyube	TJK	0.032	81	0.121	57	0.074	50	0.109	43	0.108	60
61.3	Nouakchott	MRT	0.041	121	0.115	62	0.073	52				
62.6	Kurgan-Tyube	TJK	0.032	88	0.120	58	0.073	53	0.108	44	0.107	61
62.8	Mekele	ETH	0.055	19	0.109	71	0.051	101	0.108	46		
63.3	Gaza Strip	PSE	0.041	99	0.125	53	0.059	83			0.121	48
65.8	Kersa	ETH	0.047	32	0.112	67	0.058	87			0.108	59
66.4	Dushanbe	TJK	0.033	205	0.111	69	0.070	57	0.105	50	0.104	66
67.2	Libreville	GAB	0.054	68	0.100	88	0.059	82	0.100	55	0.099	73
67.3	Surkhet	NPL	0.034	89	0.113	64	0.075	49				
68.2	Kosti	SDN	0.049	39	0.103	85	0.059	84	0.104	52	0.101	72
68.7	Adel Bagrou	MRT	0.053	54	0.100	87	0.061	79				
69.2	Dushanbe	TJK	0.031	211	0.110	70	0.070	58	0.104	51	0.104	68
70.3	Kurgan-Tyube	TJK	0.036	149	0.109	74	0.062	75	0.106	48		

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... Table A.1 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log ∆	Rank log ∆	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
73.3	Kersa	ETH	0.045	40	0.107	75	0.056	93			0.103	69
73.7	Chisinau	MDA	0.058	42	0.105	80	0.046	114				
74.8	Kurgan-Tyube	TJK	0.032	159	0.104	82	0.060	81	0.100	54	0.107	62
75.8	Bandim	GNB	0.038	94	0.104	83	0.066	63			0.095	78
77.4	Kurgan-Tyube	TJK	0.029	103	0.106	76	0.061	78	0.098	59	0.104	65
78.4	Cayes	HTI	0.044	64	0.112	66	0.031	172	0.111	42	0.113	55
79.0	Kathmandu	NPL	0.036	85	0.097	94	0.062	74	0.098	60	0.094	82
79.4	Abi Adi	ETH	0.046	27	0.098	93	0.048	108	0.095	64	0.094	80
81.4	Kurgan-Tyube	TJK	0.028	112	0.105	79	0.061	80	0.095	63	0.104	67
82.4	Jacmel	HTI	0.033	137	0.105	81	0.044	122	0.103	53	0.107	63
82.5	Dhanusha	NPL	0.037	156	0.105	78	0.083	38			0.065	133
84.4	Maymana	AFG	0.026	148	0.109	72	0.062	76	0.092	70	0.101	71
84.8	Jumla	NPL	0.024	165	0.106	77	0.073	51	0.098	58	0.094	81
85.0	Kabul	AFG	0.026	139	0.109	73	0.062	77	0.089	75	0.107	64
87.8	Mazar e Serif	AFG	0.030	175	0.097	95	0.051	98	0.094	65	0.095	79
89.3	Dese	ETH	0.037	57	0.096	98	0.045	117	0.095	62		
89.4	Parsa	NPL	0.040	104	0.097	96	0.057	88	0.083	92	0.085	97
89.4	Jalalabad	AFG	0.030	203	0.100	89	0.045	118	0.096	61	0.096	75
90.6	Harari	ETH	0.038	60	0.092	106	0.048	106	0.090	74	0.089	89
92.2	Kandahar	AFG	0.025	179	0.112	68	0.063	73	0.089	78	0.086	95
92.6	Kandahar	AFG	0.025	201	0.115	63	0.067	61	0.085	86	0.082	103
92.6	Illam	NPL	0.043	71	0.102	86	0.070	59	0.071	108	0.057	149
95.8	Abi Adi	ETH	0.044	49	0.093	103	0.036	154	0.091	73	0.089	90
96.8	Hirat	AFG	0.029	62	0.094	101	0.044	123	0.093	67	0.092	83
97.2	Kabul	AFG	0.029	147	0.097	97	0.051	99	0.086	84	0.087	93
100.4	Jimma	ETH	0.033	66	0.090	112	0.043	130	0.086	83	0.092	86
100.4	Kabul	AFG	0.023	151	0.098	92	0.053	95	0.092	71	0.092	85
101.8	Quetta	PAK	0.030	182	0.088	117	0.066	62	0.068	113	0.073	116
103.4	Hinche	HTI	0.039	52	0.092	107	0.043	131	0.084	90	0.074	112

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... Table A.1 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log ∆	Rank log ∆	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
105.2	Jalalabad	AFG	0.025	176	0.091	108	0.048	107	0.092	69	0.088	91
105.2	Kassala	SDN	0.034	127	0.086	119	0.041	138	0.087	81	0.084	101
105.4	Quetta	PAK	0.034	157	0.084	122	0.064	70	0.063	121	0.069	126
105.8	Jalalabad	AFG	0.023	192	0.094	100	0.047	111	0.091	72	0.091	88
105.8	Kabul	AFG	0.026	133	0.089	114	0.051	100	0.089	76	0.085	99
107.4	Faizabad	AFG	0.021	212	0.094	102	0.052	97	0.093	66	0.091	87
107.6	Kurgan-Tyube	TJK	0.025	128	0.092	105	0.057	89	0.078	97	0.082	102
108.2	Hirat	AFG	0.028	74	0.091	110	0.039	142	0.089	77	0.088	92
108.4	Kandahar	AFG	0.018	238	0.099	90	0.058	85	0.086	82	0.096	76
108.8	Awasa	ETH	0.042	67	0.081	125	0.034	159	0.083	91	0.081	104
109.7	Ibadan	NGA	0.039	93	0.087	118	0.041	136				
111.4	Fayzabad	AFG	0.020	193	0.092	104	0.050	102	0.092	68	0.086	94
112.0	Herat	AFG	0.021	191	0.085	121	0.036	152	0.076	100	0.275	7
112.4	Maimana	AFG	0.022	124	0.090	113	0.045	119	0.085	87	0.096	77
112.6	Kurgan-Tyube	TJK	0.024	140	0.091	111	0.057	91	0.076	99	0.080	106
114.4	Batticaloa	LKA	0.030	109	0.084	123	0.033	162	0.077	98	0.092	84
114.6	Dushanbe	TJK	0.026	194	0.078	127	0.047	110	0.080	94	0.078	108
115.6	Peshawar	PAK	0.031	125	0.074	136	0.050	103	0.069	109	0.065	132
117.5	Bhopal	IND	0.042	59	0.073	142	0.035	157	0.071	105		
117.8	Addis Ababa	ETH	0.030	79	0.078	126	0.036	153	0.079	95	0.077	109
118.4	Dushanbe	TJK	0.025	190	0.077	130	0.046	113	0.079	96	0.077	110
120.4	Diredawa	ETH	0.037	77	0.073	140	0.034	161	0.073	101	0.073	118
120.6	Mazar	AFG	0.020	223	0.091	109	0.047	109	0.084	89	0.081	105
120.8	Herat	AFG	0.020	245	0.094	99	0.044	125	0.082	93	0.084	100
121.0	Jalalabad	AFG	0.025	161	0.088	116	0.043	132	0.084	88		
121.5	Addis Ababa	ETH	0.029	105	0.077	129	0.042	133			0.073	117
123.2	Dushanbe	TJK	0.027	196	0.074	135	0.040	139	0.072	104	0.074	113
123.2	Dushanbe	TJK	0.028	187	0.074	137	0.040	140	0.071	106	0.073	114
123.6	Minsk	BLR	0.033	75	0.072	145	0.040	141	0.072	103	0.061	137

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... Table A.1 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
123.6	Herat	AFG	0.026	144	0.103	84	0.010	278	0.099	56	0.101	70
124.3	Jalalabad	AFG	0.021	188	0.089	115	0.043	127	0.088	79		
125.3	Kaski	NPL	0.028	180	0.073	141	0.045	120	0.062	123		
131.3	Trincomalee	LKA	0.029	142	0.076	131	0.031	171	0.069	111		
131.8	Mumbai	IND	0.027	101	0.069	154	0.038	146	0.069	110	0.069	125
132.2	Cap Haitien	HTI	0.025	118	0.068	157	0.023	206	0.066	117	0.140	35
132.3	Rolpa	NPL	0.018	195	0.085	120	0.056	92			0.080	107
133.3	San Salvador	SLV	0.026	229	0.082	124	0.039	145				
133.8	Kandahar	AFG	0.027	164	0.075	132	0.035	158			0.070	122
135.6	Lahore	PAK	0.027	225	0.063	176	0.049	105	0.059	129	0.060	142
135.8	Ouanaminthe	HTI	0.029	70	0.071	146	0.033	165			0.070	124
136.6	Morang	NPL	0.030	123	0.066	165	0.039	144	0.061	125	0.057	146
137.5	Port-au-Prince	HTI	0.027	111	0.075	134	0.032	167			0.071	121
138.2	Banke	NPL	0.016	251	0.074	139	0.053	94	0.071	107	0.072	120
138.2	Peshawar	PAK	0.029	115	0.066	161	0.044	124	0.057	132	0.054	159
138.5	Ouanaminthe	HTI	0.027	83	0.068	156	0.029	181			0.086	96
139.4	Naryn	KGZ	0.023	132	0.069	155	0.019	228	0.065	120	0.147	32
139.8	Gaza Strip	PSE	0.026	237	0.070	149	0.031	173	0.069	112	0.068	127
140.5	Lahore	PAK	0.025	185	0.063	174	0.047	112	0.056	134		
142.0	Quetta	PAK	0.020	244	0.074	138	0.057	90			0.056	154
144.0	Bhopal	IND	0.025	143	0.070	151	0.038	148			0.062	136
145.8	Kandahar	AFG	0.023	171	0.071	147	0.031	175	0.067	115	0.066	131
147.0	Karachi	PAK	0.017	170	0.072	144	0.052	96			0.068	128
147.6	Yaundé	CMR	0.023	210	0.062	180	0.046	115	0.056	135	0.058	145
148.8	Boghé	MRT	0.025	110	0.073	143	0.025	201	0.072	102		
149.6	Batken	KGZ	0.029	76	0.066	163	0.023	208	0.062	124	0.060	139
150.6	Batken	KGZ	0.019	122	0.057	192	0.022	210	0.057	133	0.205	17
150.8	Cap-Haitien	HTI	0.026	107	0.070	150	0.023	205	0.066	116		
150.8	Vavuniya	LKA	0.025	126	0.068	158	0.020	224	0.063	122	0.085	98

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... Table A.1 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
151.3	National Average	URY	0.036	47	0.078	128					0.028	240
151.5	Kurgan-Tyube	TJK	0.029	119	0.066	162	0.024	204			0.068	129
151.6	Nili	AFG	0.029	73	0.070	153	0.017	245	0.068	114	0.066	130
153.0	Kailali	NPL	0.019	200	0.064	171	0.043	129	0.061	127	0.060	141
153.8	Rupandehi	NPL	0.020	197	0.063	178	0.045	121	0.057	130	0.057	147
154.2	Jhapa	NPL	0.018	146	0.061	183	0.045	116	0.061	126	0.061	138
154.6	Karachi	PAK	0.022	141	0.065	168	0.041	135	0.055	136	0.054	160
156.4	National Average	CRI	0.021	160	0.063	177	0.036	156	0.061	128	0.058	143
157.5	Benguluru	IND	0.017	204	0.066	164	0.049	104			0.060	140
157.8	Peshawar	PAK	0.023	135	0.059	185	0.041	137	0.051	146	0.053	161
159.6	Nili	AFG	0.026	86	0.070	152	0.015	254	0.065	119	0.065	134
162.0	Barisal	BGD	0.027	145	0.066	166	0.019	234			0.073	119
163.0	Bujumbura	BDI	0.025	213	0.066	167	0.030	178				
163.2	Bangui	CAF	0.019	189	0.058	187	0.044	126	0.055	139	0.052	166
165.0	Kabul	AFG	0.021	172	0.075	133	0.028	183				
165.3	Sughd	TJK	0.032	55	0.059	186	0.020	226			0.056	153
166.0	Multan	PAK	0.020	173	0.056	196	0.039	143	0.054	140	0.053	163
166.6	Jalal-Abad	KGZ	0.024	102	0.065	169	0.012	268	0.065	118	0.070	123
169.8	Yogyakarta	IDN	0.016	234	0.067	159	0.032	168	0.052	143	0.057	152
170.8	Medan	IDN	0.010	253	0.054	207	0.020	222	0.048	157	0.857	1
171.3	Montevideo	URY	0.027	78	0.070	148					0.029	239
171.8	Peshawar	PAK	0.024	69	0.055	204	0.032	170	0.048	159		
172.0	Gharm	TJK	0.022	202	0.056	198	0.026	192	0.055	137	0.053	165
174.4	Multan	PAK	0.023	154	0.052	221	0.038	147	0.051	145	0.045	194
175.5	Jaipur	IND	0.022	158	0.053	214	0.036	151			0.052	167
175.8	Karachi	PAK	0.013	241	0.062	181	0.043	128			0.057	148
176.5	Mannar	LKA	0.022	136	0.067	160	0.020	225	0.049	152		
176.6	Lahore	PAK	0.019	240	0.053	211	0.042	134	0.048	161	0.049	175
176.8	Gonaives	HTI	0.018	227	0.063	179	0.030	179			0.062	135

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... *Table A.1 continued*

Average rank	Market	ISO3	SD Season	Rank Season	SD log ∆	Rank log ∆	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
177.8	Osh	KGZ	0.026	84	0.064	173	0.007	288			0.073	115
178.8	Kupang	IDN	0.013	255	0.064	172	0.026	190	0.057	131	0.056	157
179.7	Dhaka	BGD	0.031	90	0.063	175	0.013	264				
180.0	Sao Paulo	BRA	0.017	235	0.056	200	0.033	163	0.050	148	0.050	171
182.3	Peshawar	PAK	0.027	58	0.058	189	0.018	236				
182.4	Multan	PAK	0.022	95	0.048	235	0.032	169	0.048	160	0.048	181
182.4	Abuja	NGA	0.019	178	0.051	226	0.038	149	0.048	155	0.048	179
182.6	Patna	IND	0.021	152	0.050	227	0.027	187	0.050	149	0.050	173
183.0	National Average	TJK	0.020	138	0.047	239	0.008	283	0.047	166	0.143	33
183.3	Rajshahi	BGD	0.021	131	0.053	216			0.050	151		
183.8	West Bank	PSE	0.013	226	0.055	203	0.031	177	0.055	138	0.055	158
184.2	Port-de-Paix	HTI	0.014	228	0.045	248	0.016	251	0.037	183	0.784	2
184.3	Dushanbe	TJK	0.021	163	0.065	170	0.025	199				
186.7	Gonaives	HTI	0.019	209	0.062	182	0.031	174				
187.3	Delhi	IND	0.018	215	0.054	206	0.037	150			0.048	180
187.4	Bishkek	KGZ	0.019	162	0.060	184	0.018	242	0.044	171	0.058	144
188.8	Hyderabad	IND	0.015	248	0.053	212	0.036	155	0.048	162	0.047	182
190.4	Aceh	IDN	0.006	295	0.058	190	0.023	207	0.050	150	0.074	111
191.4	Manado	IDN	0.012	274	0.057	191	0.022	211	0.051	147	0.057	151
191.5	Chennai	IND	0.017	242	0.053	217	0.033	164			0.052	168
191.6	West Bank	PSE	0.023	214	0.047	241	0.025	196	0.046	170	0.046	187
191.6	Multan	PAK	0.021	100	0.046	246	0.029	180	0.046	168	0.046	183
192.0	Patna	IND	0.020	166	0.053	215	0.033	166				
192.0	Samarinda	IDN	0.010	272	0.057	195	0.025	198	0.054	141	0.056	156
192.7	Sylhet	BGD	0.024	134	0.058	188	0.018	237				
194.0	Kathmandu	NPL	0.021	198	0.049	230	0.031	176			0.045	188
195.6	Banjarmasin	IDN	0.009	290	0.056	197	0.027	189	0.047	165	0.057	150
195.6	Lucknow	IND	0.020	155	0.046	245	0.024	203	0.049	154	0.046	186
197.3	Dhaka	BGD	0.026	116	0.055	202	0.007	286			0.053	164

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... Table A.1 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log ∆	Rank log ∆	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
197.8	Khulna	BGD	0.018	177	0.052	220	0.017	244	0.052	142	0.050	172
197.8	National Average	KGZ	0.019	153	0.057	194	0.013	263	0.039	178	0.056	155
198.4	Lahore	PAK	0.022	117	0.042	255	0.028	185	0.041	175	0.041	204
198.6	Palembang	IDN	0.012	283	0.057	193	0.022	209	0.048	158	0.049	177
199.8	Port-de-Paix	HTI	0.014	233	0.045	250	0.015	253			0.111	57
200.0	Colombo City	LKA	0.019	183	0.049	229	0.025	195			0.050	169
202.0	Panama City	PAN	0.019	216	0.044	252	0.027	188	0.044	172	0.043	198
202.5	Multan	PAK	0.017	184	0.047	237	0.034	160			0.045	189
205.6	Jayapura	IDN	0.011	250	0.054	208	0.022	215	0.046	169	0.050	174
205.8	Gaza Strip	PSE	0.018	207	0.048	233	0.026	193			0.046	185
206.4	Kendari	IDN	0.007	300	0.053	218	0.021	220	0.051	144	0.053	162
207.0	Causeni	MDA	0.017	230	0.055	205	0.025	200				
208.0	National Average	NIC	0.022	206	0.045	249	0.022	213			0.045	195
208.4	Palangkaraya	IDN	0.011	268	0.054	210	0.019	227	0.047	164	0.049	178
209.0	Minsk	BLR	0.022	82	0.042	254	0.010	275	0.042	174	0.050	170
210.6	Chittagong	BGD	0.016	169	0.051	225	0.012	270	0.049	153	0.049	176
211.0	Ambon	IDN	0.010	267	0.052	219	0.022	212	0.047	167	0.046	184
211.5	Ahmedabad	IND	0.014	264	0.047	236	0.028	184			0.045	190
212.0	Palpa	NPL	0.014	218	0.050	228	0.028	182			0.041	203
212.8	National Average	TJK	0.016	217	0.047	240	0.026	191			0.045	192
214.3	Jambi	IDN	0.011	285	0.056	199	0.026	194			0.043	199
214.3	Mumbai	IND	0.014	243	0.047	238	0.028	186			0.045	193
216.0	Khatlon	TJK	0.022	108	0.041	261					0.036	216
217.0	Jalal-Abad	KGZ	0.016	181	0.054	209	0.005	294	0.048	156	0.044	196
217.3	Pekanbaru	IDN	0.012	256	0.052	222	0.021	221	0.042	173		
217.6	Dhaka	BGD	0.019	150	0.049	231	0.003	297	0.047	163	0.045	191
218.4	S.Antao	CPV	0.016	232	0.039	265	0.021	217	0.040	177	0.040	207
219.3	S.Vincente	CPV	0.014	261	0.047	242	0.025	197			0.043	200
220.6	Padang	IDN	0.010	265	0.052	223	0.019	233	0.038	181	0.044	197

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... Table A.1 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
220.8	Ulaanbaatar	MNG	0.017	208	0.048	232	0.010	274	0.037	182	0.042	201
221.7	Palu	IDN	0.012	269	0.055	201	0.022	214				
221.8	National Average	URY	0.017	167	0.041	257	0.019	231	0.041	176		
223.2	Dushanbe	TJK	0.020	129	0.041	256	0.010	277	0.039	179	0.038	212
225.3	Naryn	KGZ	0.017	199	0.046	244	0.016	249	0.034	187		
228.0	Ujung Pandang	IDN	0.009	266	0.053	213	0.021	219			0.040	206
229.8	Bishkek	KGZ	0.013	222	0.046	247	0.018	238	0.032	191	0.034	224
230.0	Montevideo	URY	0.016	174			0.019	235				
232.2	West Bank	PSE	0.012	254	0.041	262	0.018	241	0.036	185	0.037	214
233.3	Trivandrum	IND	0.013	219	0.044	253	0.024	202				
234.3	Nairobi	KEN	0.013	257	0.041	259	0.020	223			0.039	208
234.8	Jakarta	IDN	0.011	263	0.048	234	0.019	230			0.036	215
236.5	Colombo	LKA	0.014	231	0.041	260	0.016	247			0.041	205
237.8	Sao Paulo	BRA	0.009	284	0.040	264	0.014	259	0.038	180	0.038	211
238.0	Pontianak	IDN	0.010	273	0.052	224	0.018	240			0.036	217
238.2	Mumbai	IND	0.013	249	0.033	277	0.014	258	0.034	186	0.034	222
238.4	National Average	GEO	0.011	247	0.035	271	0.018	239	0.033	189	0.033	227
238.6	Douala	CMR	0.012	246	0.032	281	0.019	232	0.032	190	0.031	232
238.8	National Average	BLR	0.017	168	0.035	272	0.006	292	0.034	188	0.034	223
240.0	Gaza Strip	PSE	0.012	270	0.039	268	0.019	229			0.039	209
241.8	Kampala	UGA	0.013	259	0.033	278	0.021	218			0.032	229
243.0	Bhubaneshwar	IND	0.009	271	0.034	275	0.021	216			0.042	202
245.2	Chennai	IND	0.012	224	0.031	286	0.013	262	0.031	192	0.031	235
247.0	Osh	KGZ	0.008	278	0.035	273	0.008	282	0.037	184	0.037	213
248.4	Nairobi	KEN	0.008	288	0.031	284	0.013	261	0.029	194	0.036	218
248.8	National Average	BLR	0.019	120	0.036	269	0.003	300			0.035	221
248.8	Chennai	IND	0.013	236	0.033	276	0.016	250			0.032	228
251.3	National Average	AZE	0.007	301	0.039	266	0.017	243			0.038	210
252.5	Karachi	PAK	0.010	252	0.039	267	0.015	252			0.036	219

Continued on next page...

... Table A.1 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
253.5	Shillong	IND	0.009	260	0.032	280	0.013	265	0.029	193		
254.0	Denpasar	IDN	0.006	289	0.047	243	0.014	256			0.035	220
254.3	National Average	KGZ	0.012	221	0.040	263	0.011	273			0.033	226
254.5	New Delhi	IND	0.015	186	0.032	282	0.011	271			0.031	233
256.0	Karachi	PAK	0.011	239	0.041	258	0.016	246				
256.3	Nouakchott	MRT	0.011	258	0.035	270	0.012	269			0.033	225
258.8	Mataram	IDN	0.008	292	0.045	251	0.011	272			0.031	231
259.7	Santiago	CPV	0.012	220	0.033	279	0.016	248				
264.8	West Bank	PSE	0.009	277	0.030	287	0.014	255			0.030	237
265.5	National Average	ARM	0.009	287	0.031	283	0.012	267			0.031	234
267.5	National Average	GTM	0.008	275	0.027	288	0.014	257			0.026	241
269.0	National Average	ARM	0.010	286	0.031	285	0.007	287			0.031	236
270.0	National Average	GTM	0.007	281	0.026	289	0.014	260			0.024	242
271.0	National Average	AZE	0.008	282	0.034	274	0.003	298			0.032	230
275.8	National Average	GEO	0.007	262	0.024	290	0.009	280			0.021	243
276.0	National Average	IDN	0.007	276	0.019	294					0.014	247
281.3	National Average	ARM	0.006	280	0.019	295	0.007	291			0.019	244
281.5	National Average	RUS	0.006	296	0.019	296	0.007	289			0.019	245
282.5	Lima	PER	0.004	298	0.017	297	0.006	293			0.029	238
282.5	National Average	ARM	0.005	297	0.017	299	0.008	285			0.016	246
284.0	National Average	CHN	0.007	293	0.012	302	0.003	295			0.012	248
287.3	Niamey	NER	0.004	302	0.021	293	0.012	266				
288.3	Santiago	CHL	0.007	303	0.022	291	0.008	281				
288.7	National Average	TUN	0.007	279	0.017	298	0.010	276				
288.8	Lima	PER	0.002	305	0.009	304	0.003	296			0.008	250
288.8	Lima	PER	0.002	304	0.011	303	0.003	299			0.009	249
292.3	National Average	TUN	0.006	291	0.016	300	0.009	279				
293.7	National Average	RUS	0.006	299	0.021	292	0.007	290				
295.3	National Average	TUN	0.005	294	0.014	301	0.008	284				

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... Table A.1 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
304.0	Maputo	MOZ	0.000	306	0.000	305	0.000	301				

Source: Author's computation based on ZEF [2014].

Table A.2: Maize price volatility by market

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
4.4	Man	CIV	0.160	5	0.306	5	0.162	7	0.282	2	0.281	3
8.3	Mtakataka	MWI	0.148	12	0.275	7	0.153	9			0.261	5
12.8	Bugarama	RWA	0.131	19	0.246	13	0.178	6	0.231	13		
13.8	Rwagitima	RWA	0.152	8	0.257	9	0.123	31	0.241	7	0.234	14
14.5	Mitundu	MWI	0.150	11	0.252	11	0.135	21			0.234	15
16.0	Harare	ZWE	0.102	74	0.357	2	0.214	1	0.312	1	0.300	2
19.3	Nanjiri	MWI	0.138	13	0.233	23	0.124	29	0.233	12		
20.8	Rukomo	RWA	0.165	4	0.255	10	0.107	60	0.241	8	0.218	22
21.8	Salima	MWI	0.110	53	0.249	12	0.143	14			0.245	8
23.3	Milange	MOZ	0.171	3	0.237	18	0.116	45			0.212	27
23.3	Congo - Nil	RWA	0.128	22	0.232	24	0.142	15			0.209	32
24.4	Buale	SOM	0.092	100	0.324	3	0.198	3	0.250	5	0.238	11
24.6	Lunzu	MWI	0.153	6	0.226	27	0.111	54	0.226	16	0.220	20
25.4	Thete	MWI	0.178	1	0.235	21	0.098	75	0.234	11	0.224	19
25.6	Buale	SOM	0.094	97	0.321	4	0.194	4	0.246	6	0.231	17
28.8	Mukarange	RWA	0.153	7	0.230	25	0.097	82	0.224	17	0.235	13
30.0	Harare	ZWE	0.099	87	0.370	1	0.202	2				
31.0	Mitundu	MWI	0.122	29	0.220	31	0.119	39	0.206	25		
31.3	Baidao	SOM	0.103	71	0.244	14	0.124	30			0.241	10
32.0	Baidoa	SOM	0.102	75	0.237	17	0.116	47	0.236	9	0.235	12
34.0	Bouake	CIV	0.090	108	0.234	22	0.154	8	0.231	14	0.226	18

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... Table A.2 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
34.8	Salima	MWI	0.099	86	0.221	30	0.129	24	0.219	18	0.234	16
35.0	Afgoi	SOM	0.116	42	0.219	32	0.117	43	0.209	23	0.207	35
35.6	Lunzu	MWI	0.137	14	0.210	38	0.100	71	0.210	22	0.208	33
38.3	Kasempa	ZMB	0.118	33	0.214	36	0.110	55			0.212	29
38.6	Afmadow	SOM	0.076	169	0.260	8	0.188	5	0.261	4	0.251	7
39.0	Kawambwa	ZMB	0.117	40	0.200	49	0.121	36			0.209	31
39.0	Mwinilunga	ZMB	0.109	60	0.219	33	0.118	42	0.206	26	0.208	34
39.4	Delo	ETH	0.078	152	0.243	16	0.150	10	0.236	10	0.242	9
41.4	Bushenge	RWA	0.106	66	0.207	43	0.129	25	0.205	27	0.191	46
42.0	Anie	TGO	0.118	37	0.199	53	0.113	49	0.198	32	0.197	39
46.4	Mbandaka	COD	0.113	49	0.197	56	0.113	50	0.198	33	0.192	44
48.3	Mzimba	MWI	0.128	21	0.190	71	0.000		0.187	47	0.188	54
49.3	Nyakarambi	RWA	0.135	16	0.243	15	0.081	151	0.231	15		
50.0	Karonga	MWI	0.152	9	0.198	55	0.090	102	0.198	34		
50.6	Delo	ETH	0.076	168	0.222	28	0.139	17	0.216	19	0.219	21
51.0	Rumphi	MWI	0.132	18	0.201	48	0.093	98	0.189	46	0.192	45
51.8	Bouake	CIV	0.102	77	0.192	62	0.128	27	0.190	44	0.189	49
51.8	Chiradzulu	MWI	0.136	15	0.207	42	0.084	130	0.201	30	0.193	42
52.0	Rukomo	RWA	0.094	98	0.207	41	0.138	18			0.189	51
52.8	Namwera	MWI	0.113	48	0.209	39	0.084	128	0.209	24	0.213	25
54.0	Mongu	ZMB	0.104	68	0.205	45	0.118	41	0.181	53	0.184	63
54.2	Nsanje	MWI	0.134	17	0.199	52	0.095	88	0.182	52	0.184	62
55.2	Amegnran	TGO	0.070	186	0.226	26	0.148	13	0.213	21	0.211	30
55.4	Ntaja	MWI	0.172	2	0.218	34	0.072	195	0.215	20	0.213	26
59.6	Nchalo	MWI	0.125	27	0.200	50	0.097	81	0.180	54	0.173	86
61.6	Kisangani	COD	0.097	92	0.196	57	0.108	57	0.190	42	0.186	60
62.4	Wolenchiti	ETH	0.108	63	0.186	75	0.098	80	0.191	41	0.188	53
63.0	Balaka	MWI	0.127	24	0.193	61	0.086	121	0.186	50	0.186	59
63.2	Juba	SSD	0.080	138	0.190	73	0.122	33	0.186	49	0.216	23

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... Table A.2 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
65.8	Lugh	SOM	0.060	232	0.222	29	0.140	16	0.202	28	0.216	24
67.0	Karonga	MWI	0.127	25	0.183	83	0.094	92			0.180	68
67.6	Yabelo	ETH	0.080	139	0.193	60	0.101	67	0.194	35	0.204	37
68.2	Borama	SOM	0.065	203	0.212	37	0.128	26	0.193	37	0.201	38
69.6	Yabelo	ETH	0.082	128	0.192	66	0.099	74	0.191	40	0.196	40
70.8	Lilongwe	MWI	0.110	56	0.184	80	0.100	72			0.177	75
71.0	Mandera	KEN	0.052	296	0.282	6	0.117	44	0.279	3	0.253	6
71.6	Mwanza	MWI	0.130	20	0.192	63	0.076	174	0.194	36	0.183	65
72.0	Ngabu	MWI	0.128	23	0.191	70	0.085	124	0.178	58	0.173	85
73.6	Serenje	ZMB	0.110	55	0.180	90	0.097	85	0.180	56	0.175	82
73.8	Nsanje	MWI	0.119	31	0.181	89	0.090	106			0.180	69
75.8	Bangula	MWI	0.124	28	0.195	59	0.075	177	0.192	39		
76.5	Kasama	ZMB	0.103	69	0.185	77	0.094	96			0.183	64
78.0	Nkhotakota	MWI	0.127	26	0.192	67	0.079	158			0.185	61
78.5	Angonia	MOZ	0.119	32	0.196	58	0.075	181			0.193	43
79.5	Nsundwe	MWI	0.104	67	0.190	72	0.083	131	0.186	48		
80.0	Bangui	CAF	0.083	123	0.183	82	0.121	35				
81.8	Mzimba	MWI	0.078	149	0.175	106	0.122	32	0.174	66	0.186	56
83.0	Kabwe Rural	ZMB	0.087	114	0.180	95	0.118	40			0.175	83
83.8	Nsanje	MWI	0.117	39	0.184	78	0.078	163	0.177	61	0.176	78
84.5	Qorioley	SOM	0.113	50	0.192	65	0.076	173			0.189	50
86.0	Ntcheu	MWI	0.114	44	0.180	91	0.083	134	0.173	68	0.170	93
87.3	Mpika	ZMB	0.111	51	0.176	103	0.090	108				
88.6	Gharm	TJK	0.045	356	0.237	19	0.150	11	0.201	29	0.212	28
88.7	Kitui	KEN	0.080	143	0.203	46	0.098	77				
89.4	Korbongou	TGO	0.071	181	0.184	81	0.114	48	0.176	64	0.178	73
90.6	Mogadishu	SOM	0.083	126	0.175	105	0.100	73	0.175	65	0.174	84
91.0	Nkhata Bay	MWI	0.118	34	0.185	76	0.067	223	0.184	51	0.178	71
91.0	Luwingu	ZMB	0.086	119	0.174	111	0.100	70	0.177	63	0.170	92

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... Table A.2 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
91.8	Gharm	TJK	0.044	360	0.236	20	0.149	12	0.199	31	0.206	36
92.3	Muloza	MWI	0.118	36	0.180	92	0.081	147			0.169	94
92.6	Jamame	SOM	0.062	227	0.205	44	0.107	59	0.168	78	0.187	55
93.6	Gorongosa	MOZ	0.106	65	0.182	86	0.081	145	0.170	74	0.168	98
93.6	Nikki	BEN	0.092	101	0.170	122	0.102	66	0.168	79	0.166	100
95.8	Khujand	TJK	0.057	253	0.202	47	0.137	19	0.161	93	0.180	67
99.3	Katako	NER	0.076	167	0.209	40	0.113	51			0.154	139
100.6	Wolenchiti	ETH	0.101	78	0.172	118	0.086	122	0.168	77	0.164	108
101.6	Ribaue	MOZ	0.114	45	0.180	94	0.063	238	0.179	57	0.178	74
101.8	Chitipa	MWI	0.151	10	0.198	54	0.058	267			0.177	76
102.7	Esteli	NIC	0.073	176	0.178	98	0.121	34				
104.8	Khujand	TJK	0.054	278	0.200	51	0.136	20	0.157	103	0.178	72
104.8	Lizulu	MWI	0.110	54	0.180	93	0.063	239	0.178	59	0.176	79
106.0	Mponela	MWI	0.116	41	0.192	64	0.048	322	0.190	45	0.186	58
106.8	Sodo	ETH	0.098	88	0.176	102	0.081	150			0.173	87
107.4	Senanga	ZMB	0.077	156	0.173	116	0.105	62	0.157	104	0.166	99
108.2	Ntchisi	MWI	0.103	70	0.191	68	0.052	299	0.193	38	0.182	66
110.0	Sare Bojo	GMB	0.076	163	0.165	131	0.107	58	0.165	82	0.161	116
110.3	Chimbiya	MWI	0.091	102	0.173	112	0.080	157	0.172	70		
110.6	Merka	SOM	0.111	52	0.175	109	0.062	249	0.177	62	0.176	81
111.8	Barra	GMB	0.061	229	0.184	79	0.112	52	0.180	55	0.153	144
112.8	Nyagatare	RWA	0.109	58	0.175	107	0.065	231	0.170	73	0.169	95
113.6	Doblei	SOM	0.059	238	0.178	99	0.116	46	0.165	84	0.166	101
114.4	Kismayo	SOM	0.044	362	0.214	35	0.094	91	0.190	43	0.195	41
114.5	Samfya	ZMB	0.108	61	0.174	110	0.071	196			0.171	91
116.0	Petauke	ZMB	0.073	173	0.163	137	0.103	63	0.165	86	0.161	121
117.5	Jeremie	HTI	0.070	187	0.180	96	0.086	117			0.179	70
120.0	Kitui	KEN	0.058	247	0.177	100	0.106	61	0.172	69	0.160	123
121.4	Mogadishu	SOM	0.098	89	0.171	121	0.067	218	0.169	75	0.165	104

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... Table A.2 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
121.8	Basse Santa su	GMB	0.066	201	0.161	148	0.120	37	0.159	98	0.159	125
122.6	Manica	MOZ	0.120	30	0.165	132	0.062	245	0.163	88	0.161	118
123.8	Ngabu	MWI	0.100	81	0.167	126	0.075	179	0.160	95	0.155	138
123.8	Gode	ETH	0.062	223	0.173	115	0.098	78	0.153	114	0.171	89
124.6	Dwangwa	MWI	0.113	47	0.175	104	0.054	286	0.167	80	0.164	106
124.6	Mzuzu	MWI	0.101	79	0.163	143	0.076	170	0.158	101	0.157	130
125.3	Sodo	ETH	0.099	84	0.166	127	0.077	165				
125.6	Kismayo	SOM	0.054	284	0.182	88	0.102	64	0.165	85	0.164	107
125.8	Dushanbe	TJK	0.050	304	0.188	74	0.130	23			0.166	102
126.2	Kaoma	ZMB	0.086	118	0.166	128	0.081	149	0.159	99	0.155	137
127.5	Jilib	SOM	0.062	224	0.183	85	0.081	144			0.186	57
128.2	Kasama	ZMB	0.090	107	0.156	162	0.088	113	0.155	107	0.151	152
128.3	Nchelenge	ZMB	0.102	76	0.167	125	0.074	185			0.159	127
129.0	Manica	MOZ	0.118	38	0.173	117	0.051	309	0.170	72	0.164	109
129.2	Ruhuha	RWA	0.087	117	0.157	157	0.085	125	0.156	105	0.154	142
129.8	Mzuzu	MWI	0.091	103	0.164	136	0.073	191	0.161	91	0.159	128
130.0	Dushanbe	TJK	0.048	333	0.191	69	0.131	22			0.169	96
130.8	Kabwe	ZMB	0.082	129	0.163	142	0.098	76	0.146	130	0.143	177
131.4	Luchenza	MWI	0.098	90	0.165	130	0.069	211	0.160	94	0.156	132
131.5	Kurgan-Tyube	TJK	0.062	226	0.175	108	0.088	115			0.177	77
132.0	Marka	SOM	0.107	64	0.172	119	0.056	278	0.173	67		
132.3	Rundu	NAM	0.061	230	0.162	146	0.108	56	0.159	97		
132.4	Bakau	GMB	0.049	321	0.173	113	0.125	28	0.166	81	0.161	119
133.4	Mumbwa	ZMB	0.078	148	0.154	169	0.094	94	0.152	121	0.155	135
135.0	Sikela	ETH	0.082	132	0.178	97	0.051	306	0.177	60	0.176	80
135.4	Jowhar	SOM	0.095	93	0.166	129	0.059	263	0.164	87	0.165	105
135.5	Luanshya	ZMB	0.080	141	0.161	150	0.086	120			0.156	131
136.0	Lomé	TGO	0.076	166	0.162	144	0.089	112	0.153	112	0.152	146
137.0	Parakou	BEN	0.069	188	0.171	120	0.069	216	0.170	71	0.171	90

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... *Table A.2 continued*

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
138.0	Liwonde	MWI	0.110	57	0.163	138	0.051	310			0.191	47
138.5	Mbala	ZMB	0.095	95	0.150	183	0.086	119			0.150	157
138.8	Mangochi	MWI	0.118	35	0.168	123	0.049	319	0.165	83	0.155	134
139.0	Chikwawa	MWI	0.114	46	0.162	145	0.059	261	0.157	102	0.154	141
139.5	Mchinji	MWI	0.089	112	0.173	114	0.065	229			0.165	103
139.8	Ketou	BEN	0.091	104	0.158	154	0.076	169	0.156	106	0.147	166
140.6	Robit	ETH	0.052	298	0.165	133	0.101	69	0.162	89	0.162	114
141.8	Mzuzu	MWI	0.081	137	0.154	164	0.080	154	0.153	111	0.153	143
141.8	Kara	TGO	0.062	220	0.163	141	0.082	136	0.161	92	0.161	120
142.0	Shoa Robit	ETH	0.059	241	0.167	124	0.094	93			0.163	110
142.5	Masindi	UGA	0.090	106	0.162	147	0.079	159			0.150	158
142.8	Dar es Salaam	TZA	0.059	245	0.157	159	0.098	79	0.143	143	0.172	88
143.3	Diéma	MLI	0.078	153	0.183	84	0.055	284			0.188	52
143.8	Moussoro	TCD	0.081	136	0.154	166	0.090	103			0.146	170
143.8	Solwezi	ZMB	0.097	91	0.158	156	0.069	212	0.153	115	0.153	145
145.2	Abomsa	ETH	0.077	162	0.152	175	0.087	116	0.152	118	0.151	155
145.3	Kurgan-Tyube	TJK	0.062	225	0.176	101	0.089	110				
145.4	Abomey	BEN	0.095	94	0.151	182	0.077	166	0.150	124	0.148	161
147.8	Lamin	GMB	0.053	285	0.159	153	0.112	53	0.158	100		
148.6	National Average	MWI	0.103	72	0.154	168	0.067	222	0.150	122	0.149	159
148.8	Nampula	MOZ	0.108	62	0.161	149	0.051	308	0.159	96	0.157	129
148.8	Lilongwe	MWI	0.082	133	0.142	210	0.082	141	0.141	145	0.162	115
149.4	Malanville	BEN	0.077	158	0.153	171	0.082	138	0.152	120	0.149	160
152.6	Congo - Nil	RWA	0.079	146	0.146	195	0.097	83	0.140	146	0.137	193
152.8	Chontales	NIC	0.072	180	0.152	177	0.094	90			0.147	164
154.0	Isoka	ZMB	0.083	127	0.149	186	0.078	161	0.148	127	0.146	169
154.6	Mkushi	ZMB	0.081	134	0.155	163	0.071	202	0.150	123	0.151	151
156.3	Monze	ZMB	0.083	125	0.154	167	0.076	168			0.147	165
156.8	Galkayo	SOM	0.050	310	0.163	139	0.090	105	0.155	108	0.160	122

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... Table A.2 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
158.4	Bunia	COD	0.073	174	0.153	173	0.075	180	0.152	117	0.152	148
158.8	Galkayo	SOM	0.050	311	0.163	140	0.090	107	0.155	110	0.159	126
159.0	Mwense	ZMB	0.095	96	0.153	172	0.060	258	0.152	116	0.151	153
162.8	Abomsa	ETH	0.073	177	0.147	193	0.081	152	0.146	129		
163.4	Gode	ETH	0.055	270	0.157	158	0.092	99	0.134	157	0.156	133
164.8	Malanville	BEN	0.074	171	0.145	201	0.089	111			0.143	176
165.0	Castors	SEN	0.042	381	0.144	206	0.102	65	0.129	172	0.302	1
166.4	Nkhoma	MWI	0.082	131	0.157	160	0.053	296	0.155	109	0.155	136
166.6	Kasungu	MWI	0.115	43	0.182	87	0.011	530	0.169	76	0.169	97
167.0	Mazabuka	ZMB	0.071	184	0.152	176	0.074	184	0.143	137	0.151	154
167.8	Nampula	MOZ	0.109	59	0.151	181	0.053	293	0.145	132	0.144	174
170.6	Hudur	SOM	0.059	237	0.165	134	0.057	275	0.162	90	0.161	117
172.3	Katete	ZMB	0.065	209	0.149	187	0.085	127	0.132	166		
172.3	Byumba	RWA	0.067	194	0.140	214	0.096	86			0.136	195
173.4	Djougou	BEN	0.077	155	0.145	199	0.074	188	0.143	142	0.142	183
174.5	Fada N'Gourma	BFA	0.065	202	0.150	184	0.086	123			0.138	189
174.8	Lizulu	MWI	0.100	82	0.148	188	0.062	244			0.140	185
176.0	Gaya	NER	0.082	130	0.141	213	0.075	175			0.139	186
176.2	Nyagatare	RWA	0.065	207	0.141	212	0.091	100	0.123	200	0.148	162
176.6	Kita	MLI	0.102	73	0.146	196	0.051	313	0.147	128	0.145	173
178.2	Chikhwawa	MWI	0.085	120	0.151	180	0.051	302	0.149	126	0.147	163
178.8	Liwonde	MWI	0.099	85	0.156	161	0.045	345			0.159	124
178.8	Mongu	ZMB	0.077	157	0.144	207	0.076	171	0.143	139	0.130	220
179.8	Jeremie	HTI	0.068	190	0.164	135	0.055	282			0.163	112
181.0	Kindia	GIN	0.058	248	0.133	246	0.090	104	0.134	158	0.152	149
183.5	S.Antao	CPV	0.051	301	0.158	155	0.096	87			0.137	191
183.6	Awassa zuriya	ETH	0.068	189	0.147	192	0.070	204	0.143	141	0.137	192
184.2	Natitingou	BEN	0.072	179	0.136	228	0.080	156	0.136	156	0.134	202
186.2	Lilongwe	MWI	0.057	255	0.139	220	0.082	140	0.130	169	0.152	147

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... Table A.2 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
186.4	Bla	MLI	0.088	113	0.130	257	0.042	363	0.137	151	0.190	48
186.5	Mukarange	RWA	0.050	309	0.154	165	0.119	38			0.125	234
187.8	Koumantou	MLI	0.093	99	0.141	211	0.053	291	0.132	163	0.144	175
188.8	Hargeisa	SOM	0.053	287	0.160	151	0.070	206			0.163	111
190.2	Moussoro	TCD	0.063	218	0.138	221	0.083	132	0.133	161	0.130	219
191.8	Hargeisa	SOM	0.053	295	0.160	152	0.070	207			0.162	113
193.0	Saminaka	NGA	0.057	257	0.127	268	0.094	95	0.124	195	0.152	150
193.5	Kalulushi	ZMB	0.081	135	0.140	216	0.066	226			0.134	197
196.6	Kita	MLI	0.089	110	0.124	281	0.074	187	0.125	192	0.132	213
197.2	Mansa	ZMB	0.100	83	0.146	198	0.039	384	0.144	134	0.139	187
197.6	Bohicon	BEN	0.080	140	0.140	215	0.053	290	0.139	147	0.135	196
197.6	Rwagitima	RWA	0.076	164	0.138	223	0.064	237	0.138	148	0.132	216
197.8	Bedessa	ETH	0.057	258	0.151	179	0.061	251	0.152	119	0.142	182
198.5	Base	RWA	0.079	147	0.144	208	0.062	250	0.125	189		
199.8	Malanville	BEN	0.076	165	0.125	273	0.089	109			0.121	252
200.5	Chokwe	MOZ	0.060	233	0.145	202	0.066	227	0.143	140		
202.0	Dantokpa	BEN	0.077	160	0.134	236	0.061	252	0.133	160		
202.8	Kitwe	ZMB	0.077	154	0.136	227	0.067	224			0.133	206
203.2	Montepuez	MOZ	0.078	151	0.139	217	0.053	294	0.137	150	0.134	204
204.0	Mansa	ZMB	0.100	80	0.146	197	0.034	411	0.142	144	0.138	188
205.2	Jijiga	ETH	0.043	370	0.147	190	0.077	164	0.145	131	0.145	171
206.5	Choma	ZMB	0.084	121	0.131	251	0.061	254			0.134	200
206.5	Maxixe	MOZ	0.083	124	0.147	194	0.048	324			0.141	184
208.0	Nouakchott	MRT	0.050	316	0.139	218	0.101	68	0.125	191	0.121	247
208.6	National Average	GHA	0.091	105	0.130	254	0.054	288	0.129	174	0.129	222
208.8	Bedessa	ETH	0.053	289	0.150	185	0.064	236	0.150	125		
209.3	Cinkassé	TGO	0.059	242	0.136	226	0.069	215	0.136	154		
209.3	Bol	TCD	0.074	172	0.147	189	0.051	304			0.145	172
210.0	Musha	RWA	0.057	254	0.147	191	0.095	89	0.111	233	0.110	283

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... *Table A.2 continued*

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
210.6	Bol	TCD	0.063	215	0.145	204	0.049	320	0.144	135	0.142	179
210.8	Ibadan	NGA	0.067	197	0.135	232	0.071	203			0.133	211
211.6	Dire Dawa	ETH	0.054	283	0.134	241	0.082	137	0.126	187	0.133	210
211.8	Jeremie	HTI	0.053	294	0.153	174	0.047	338	0.153	113	0.154	140
212.0	Labé	GIN	0.046	348	0.134	240	0.090	101	0.122	203	0.146	168
212.3	Bangula	MWI	0.084	122	0.151	178	0.038	393			0.150	156
212.8	Bol	TCD	0.067	196	0.144	205	0.045	347	0.144	136	0.142	180
213.5	Awassa Zuriya	ETH	0.065	210	0.143	209	0.065	228			0.133	207
213.6	Ruyigi	BDI	0.064	211	0.125	274	0.083	135	0.125	193	0.120	255
213.8	Mchinji	MWI	0.087	116	0.154	170	0.039	379			0.137	190
214.3	Gisenyi	RWA	0.059	243	0.126	271	0.084	129				
214.7	Tamale	GHA	0.065	205	0.134	242	0.071	197				
217.6	Kabwe Urban	ZMB	0.087	115	0.130	259	0.051	303	0.127	182	0.126	229
217.6	Ndola Rural	ZMB	0.058	252	0.131	253	0.072	193	0.129	173	0.131	217
218.0	Latri kunda	GMB	0.046	351	0.137	225	0.093	97			0.134	199
218.3	Wajir	KEN	0.049	323	0.133	247	0.082	139	0.132	164		
218.4	Babile	ETH	0.050	308	0.139	219	0.069	213	0.137	149	0.134	203
218.8	Jijiga	ETH	0.037	413	0.145	203	0.078	162	0.143	138	0.142	178
220.0	Loulouni	MLI	0.077	161	0.128	266	0.063	240	0.125	194	0.123	239
220.4	Alamata	ETH	0.057	256	0.134	244	0.067	225	0.132	165	0.132	212
220.8	Alamata	ETH	0.056	260	0.134	238	0.064	235	0.133	162	0.133	209
220.8	Kobo	ETH	0.064	213	0.133	245	0.061	253	0.132	167	0.128	226
221.3	Hinche	HTI	0.053	292	0.136	230	0.082	142				
221.6	Managua	NIC	0.066	199	0.127	269	0.071	199	0.123	197	0.122	244
221.6	Dioïla	MLI	0.089	111	0.130	255	0.044	351	0.130	168	0.129	223
221.8	Kitwe	ZMB	0.079	144	0.130	260	0.058	265			0.130	218
223.0	Kalomo	ZMB	0.072	178	0.129	261	0.058	264	0.127	181	0.126	231
223.8	Musanze	RWA	0.080	142	0.133	249	0.043	361	0.137	152	0.132	215
224.0	Hinche	HTI	0.048	334	0.135	234	0.081	146	0.128	176	0.126	230

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... *Table A.2 continued*

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
224.2	Babile	ETH	0.047	336	0.138	222	0.070	205	0.137	153	0.134	205
226.0	Gitega	BDI	0.049	322	0.134	239	0.069	209	0.134	159	0.134	201
226.2	Diebougou	BFA	0.068	191	0.136	229	0.045	348	0.136	155	0.133	208
227.5	Dire Dawa	ETH	0.054	281	0.134	243	0.081	148			0.123	238
228.0	Base	RWA	0.079	145	0.127	267	0.047	330	0.129	171	0.127	227
228.0	Hinche	HTI	0.051	300	0.132	250	0.078	160	0.126	184	0.121	246
229.0	Brikama	GMB	0.043	372	0.135	231	0.097	84	0.118	213	0.122	245
229.6	Chisinau	MDA	0.056	262	0.137	224	0.063	242	0.127	180	0.123	240
230.3	Gaya	NER	0.063	216	0.125	278	0.073	190			0.124	237
231.3	Cotonou	BEN	0.055	267	0.130	258	0.075	176			0.129	224
232.4	Chokwe	MOZ	0.042	376	0.145	200	0.057	272	0.145	133	0.142	181
235.8	Mahoko	RWA	0.039	394	0.134	237	0.080	155	0.127	179	0.132	214
236.6	Mufulira	ZMB	0.047	341	0.129	262	0.074	182	0.129	170	0.126	228
238.5	Banfora	BFA	0.075	170	0.125	275	0.058	268			0.122	241
239.2	Garoua	CMR	0.055	269	0.122	291	0.081	143	0.108	243	0.121	250
239.4	Diffa Commune	NER	0.060	234	0.121	293	0.071	198	0.118	210	0.116	262
240.3	Cotonou	BEN	0.071	182	0.125	277	0.058	266			0.124	236
241.6	N'Djamena	TCD	0.058	249	0.124	284	0.072	194	0.118	211	0.114	270
243.2	Beddenno	ETH	0.055	268	0.124	282	0.065	230	0.126	185	0.121	251
246.0	Gonaives	HTI	0.044	364	0.133	248	0.075	178			0.137	194
246.8	Mbandaka	COD	0.059	240	0.119	301	0.073	189			0.119	257
248.2	Choma	ZMB	0.065	206	0.119	302	0.057	277	0.122	202	0.120	254
248.3	Gonaives	HTI	0.046	347	0.130	256	0.072	192			0.134	198
248.3	Belet Weyne	SOM	0.055	266	0.128	265	0.055	285	0.128	177		
249.6	Soma	GMB	0.056	265	0.118	309	0.076	167	0.117	216	0.107	291
252.6	Thiodaye	SEN	0.060	235	0.121	295	0.067	219	0.111	232	0.110	282
253.8	Rugarama	RWA	0.049	319	0.118	311	0.088	114	0.107	245	0.112	280
254.2	Managua	NIC	0.065	208	0.118	307	0.057	274	0.117	215	0.115	267
254.6	Maxixe	MOZ	0.062	222	0.126	270	0.046	344	0.126	188	0.121	249

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... Table A.2 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
254.8	Ndago	RWA	0.048	330	0.120	297	0.083	133	0.108	241	0.114	273
255.4	Banjul	GMB	0.041	384	0.121	294	0.086	118	0.119	209	0.114	272
256.2	Xai-Xai	MOZ	0.056	264	0.135	233	0.041	369	0.127	183	0.126	232
257.3	Dapaong	TGO	0.066	200	0.134	235	0.037	398	0.124	196		
257.4	Chingola	ZMB	0.053	290	0.129	264	0.051	312	0.126	186	0.125	235
257.6	Lusaka Rural	ZMB	0.089	109	0.123	289	0.036	404	0.116	218	0.115	268
258.0	Kibirizi	RWA	0.048	329	0.117	314	0.076	172	0.116	217		
259.3	Beddenno	ETH	0.054	277	0.124	280	0.067	221				
259.6	Kibirizi	RWA	0.045	354	0.125	276	0.071	201	0.119	208	0.117	259
260.0	Lundazi	ZMB	0.056	263	0.131	252	0.038	385	0.129	175	0.128	225
262.0	Serrekunda	GMB	0.038	404	0.125	279	0.085	126	0.109	239		
263.4	Mahoko	RWA	0.043	371	0.119	304	0.080	153	0.107	246	0.122	243
264.8	Bati	ETH	0.048	326	0.129	263	0.053	292	0.128	178		
266.7	Wonago	ETH	0.051	303	0.123	287	0.069	210				
269.3	Fana	MLI	0.078	150	0.119	306	0.038	388			0.125	233
270.0	Iringa	TZA	0.048	331	0.120	298	0.060	259	0.120	206	0.119	256
270.8	Kicukiro	RWA	0.047	343	0.117	313	0.074	183	0.112	228	0.108	287
272.6	Jacmel	HTI	0.057	259	0.113	324	0.057	276	0.113	227	0.112	277
272.8	Jacmel	HTI	0.064	212	0.114	322	0.056	281			0.113	276
273.0	Solwezi	ZMB	0.065	204	0.117	312	0.042	364	0.115	219	0.115	266
274.8	Ndjamena	TCD	0.062	221	0.110	336	0.055	283	0.108	240	0.106	294
275.3	Abi Adi	ETH	0.050	313	0.124	283	0.060	257			0.121	248
275.4	Jacmel	HTI	0.062	228	0.110	332	0.053	289	0.110	238	0.108	290
275.5	Rugarama	RWA	0.073	175	0.118	310	0.037	396			0.130	221
276.0	Livingstone	ZMB	0.054	276	0.112	328	0.051	311	0.118	212	0.120	253
276.4	Chipata	ZMB	0.055	273	0.109	340	0.069	217	0.103	253	0.104	299
278.8	Cayes	HTI	0.059	239	0.118	308	0.040	375	0.117	214	0.117	258
281.8	Kaura	NGA	0.046	346	0.109	338	0.074	186	0.103	257		
282.8	Garissa	KEN	0.041	386	0.119	305	0.061	255	0.119	207	0.117	261

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... Table A.2 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
284.3	Abi Adi	ETH	0.050	305	0.123	288	0.060	260				
284.8	Koutiala	MLI	0.071	183	0.111	331	0.036	401	0.114	221	0.108	288
285.4	Nyanza	RWA	0.047	345	0.120	300	0.051	307	0.120	204	0.114	271
285.6	Moyale	KEN	0.039	395	0.117	315	0.069	214	0.113	226	0.112	278
286.0	Luangwa	ZMB	0.060	231	0.112	329	0.043	358	0.111	237	0.113	275
286.5	Kabaya	RWA	0.071	185	0.120	299	0.036	402			0.117	260
287.0	Giwa	NGA	0.050	307	0.115	320	0.054	287	0.111	234		
287.0	Diffa	NER	0.058	246	0.104	353	0.057	270	0.102	259	0.100	307
287.0	Kabaya	RWA	0.051	302	0.111	330	0.062	247	0.098	267	0.108	289
287.4	León	NIC	0.053	293	0.114	321	0.044	356	0.113	225	0.122	242
289.2	Nguigmi	NER	0.043	368	0.116	316	0.057	273	0.115	220	0.114	269
289.4	Les Cayes	HTI	0.056	261	0.115	319	0.040	371	0.114	222	0.113	274
291.0	Bati	ETH	0.049	320	0.122	290	0.047	339	0.122	201	0.101	305
291.4	Hossana	ETH	0.064	214	0.107	346	0.044	353	0.106	249	0.105	295
293.4	Hossana	ETH	0.063	217	0.105	351	0.044	354	0.107	248	0.104	297
294.6	Ségou Château	MLI	0.059	236	0.112	326	0.038	389	0.111	236	0.108	286
294.8	Ségou Centre	MLI	0.058	250	0.112	327	0.039	382	0.112	231	0.109	284
295.2	Byumba	RWA	0.050	306	0.115	318	0.045	346	0.108	242	0.115	264
295.6	Deder	ETH	0.050	314	0.109	339	0.050	316	0.113	224	0.109	285
296.3	Ouanaminthe	HTI	0.050	315	0.125	272	0.035	408	0.125	190		
296.6	Ouanaminthe	HTI	0.048	327	0.124	285	0.035	410	0.123	198	0.116	263
296.8	Cayes	HTI	0.048	332	0.116	317	0.047	340	0.112	230	0.115	265
297.6	Deder	ETH	0.048	325	0.110	333	0.050	315	0.114	223	0.107	292
301.8	Muyinga	BDI	0.043	373	0.112	325	0.053	295	0.111	235	0.110	281
302.0	Ndindy	SEN	0.035	436	0.119	303	0.071	200	0.103	255	0.096	316
303.8	Kirundo	BDI	0.039	397	0.121	296	0.049	317	0.120	205		
308.5	Bamenda	CMR	0.047	340	0.110	334	0.052	297	0.100	263		
309.8	N'Djamena	TCD	0.054	279	0.101	364	0.047	335	0.101	261	0.099	310
311.0	Ourossogui	SEN	0.044	359	0.102	361	0.061	256	0.098	268		

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... Table A.2 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
311.0	Koury	MLI	0.067	198	0.103	357	0.029	444	0.103	254	0.102	302
312.4	Douala	CMR	0.036	418	0.105	350	0.062	246	0.105	250	0.104	298
313.3	Ouanaminthe	HTI	0.045	353	0.124	286	0.034	415	0.123	199		
313.3	Lodwar (Turkana)	KEN	0.028	481	0.114	323	0.067	220	0.112	229		
314.0	Ndiagne	SEN	0.043	374	0.106	348	0.070	208			0.092	326
315.7	Bandim	GNB	0.044	361	0.107	345	0.063	241				
317.8	Gaseke	RWA	0.046	352	0.108	342	0.047	333	0.100	262	0.103	300
320.0	S.Vincente	CPV	0.045	355	0.098	373	0.065	232				
320.2	Kampala	UGA	0.040	393	0.110	337	0.047	334	0.108	244	0.107	293
321.4	Niono	MLI	0.052	297	0.102	363	0.039	378	0.101	260	0.100	309
321.5	Lusaka Urban	ZMB	0.055	271	0.101	365	0.046	342			0.100	308
321.8	Lusaka	ZMB	0.044	365	0.099	368	0.052	298	0.099	265	0.098	313
322.4	Maputo	MOZ	0.048	335	0.108	343	0.038	386	0.107	247	0.103	301
324.0	Loulouni	MLI	0.067	195	0.095	380	0.029	443	0.093	275	0.091	327
326.8	Mukamira	RWA	0.038	402	0.099	369	0.062	243	0.090	281	0.087	339
328.0	Butare	RWA	0.041	390	0.103	356	0.043	357	0.102	258	0.112	279
329.2	Jacmel	HTI	0.033	453	0.099	370	0.064	234	0.097	269	0.095	320
330.8	Tonka	MLI	0.026	487	0.103	359	0.062	248	0.103	256	0.101	304
331.4	National Average	NIC	0.077	159	0.104	354	0.018	506	0.088	289	0.085	349
331.8	Sikasso Centre	MLI	0.063	219	0.094	382	0.027	459	0.093	276	0.092	323
332.5	Dan Issa	NER	0.053	291	0.102	362	0.041	366			0.098	311
333.0	Ansongo	MLI	0.047	338	0.098	372	0.041	367	0.096	271	0.095	317
333.8	Koudougou	BFA	0.045	357	0.108	341	0.034	413	0.104	252	0.101	306
337.8	Bambey	SEN	0.044	363	0.098	374	0.058	269			0.086	345
340.0	Wekro	ETH	0.027	483	0.103	358	0.056	279	0.090	284	0.104	296
340.5	Chipata	ZMB	0.053	286	0.108	344	0.024	481	0.104	251		
343.0	Mukamira	RWA	0.054	275	0.106	349	0.036	405				
343.8	Maputo	MOZ	0.044	367	0.100	367	0.038	391	0.094	273	0.094	321

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... Table A.2 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log ∆	Rank log ∆	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
344.2	Causeni	MDA	0.048	328	0.104	355	0.030	431	0.093	274	0.089	333
345.4	Addis Ababa	ETH	0.049	317	0.086	400	0.041	365	0.087	293	0.085	352
346.3	Wekro	ETH	0.033	459	0.104	352	0.057	271			0.102	303
347.0	Tounfafi	NER	0.049	324	0.089	394	0.048	323			0.086	347
349.0	Kayes N'Dy	MLI	0.042	380	0.101	366	0.032	421	0.099	264	0.097	314
349.4	Kongoussi	BFA	0.042	382	0.103	360	0.031	427	0.099	266	0.098	312
350.2	Mandera	KEN	0.024	502	0.093	385	0.064	233	0.087	290	0.087	341
351.2	Tenkodogo	BFA	0.047	337	0.093	383	0.031	426	0.091	280	0.090	330
351.8	Koutiala	MLI	0.068	192	0.088	396	0.008	536	0.087	291	0.087	344
352.8	Ségou Château	MLI	0.050	312	0.086	404	0.045	349			0.086	346
353.4	Badinko	MLI	0.054	280	0.099	371	0.015	519	0.092	278	0.095	319
353.8	San Pedro Sula	HND	0.046	350	0.088	395	0.038	390	0.087	292	0.087	342
353.8	Musanze	RWA	0.035	440	0.098	375	0.043	360	0.097	270	0.092	324
355.0	Sikasso	MLI	0.055	274	0.090	390	0.021	496	0.089	287	0.090	328
356.8	Kaolack	SEN	0.042	383	0.081	422	0.052	300	0.080	309	0.077	370
357.8	Bafoussam	CMR	0.042	377	0.090	389	0.036	407	0.090	282	0.089	334
362.0	Sikasso Médine	MLI	0.059	244	0.090	388	0.025	473			0.087	343
363.6	Bujumbura	BDI	0.035	427	0.086	405	0.048	326	0.085	296	0.081	364
363.6	Burao	SOM	0.016	521	0.096	378	0.047	329	0.095	272	0.095	318
363.8	Korem	ETH	0.038	403	0.091	387	0.035	409	0.090	283	0.088	337
364.3	Conakry	GIN	0.033	454	0.097	377	0.059	262				
364.4	National Average	ZMB	0.068	193	0.082	421	0.016	515	0.079	311	0.075	382
364.7	Mexico City	MEX	0.003	545	0.010	545	0.000				0.275	4
365.2	Koury	MLI	0.058	251	0.087	399	0.012	528	0.087	295	0.085	353
365.4	Korem	ETH	0.038	401	0.092	386	0.034	416	0.089	286	0.088	338
365.4	Jeremie	HTI	0.025	495	0.088	398	0.048	325	0.087	294	0.096	315
367.0	Segou	MLI	0.042	378	0.085	409	0.049	321			0.082	360
368.4	Maradi	NER	0.043	375	0.085	410	0.037	399	0.083	302	0.083	356
369.4	Bougouni	MLI	0.051	299	0.086	402	0.022	491	0.085	298	0.083	357

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... Table A.2 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
370.2	Tegucigalpa	HND	0.053	288	0.082	420	0.024	478	0.082	303	0.081	362
370.2	Kicukiro	RWA	0.038	405	0.085	408	0.036	400	0.081	306	0.090	332
370.4	Niono	MLI	0.055	272	0.078	433	0.027	457	0.077	316	0.077	374
370.5	Dosso	NER	0.047	344	0.089	392	0.036	406			0.087	340
370.8	Djikoroni	MLI	0.038	406	0.083	417	0.040	373	0.085	297	0.082	361
371.0	Marsabit	KEN	0.027	485	0.093	384	0.047	336	0.092	279		
372.0	Bla	MLI	0.054	282	0.080	426	0.031	430	0.070	341	0.075	381
373.2	Ziguichor	SEN	0.029	474	0.079	430	0.056	280	0.078	313	0.078	369
373.6	Diourbel	SEN	0.034	442	0.076	441	0.049	318	0.077	317	0.085	350
374.2	Ouagadougou	BFA	0.035	439	0.094	381	0.029	445	0.093	277	0.090	329
374.4	Kayes N'Dy	MLI	0.038	400	0.081	425	0.039	376	0.082	304	0.080	367
374.8	Hinche	HTI	0.024	497	0.084	413	0.051	305	0.084	300	0.082	359
375.6	Bujumbura	BDI	0.035	431	0.083	418	0.044	355	0.084	301	0.077	373
376.8	Agadez Commune	NER	0.034	447	0.084	416	0.045	350	0.081	305	0.080	366
377.4	Marsabit	KEN	0.027	486	0.085	407	0.046	341	0.085	299	0.084	354
378.3	Tougan	BFA	0.036	423	0.097	376	0.038	392			0.093	322
378.6	Lodwar (Turkana)	KEN	0.040	391	0.081	424	0.037	394	0.081	307	0.076	377
378.8	Nyakarambi	RWA	0.041	385	0.089	391	0.021	498	0.089	285	0.089	335
381.0	Tegucigalpa	HND	0.047	342	0.081	423	0.026	467	0.081	308	0.080	365
381.3	S.Vincente	CPV	0.038	408	0.089	393	0.046	343				
381.7	Wanle Weyne	SOM	0.049	318	0.122	292	0.009	535				
383.2	San Pedro Sula	HND	0.047	339	0.080	428	0.025	471	0.080	310	0.078	368
383.7	Ségou Centre	MLI	0.038	410	0.084	414	0.048	327				
384.3	Léré	MLI	0.037	414	0.110	335	0.028	452			0.089	336
384.7	Ruhuha	RWA	0.044	366	0.107	347	0.030	441				
384.8	Nioro	MLI	0.039	396	0.096	379	0.030	439			0.092	325
386.0	Touba	SEN	0.031	465	0.084	415	0.052	301			0.081	363
388.8	Maradi	NER	0.041	388	0.080	427	0.032	423	0.076	322	0.074	384

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... Table A.2 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log ∆	Rank log ∆	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
389.8	San	MLI	0.045	358	0.086	403	0.028	450			0.086	348
390.0	Saint-Louis	SEN	0.036	422	0.086	401	0.022	488	0.088	288	0.085	351
392.5	Bugarama	RWA	0.036	424	0.084	412	0.033	419	0.077	315		
392.8	Fatick	SEN	0.026	489	0.079	431	0.047	331	0.071	338	0.077	375
394.6	Sogoniko	MLI	0.038	398	0.077	439	0.030	438	0.076	320	0.076	378
395.0	Lafiabougou	MLI	0.037	415	0.077	436	0.030	433	0.077	319	0.077	372
395.5	Zinder	NER	0.036	425	0.082	419	0.043	359			0.075	379
395.8	Mopti Digue	MLI	0.033	451	0.088	397	0.039	380			0.083	355
396.6	Badalabougou	MLI	0.036	420	0.078	434	0.029	446	0.079	312	0.077	371
398.2	Dori	BFA	0.028	478	0.078	435	0.044	352	0.073	330	0.072	396
399.6	Gao	MLI	0.035	428	0.077	437	0.031	429	0.076	321	0.075	383
400.3	Bushenge	RWA	0.028	477	0.079	429	0.039	381	0.078	314		
401.2	Gouille Mbeuth	SEN	0.037	417	0.073	457	0.040	374	0.070	342	0.068	416
403.2	Port-de-Paix	HTI	0.021	509	0.059	501	0.027	462	0.053	377	0.146	167
403.5	Abalak	NER	0.042	379	0.072	464	0.040	370			0.070	401
404.0	Niamakoro	MLI	0.035	441	0.076	444	0.030	432	0.075	323	0.075	380
404.5	Niamey	NER	0.037	416	0.075	448	0.032	422	0.073	332		
405.6	Faladié	MLI	0.038	407	0.075	449	0.027	458	0.075	325	0.074	389
406.2	Sikasso Centre	MLI	0.046	349	0.074	453	0.018	510	0.074	326	0.073	393
407.6	Niarela	MLI	0.035	426	0.076	445	0.027	456	0.075	324	0.074	387
408.3	Sagatta	SEN	0.027	482	0.070	471	0.047	337	0.070	343		
408.6	Kamembe	RWA	0.028	479	0.072	465	0.043	362	0.072	335	0.070	402
409.4	Tillaberi	NER	0.028	476	0.074	452	0.039	383	0.072	337	0.071	399
409.4	Port-au-Prince	HTI	0.030	470	0.076	440	0.032	420	0.074	327	0.074	390
410.4	Niamey	NER	0.032	464	0.074	450	0.033	417	0.073	333	0.074	388
410.8	Magnambougou	MLI	0.035	429	0.074	454	0.028	451	0.073	328	0.073	392
412.2	Thiaroye	SEN	0.023	503	0.072	461	0.048	328	0.068	349	0.067	420
412.5	Djibo	BFA	0.033	458	0.079	432	0.029	442	0.077	318		
412.6	Nairobi	KEN	0.023	504	0.074	451	0.041	368	0.072	336	0.070	404

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... Table A.2 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
414.8	Agadez	NER	0.038	399	0.072	460	0.028	453	0.067	357	0.069	405
415.0	Ouanaminthe	HTI	0.017	517	0.077	438	0.051	314			0.073	391
415.3	Diré	MLI	0.027	484	0.075	447	0.047	332			0.071	398
417.6	Dibida	MLI	0.034	443	0.073	456	0.027	461	0.073	331	0.072	397
418.8	Santo Domingo	DOM	0.033	456	0.085	406	0.027	455			0.083	358
421.4	Medine	MLI	0.034	450	0.072	459	0.026	464	0.072	334	0.071	400
422.4	San Salvador	SLV	0.034	446	0.068	481	0.030	435	0.067	356	0.072	394
422.8	Port-au-Prince	HTI	0.030	467	0.075	446	0.024	477	0.073	329	0.072	395
423.3	Sogoniko	MLI	0.041	389	0.069	478	0.034	414			0.068	412
424.6	Niarela	MLI	0.034	444	0.064	486	0.029	449	0.065	359	0.074	385
424.8	Zinder	NER	0.035	438	0.076	443	0.034	412			0.069	406
424.8	Koulikoro Gare	MLI	0.032	462	0.070	469	0.030	440	0.069	344	0.069	409
425.2	Sikasso Médine	MLI	0.043	369	0.068	480	0.020	500	0.068	354	0.066	423
426.0	Port-au-Prince	HTI	0.020	512	0.071	466	0.037	395	0.069	347	0.068	410
427.0	Panama City	PAN	0.028	480	0.070	473	0.036	403	0.068	355	0.066	424
428.4	Fadjiguila	MLI	0.035	435	0.071	467	0.021	497	0.071	340	0.070	403
428.6	Faladié	MLI	0.038	409	0.065	485	0.026	463	0.064	360	0.064	426
429.2	Koulikoro Ba	MLI	0.032	461	0.069	475	0.029	448	0.069	348	0.068	414
429.6	Ouolofobougou	MLI	0.038	411	0.070	468	0.017	512	0.069	346	0.068	411
430.4	Magnambougou	MLI	0.036	419	0.064	489	0.027	454	0.063	362	0.063	428
434.2	Les Cayes	HTI	0.019	515	0.066	484	0.038	387	0.065	358	0.064	427
434.8	Guatemala City	GTM	0.040	392	0.061	495	0.022	490	0.062	363	0.059	434
435.3	Kayes Centre	MLI	0.035	430	0.076	442	0.023	483			0.074	386
435.7	Niamakoro	MLI	0.035	434	0.069	476	0.037	397				
435.7	Maradi Commune	NER	0.029	472	0.073	458	0.039	377				
436.3	Kayes Plateau	MLI	0.033	460	0.068	479	0.030	436	0.057	370		
437.0	San Salvador	SLV	0.035	437	0.064	488	0.026	469	0.064	361	0.061	430
438.6	Port-au-Prince	HTI	0.030	469	0.072	462	0.019	504	0.069	345	0.068	413

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... *Table A.2 continued*

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
439.6	Cap Haitien	HTI	0.024	499	0.069	474	0.026	468	0.068	350	0.069	407
443.0	Bamako	MLI	0.033	457	0.068	482	0.019	503	0.068	351	0.066	422
444.2	Cap-Haitien	HTI	0.024	501	0.069	477	0.025	472	0.068	353	0.067	418
444.6	Djenne	MLI	0.028	475	0.072	463	0.007	538	0.071	339	0.069	408
445.0	Mbafaye	SEN	0.026	488	0.058	504	0.033	418	0.055	373	0.055	442
445.3	Bossaso	SOM	0.021	510	0.084	411	0.023	484			0.076	376
446.4	Fadjiguila	MLI	0.035	432	0.058	502	0.021	493	0.059	367	0.057	438
447.0	Lafiabougou	MLI	0.036	421	0.066	483	0.026	465			0.067	419
447.0	Badalabougou	MLI	0.034	448	0.064	487	0.031	428			0.064	425
448.4	Tombouctou	MLI	0.025	492	0.070	472	0.017	511	0.068	352	0.068	415
449.0	Louga	SEN	0.023	505	0.063	490	0.040	372			0.062	429
450.3	San	MLI	0.041	387	0.070	470	0.013	527			0.067	417
450.3	S.Antao	CPV	0.019	516	0.048	520	0.030	434			0.090	331
452.4	Cebu	PHL	0.034	449	0.061	494	0.016	518	0.059	364	0.058	437
456.3	Gao	MLI	0.037	412	0.062	493	0.022	487			0.059	433
456.7	S.Vincente	CPV	0.026	491	0.073	455	0.032	424				
457.0	Cap Haitien	HTI	0.021	511	0.059	500	0.026	466	0.059	365	0.054	443
457.2	Koulikoro Ba	MLI	0.026	490	0.057	505	0.022	489	0.055	371	0.060	431
457.6	Kayes Centre	MLI	0.031	466	0.060	497	0.013	523	0.059	366	0.059	436
458.0	Guatemala City	GTM	0.033	452	0.053	513	0.020	501	0.053	376	0.053	448
458.3	Djikoroni	MLI	0.035	433	0.063	491	0.026	470			0.057	439
458.4	Koulikoro Gare	MLI	0.029	471	0.055	507	0.021	495	0.054	375	0.054	444
460.6	Gueule Tapee	SEN	0.024	496	0.062	492	0.013	525	0.058	369	0.066	421
460.6	Goure	NER	0.024	500	0.060	498	0.018	505	0.059	368	0.060	432
462.0	Davao City	PHL	0.025	494	0.052	514	0.025	474	0.051	378	0.051	450
464.0	Thies	SEN	0.020	513	0.049	516	0.027	460	0.048	379	0.047	452
466.2	National Average	ZMB	0.032	463	0.054	511	0.009	534	0.054	374	0.052	449
467.3	Dibida	MLI	0.033	455	0.060	499	0.024	480			0.059	435
469.5	Port-de-Paix	HTI	0.019	514	0.055	508	0.024	476	0.047	380		

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... Table A.2 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
473.3	Ouolofobougou	MLI	0.034	445	0.061	496	0.024	479				
475.6	Santiago	CPV	0.015	527	0.048	517	0.020	499	0.045	382	0.041	453
477.5	National Average	SWZ	0.015	524	0.048	519	0.022	486	0.047	381		
477.5	Yaundé	CMR	0.022	508	0.054	510	0.029	447			0.054	445
480.0	Medine	MLI	0.029	473	0.054	509	0.021	492			0.054	446
481.0	National Average	CRI	0.022	507	0.054	512	0.009	533	0.055	372		
482.0	National Average	PHL	0.024	498	0.040	528	0.004	539	0.035	386	0.035	459
482.6	Cap Haitien	HTI	0.015	525	0.041	527	0.015	521	0.039	385	0.038	455
483.8	Maputo	MOZ	0.017	519	0.041	525	0.030	437			0.038	454
485.5	Tombouctou	MLI	0.023	506	0.046	521	0.010	532	0.042	383		
485.8	Davao City	PHL	0.030	468	0.055	506	0.015	522			0.053	447
486.5	Mopti Digue	MLI	0.025	493	0.058	503	0.018	509			0.055	441
487.0	Touba Toul	SEN	0.017	518	0.048	518	0.032	425				
489.3	National Average	ZMB	0.015	526	0.038	530	0.016	517	0.040	384		
490.0	Iloilo	PHL	0.007	541	0.026	538	0.015	520	0.025	387	0.024	464
490.6	National Average	PHL	0.010	535	0.025	539	0.013	526	0.024	388	0.024	465
491.0	Tilene	SEN	0.015	523	0.051	515	0.025	475			0.050	451
497.8	Santiago	CPV	0.016	520	0.038	529	0.023	485			0.038	457
500.8	Mopti Guangal	MLI	0.014	528	0.044	522	0.017	513			0.056	440
503.0	Santiago	CPV	0.013	530	0.042	524	0.019	502			0.038	456
505.0	Praia	CPV	0.010	537	0.036	531	0.021	494			0.035	458
509.8	National Average	GTM	0.012	531	0.033	533	0.017	514			0.033	461
511.3	National Average	PHL	0.014	529	0.042	523	0.023	482				
511.8	National Average	GTM	0.011	533	0.031	535	0.016	516			0.031	463
515.0	Iloilo	PHL	0.009	538	0.030	536	0.013	524			0.031	462
517.0	Lima	PER	0.011	534	0.027	537	0.008	537			0.033	460
518.7	National Average	NIC	0.016	522	0.041	526	0.018	508				
520.0	S.Antao	CPV	0.005	543	0.021	540	0.010	531			0.021	466
522.0	Lima	PER	0.008	539	0.021	541	0.003	541			0.020	467

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... Table A.2 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
522.5	National Average	PHL	0.007	540	0.019	542	0.004	540			0.015	468
524.8	Luanda	AGO	0.004	544	0.010	544	0.003	542			0.010	469
527.7	MetroManila	PHL	0.007	542	0.032	534	0.018	507				
532.3	South Cotabato	PHL	0.010	536	0.036	532	0.012	529				
539.3	National Average	CHN	0.012	532	0.017	543	0.000	543				

Source: Source: Author's computation based on ZEF [2014].

Table A.3: Rice price volatility by market

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
3.0	Ngozi	BDI	0.141	5	0.347	2	0.238	2	0.194	1	0.204	5
3.8	Kankan	GIN	0.112	10	0.416	1	0.372	1			0.228	3
10.2	Ngabu	MWI	0.111	11	0.159	12	0.101	13	0.155	3	0.148	12
12.3	Gharm	TJK	0.080	37	0.219	3	0.148	3			0.174	6
12.8	Khujand	TJK	0.082	33	0.204	5	0.136	5			0.171	8
13.3	Karonga	MWI	0.218	1	0.153	13	0.076	29			0.154	10
14.5	Gharm	TJK	0.076	43	0.216	4	0.146	4			0.171	7
14.8	Mbandaka	COD	0.139	6	0.142	16	0.085	19			0.134	18
15.4	Mzuzu	MWI	0.128	9	0.133	25	0.099	14	0.127	9	0.127	20
15.8	Kalemie	COD	0.209	2	0.137	19	0.070	36	0.137	5	0.141	17
17.0	Buale	SOM	0.072	52	0.167	8	0.104	12	0.156	2	0.153	11
18.7	Khujand	TJK	0.076	44	0.201	6	0.135	6				
21.5	Jaffna	LKA	0.152	4	0.178	7	0.061	59	0.119	16		
22.6	Les Cayes	HTI	0.062	76	0.143	15	0.126	7	0.130	6	0.156	9
23.2	Montepuez	MOZ	0.061	78	0.162	9	0.115	9	0.144	4	0.144	16
23.4	Kalemie	COD	0.182	3	0.125	30	0.064	52	0.124	11	0.124	21
27.0	Cayes	HTI	0.060	85	0.138	18	0.122	8	0.125	10	0.146	14

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… Table A.3 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
29.6	Ruyigi	BDI	0.130	8	0.112	43	0.071	35	0.108	26	0.108	36
30.8	Mzuzu	MWI	0.109	12	0.109	46	0.070	40	0.109	25		
31.2	Baidoa	SOM	0.068	62	0.126	29	0.077	27	0.124	12	0.119	26
31.2	Khorog	TJK	0.052	115	0.161	10	0.113	10	0.118	17	0.211	4
32.0	Ker Pate Kore	GMB	0.075	46	0.133	24	0.080	25	0.111	22	0.105	43
33.8	Ndjamena	TCD	0.062	77	0.135	22	0.083	22	0.121	15	0.112	33
36.4	Sana'a	YEM	0.071	53	0.118	39	0.075	31	0.113	21	0.107	38
41.5	Khorog	TJK	0.050	125	0.159	11	0.111	11	0.115	19		
41.7	Parsa	NPL	0.073	50	0.128	27	0.066	48				
42.8	Khulna	BGD	0.051	120	0.136	21	0.076	30	0.122	14	0.116	29
43.4	Jalalabad	AFG	0.106	14	0.120	33	0.043	121	0.117	18	0.115	31
43.4	Ker Pate Kore	GMB	0.069	56	0.135	23	0.078	26	0.093	46	0.090	66
47.2	Marka	SOM	0.081	35	0.109	47	0.051	82	0.108	27	0.104	45
48.5	Kathmandu	NPL	0.084	29	0.093	77	0.069	43	0.093	45		
49.0	Kaolack	SEN	0.062	74	0.116	40	0.064	49	0.102	32	0.103	50
49.2	Ndjamena	TCD	0.043	163	0.124	32	0.084	20	0.105	29	0.553	2
49.6	Batticaloa	LKA	0.066	68	0.109	45	0.056	71	0.109	24	0.106	40
49.8	Ndindy	SEN	0.057	94	0.125	31	0.072	33			0.105	41
49.8	Conakry	GIN	0.096	21	0.100	60	0.064	50	0.092	49	0.089	69
51.6	Amegnran	TGO	0.039	191	0.137	20	0.094	17	0.130	7	0.123	23
54.0	Kirundo	BDI	0.079	39	0.098	62	0.062	56	0.093	48	0.091	65
54.6	Muyinga	BDI	0.084	30	0.097	67	0.055	72	0.095	42	0.095	62
55.2	Lunzu	MWI	0.098	20	0.095	74	0.053	74	0.095	44	0.092	64
56.8	Bandim	GNB	0.059	86	0.104	54	0.063	53	0.101	34		
57.5	Dar es Salaam	TZA	0.041	172	0.132	26	0.081	24	0.128	8		
58.8	Mitundu	MWI	0.050	123	0.118	38	0.076	28			0.103	46
58.8	Kurgan-Tyube	TJK	0.073	49	0.098	64	0.051	84	0.098	38	0.096	59
60.8	Trincomalee	LKA	0.082	32	0.105	50	0.043	122	0.097	39		
61.6	Borama	SOM	0.042	167	0.120	34	0.062	55	0.106	28	0.121	24

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... Table A.3 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
62.0	Chokwe	MOZ	0.045	142	0.105	52	0.072	34	0.103	31	0.102	51
62.8	Mbafaye	SEN	0.052	113	0.110	44	0.062	57	0.099	37		
64.2	Ambon	IDN	0.035	230	0.139	17	0.096	15	0.114	20	0.107	39
65.0	Tambacounda	SEN	0.058	89	0.106	49	0.059	65			0.096	57
65.3	Kurgan-Tyube	TJK	0.067	63	0.096	70	0.050	88	0.097	40		
66.0	Bandim	GNB	0.136	7	0.103	58	0.035	186	0.104	30	0.103	49
69.0	Dushanbe	TJK	0.048	135	0.119	35	0.070	37				
69.4	N'Djamena	TCD	0.038	193	0.114	41	0.082	23	0.101	35	0.097	55
69.6	Kismayo	SOM	0.066	67	0.104	55	0.043	119	0.093	47	0.096	60
69.8	N'Djamena	TCD	0.055	104	0.097	65	0.061	58	0.091	52		
70.6	Lomé	TGO	0.031	288	0.144	14	0.094	16	0.123	13	0.123	22
70.8	Gorongosa	MOZ	0.037	202	0.127	28	0.083	21			0.113	32
72.8	Katiola	CIV	0.056	97	0.091	81	0.051	85			0.118	28
74.4	Hudur	SOM	0.051	119	0.103	57	0.057	69	0.092	50	0.086	77
75.2	Nampula	MOZ	0.037	206	0.107	48	0.074	32	0.101	36	0.101	54
76.0	Iringa	TZA	0.107	13	0.085	99	0.043	120	0.085	64	0.083	84
76.0	Dushanbe	TJK	0.045	150	0.118	37	0.069	41				
77.6	Kisangani	COD	0.095	22	0.083	112	0.049	94	0.082	70	0.081	90
78.0	Banke	NPL	0.049	131	0.093	78	0.070	38	0.083	69	0.087	74
79.8	Milange	MOZ	0.060	83	0.088	92	0.052	78	0.084	66		
82.8	Mbandaka	COD	0.043	165	0.098	63	0.060	61	0.088	57	0.089	68
84.0	Bangula	MWI	0.094	23	0.084	107	0.034	194	0.085	62	0.109	34
84.0	Manica	MOZ	0.036	220	0.105	51	0.085	18			0.103	47
84.2	BrikamaBa	GMB	0.041	171	0.100	59	0.067	45	0.087	59	0.082	87
84.2	Anie	TGO	0.037	204	0.096	71	0.069	42	0.095	43	0.095	61
84.4	Gonaives	HTI	0.045	145	0.097	68	0.060	63	0.078	83	0.092	63
85.6	Kabul	AFG	0.046	140	0.099	61	0.057	68	0.083	68	0.081	91
85.7	Lahore	PAK	0.044	155	0.104	56	0.067	46				
86.0	Bunia	COD	0.073	48	0.081	121	0.051	83	0.080	76	0.077	102

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... Table A.3 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
86.8	Korbongou	TGO	0.038	194	0.095	73	0.067	47	0.090	53	0.090	67
87.3	Multan	PAK	0.057	90	0.094	75	0.048	97				
87.5	Belet Weyne	SOM	0.067	66	0.092	79	0.040	134			0.088	71
87.8	Jacmel	HTI	0.069	57	0.089	91	0.038	159	0.088	56	0.087	76
89.6	Gouille Mbeuth	SEN	0.043	159	0.092	80	0.053	76	0.087	58	0.087	75
91.0	Kedougou	SEN	0.057	92	0.089	90	0.049	91				
91.6	Hargeisa	SOM	0.031	276	0.118	36	0.060	60	0.102	33	0.102	53
91.8	Amboasary	MDG	0.057	93	0.089	89	0.060	62	0.065	123		
92.0	Quetta	PAK	0.049	134	0.089	88	0.051	86	0.086	60		
92.6	Jhapa	NPL	0.075	45	0.080	128	0.046	107	0.079	80	0.077	103
94.0	Dhankuta	NPL	0.069	55	0.078	133	0.052	77	0.076	89	0.072	116
96.3	Bignona	SEN	0.062	75	0.086	95	0.042	123			0.081	92
96.5	Nzérékoré	GIN	0.081	34	0.080	122	0.040	141			0.081	89
98.3	Kindia	GIN	0.087	27	0.079	129	0.037	166	0.082	71		
99.3	Mogadishu	SOM	0.090	24	0.091	82	0.033	206			0.082	85
100.0	Faizabad	AFG	0.048	136	0.085	100	0.044	112			0.102	52
101.4	Port-au-Prince	HTI	0.045	146	0.090	85	0.038	155	0.091	51	0.089	70
102.6	Jumla	NPL	0.023	374	0.112	42	0.070	39	0.109	23	0.109	35
104.0	Ouanaminthe	HTI	0.069	54	0.085	98	0.031	220	0.084	65	0.083	83
104.2	Jeremie	HTI	0.033	241	0.090	86	0.058	67	0.089	55	0.088	72
107.6	Moussoro	TCD	0.034	239	0.096	72	0.059	66	0.081	73	0.082	88
107.6	Jalalabad	AFG	0.089	25	0.096	69	0.019	345	0.097	41	0.096	58
110.2	Cap Haitien	HTI	0.045	143	0.080	127	0.040	139	0.066	117	0.120	25
111.3	Bouake	CIV	0.041	173	0.083	113	0.051	87	0.081	72		
112.2	Nili	AFG	0.053	108	0.084	105	0.034	200	0.084	67	0.084	81
114.2	Salima	MWI	0.080	36	0.078	137	0.031	217	0.079	81	0.078	100
114.5	Rolpa	NPL	0.042	166	0.080	123	0.048	95	0.080	74		
114.8	Tubmanburg	LBR	0.037	207	0.081	119	0.054	73	0.078	82	0.080	93
117.2	Sokolo	MLI	0.102	17	0.073	154	0.033	204	0.073	99	0.074	112

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... Table A.3 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log ∆	Rank log ∆	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
118.0	Lilongwe	MWI	0.079	38	0.105	53	0.018	358	0.085	61	0.085	80
120.0	Antisiranana I	MDG	0.046	141	0.084	108	0.056	70	0.066	118	0.063	163
121.5	Kankan	GIN	0.103	16	0.080	125	0.029	247			0.079	98
121.5	Tilene	SEN	0.028	314	0.097	66	0.060	64			0.105	42
122.0	Bakau	GMB	0.035	227	0.081	116	0.049	93	0.080	75	0.078	99
123.5	Kathmandu	NPL	0.066	69	0.069	178	0.000					
123.8	Soma	GMB	0.036	223	0.083	111	0.050	89	0.076	91	0.076	105
124.2	Galkayo	SOM	0.051	117	0.082	115	0.032	214	0.080	78	0.079	97
125.3	Peshawar	PAK	0.037	210	0.090	87	0.052	79				
125.4	Soma	GMB	0.036	216	0.083	110	0.048	98	0.075	93	0.074	110
125.4	Rupandehi	NPL	0.050	127	0.071	166	0.045	108	0.071	106	0.070	120
125.8	Cap haitien	HTI	0.043	164	0.091	84	0.031	218			0.107	37
126.5	Port-de-Paix	HTI	0.044	153	0.081	117	0.041	130			0.076	106
128.4	Karachi	PAK	0.049	133	0.083	114	0.036	178	0.057	173	0.105	44
128.7	Jacmel	HTI	0.065	70	0.087	94	0.031	222				
130.4	Illam	NPL	0.060	82	0.066	186	0.043	115	0.065	125	0.066	144
130.5	Kindia	GIN	0.032	259	0.083	109	0.046	106			0.103	48
130.8	Bunia	COD	0.086	28	0.068	181	0.036	174			0.068	140
131.2	Lamin	GMB	0.032	257	0.080	124	0.047	104	0.080	77	0.080	94
132.8	Bengkulu	IDN	0.035	229	0.081	120	0.050	90	0.075	92		
134.8	Quetta	PAK	0.050	129	0.077	139	0.036	181	0.076	90		
135.2	Cap-Haitien	HTI	0.038	200	0.091	83	0.027	266	0.089	54	0.088	73
137.2	Kaur Wharf Town	GMB	0.051	122	0.069	173	0.033	205	0.070	108	0.086	78
140.0	Bhopal	IND	0.034	237	0.077	138	0.051	81			0.077	104
142.3	Nili	AFG	0.056	100	0.078	132	0.028	252	0.078	85		
143.0	National Average	LAO	0.103	15	0.069	180	0.027	269	0.069	112	0.068	139
143.2	Passy	SEN	0.036	221	0.075	145	0.040	142	0.074	97	0.074	111
143.2	Ndugu Kebbeh	GMB	0.033	248	0.074	149	0.051	80	0.070	107	0.069	132

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... Table A.3 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
143.3	Gueule Tapee	SEN	0.032	264	0.085	103	0.046	105			0.077	101
144.8	Porokhane	SEN	0.027	325	0.085	101	0.047	101	0.077	88	0.076	109
144.8	Dogofri	MLI	0.084	31	0.066	189	0.029	237	0.067	115	0.065	152
145.6	Barra	GMB	0.035	226	0.071	165	0.044	114	0.073	98	0.070	125
145.8	Mananjary	MDG	0.036	215	0.078	136	0.067	44			0.060	188
146.6	Bouake	CIV	0.033	252	0.075	147	0.047	99	0.071	104	0.069	131
147.2	Ribaue	MOZ	0.025	351	0.086	96	0.044	110	0.060	160	0.129	19
148.8	Kandahar	AFG	0.049	130	0.078	135	0.029	243	0.077	87		
151.8	Labé	GIN	0.061	79	0.065	206	0.024	295			0.118	27
151.8	Kara	TGO	0.016	450	0.084	106	0.062	54	0.085	63	0.082	86
153.5	Fatick	SEN	0.027	331	0.085	102	0.047	102			0.085	79
153.6	Conakry	GIN	0.030	293	0.074	148	0.043	118	0.074	95	0.073	114
153.8	Bujumbura	BDI	0.062	73	0.065	205	0.033	201	0.064	132	0.064	158
154.6	Toliara I	MDG	0.055	103	0.065	208	0.036	180	0.064	126	0.065	156
154.8	Fayzabad	AFG	0.041	174	0.071	167	0.029	248			0.115	30
155.0	Bujumbura	BDI	0.068	59	0.065	203	0.037	173			0.061	185
155.2	Bansang	GMB	0.031	286	0.075	146	0.053	75	0.070	109	0.064	160
156.8	Saint-Louis	SEN	0.038	192	0.068	182	0.038	153	0.072	100		
160.5	Morang	NPL	0.045	148	0.066	191	0.040	144			0.064	159
162.4	Jeremie	HTI	0.041	170	0.076	143	0.030	226	0.059	165	0.076	108
163.0	Man	CIV	0.072	51	0.065	207	0.028	256	0.063	138		
163.0	Kabul	AFG	0.040	176	0.072	159	0.000		0.062	142	0.062	175
163.4	Gitega	BDI	0.089	26	0.073	157	0.015	404	0.071	103	0.070	127
164.0	Kandahar	AFG	0.045	147	0.077	141	0.028	261			0.076	107
165.5	Ndugu Kebbeh	GMB	0.029	301	0.081	118	0.045	109			0.069	134
166.0	Ambovombe Androy	MDG	0.053	111	0.062	227	0.039	147	0.061	151	0.060	194
166.4	Bakau	GMB	0.027	326	0.072	162	0.043	116	0.071	105	0.070	123
169.4	Surkhet	NPL	0.050	124	0.059	256	0.037	168	0.063	135	0.063	164

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... Table A.3 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
169.6	Kupang	IDN	0.024	357	0.077	140	0.047	103	0.069	111	0.068	137
170.8	Serrekunda	GMB	0.031	279	0.073	153	0.041	129			0.070	122
172.0	Ourossogui	SEN	0.051	116	0.063	214	0.030	231	0.061	152	0.066	147
172.6	Toamasina I	MDG	0.057	95	0.058	269	0.047	100	0.056	179	0.056	220
173.6	Nouakchott	MRT	0.023	372	0.072	161	0.048	96	0.070	110	0.069	129
174.0	Bamenda	CMR	0.029	310	0.073	155	0.044	111	0.066	120		
175.4	Hinche	HTI	0.026	342	0.078	134	0.035	183	0.074	94	0.070	124
175.7	Multan	PAK	0.057	91	0.069	176	0.028	260				
176.8	Benguluru	IND	0.021	401	0.094	76	0.064	51	0.056	178	0.061	178
177.4	Colombo City	LKA	0.067	64	0.061	239	0.029	250	0.062	143	0.060	191
177.6	Bangui	CAF	0.038	196	0.062	230	0.044	113	0.062	144	0.059	205
178.2	Lilongwe	MWI	0.039	182	0.069	172	0.025	286	0.068	113	0.068	138
178.2	Kailali	NPL	0.046	139	0.059	259	0.041	127	0.057	171	0.059	195
178.6	Bambey	SEN	0.033	250	0.072	160	0.038	161	0.056	176	0.066	146
178.8	Tombouctou	MLI	0.034	238	0.055	295	0.038	156	0.054	192	0.148	13
179.7	Port-au-Prince	HTI	0.039	186	0.062	225	0.041	128				
180.0	Mazar e Serif	AFG	0.037	205	0.067	183	0.035	187	0.062	145		
180.3	Jeremie	HTI	0.038	197	0.077	142	0.029	236	0.062	146		
180.8	Hinche	HTI	0.045	152	0.062	228	0.038	154	0.055	186	0.061	184
181.0	Jeremie	HTI	0.028	324	0.084	104	0.023	309	0.078	86	0.084	82
181.0	Cayes	HTI	0.036	222	0.076	144	0.020	330	0.074	96	0.074	113
181.6	Hinche	HTI	0.039	188	0.060	245	0.037	165	0.057	174	0.068	136
183.3	Mpal	SEN	0.034	235	0.066	194	0.039	149	0.061	155		
184.0	Wellingara	GMB	0.033	240	0.063	215	0.037	167	0.063	137	0.063	161
185.0	Wassu	GMB	0.035	231	0.065	204	0.036	175	0.062	147	0.063	168
185.5	Mazar	AFG	0.036	214	0.066	187	0.034	193			0.066	148
185.5	Dakar	SEN	0.038	195	0.069	179	0.029	242			0.070	126
186.6	Sare Ngai	GMB	0.054	106	0.060	253	0.031	216	0.059	162	0.059	196
187.0	Katiola	CIV	0.033	243	0.065	201	0.039	150			0.065	154

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... Table A.3 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
188.3	Angonia	MOZ	0.029	304	0.067	185	0.049	92			0.062	172
190.8	Hinche	HTI	0.023	371	0.074	150	0.032	211	0.072	101	0.070	121
191.0	Port-au-Prince	HTI	0.039	190	0.059	257	0.041	126				
192.3	Thies	SEN	0.024	358	0.074	151	0.040	145			0.072	115
192.8	Basse Santa su	GMB	0.025	349	0.072	164	0.042	125			0.069	133
192.8	Latri kunda	GMB	0.029	309	0.065	198	0.035	188	0.065	124	0.066	145
195.3	Kerewan	GMB	0.029	307	0.072	163	0.036	176			0.068	135
195.3	Thiaroye	SEN	0.029	296	0.073	152	0.034	197	0.063	136		
196.8	Barisal	BGD	0.044	156	0.063	217	0.027	271			0.066	143
197.8	Soma	GMB	0.029	311	0.064	210	0.036	177	0.062	150	0.067	141
198.7	Bafoussam	CMR	0.030	290	0.070	169	0.040	137				
198.8	Palpa	NPL	0.036	219	0.061	238	0.043	117			0.056	221
199.8	Lasanod	SOM	0.033	247	0.073	158	0.022	321	0.065	122	0.065	151
200.4	Kidal	MLI	0.047	138	0.057	279	0.035	185	0.059	168	0.054	232
200.6	Serrekunda	GMB	0.027	332	0.066	192	0.039	151	0.065	121	0.059	207
202.3	Vavuniya	LKA	0.040	178	0.061	241	0.028	251	0.063	139		
202.6	Kaolack	SEN	0.019	416	0.070	170	0.035	182	0.064	127	0.072	118
202.8	Kaur Wharf Town	GMB	0.024	355	0.065	202	0.038	157	0.064	131	0.063	169
203.0	Savannakhet	LAO	0.038	201	0.064	212	0.023	306	0.063	134	0.063	162
203.5	Banjul	GMB	0.034	234	0.064	211	0.033	202			0.063	167
203.7	Peshawar	PAK	0.026	337	0.078	131	0.040	143				
203.8	Latri kunda	GMB	0.031	268	0.066	190	0.033	208			0.066	149
204.0	Ker Pate Kore	GMB	0.038	198	0.059	260	0.034	195	0.059	166	0.059	201
204.0	Bossaso	SOM	0.034	233	0.070	171	0.022	323	0.066	119	0.062	174
204.8	Monimpébougou	MLI	0.056	96	0.058	268	0.026	273	0.057	172	0.057	215
205.2	Kuntaur	GMB	0.024	361	0.065	199	0.038	162	0.063	133	0.062	171
205.6	Wassu	GMB	0.020	412	0.069	175	0.040	135	0.064	129	0.061	177
205.8	Dhaka	BGD	0.037	203	0.061	236	0.030	233	0.061	157	0.059	200

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... Table A.3 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
206.8	Niono	MLI	0.079	40	0.058	272	0.023	302			0.057	213
210.4	Serrekunda	GMB	0.032	258	0.061	237	0.032	212	0.060	158	0.060	187
210.5	Loulouni	MLI	0.076	42	0.054	302	0.028	262			0.054	236
212.0	Gbarnga	LBR	0.028	317	0.061	243	0.040	133			0.065	155
212.7	Nzérékoré	GIN	0.036	218	0.065	197	0.031	223				
213.4	Cinkassé	TGO	0.032	266	0.059	255	0.037	171	0.059	164	0.057	211
214.0	Maimana	AFG	0.023	381	0.073	156	0.023	312	0.071	102	0.071	119
215.4	Kuntaur	GMB	0.019	423	0.065	209	0.038	160	0.064	128	0.065	157
217.4	Lamin	GMB	0.024	356	0.063	216	0.034	199	0.063	140	0.062	176
217.8	Thies	SEN	0.035	224	0.060	248	0.028	259	0.060	161	0.059	197
219.5	Mataram	IDN	0.056	99	0.057	277	0.023	315	0.054	187		
219.6	Kuntaur	GMB	0.021	398	0.065	200	0.037	169	0.062	141	0.060	190
220.6	Sibanor	GMB	0.029	308	0.062	224	0.031	219	0.061	153	0.059	199
220.8	Tillaberi	NER	0.021	400	0.063	222	0.041	131	0.064	130		
221.0	Touba Toul	SEN	0.031	282	0.062	231	0.028	263	0.062	149	0.061	180
221.5	Jacmel	HTI	0.037	209	0.060	251	0.029	244			0.061	182
222.0	Sare Bojo	GMB	0.031	273	0.061	240	0.032	209			0.063	166
222.3	Thilmakha	SEN	0.033	244	0.063	219	0.027	272	0.061	154		
222.5	Jacmel	HTI	0.033	242	0.061	235	0.032	210			0.059	203
222.6	Cayes	HTI	0.030	289	0.069	177	0.017	378	0.067	116	0.065	153
223.0	Dong Thap	VNM	0.029	299	0.079	130	0.008	485	0.078	84	0.072	117
223.4	Karachi	PAK	0.056	98	0.058	271	0.015	400	0.057	175	0.062	173
223.8	Kerewan	GMB	0.026	341	0.061	233	0.034	191	0.061	156	0.059	198
224.0	Ujung Pandang	IDN	0.025	348	0.070	168	0.040	140	0.051	210	0.051	254
225.3	Brikama	GMB	0.027	327	0.063	213	0.034	196			0.063	165
225.8	Achham	NPL	0.040	179	0.058	274	0.032	213			0.054	237
226.0	Dhanusha	NPL	0.050	126	0.054	304	0.030	232			0.053	242
226.2	Maymana	AFG	0.028	318	0.069	174	0.017	383	0.067	114	0.067	142
229.0	Zangasso	MLI	0.036	212	0.055	297	0.030	229	0.054	189	0.056	218

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... Table A.3 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
230.2	Khammouane	LAO	0.061	80	0.055	298	0.017	376	0.059	167	0.055	230
231.0	Labé	GIN	0.031	267	0.061	234	0.021	328			0.080	95
233.0	Savannakhet	LAO	0.039	185	0.062	226	0.020	335			0.061	186
235.4	National Average	LAO	0.068	60	0.051	325	0.023	311	0.050	215	0.049	266
237.4	Diourbel	SEN	0.038	199	0.058	275	0.025	282	0.054	191	0.054	240
237.4	Tambacounda	SEN	0.029	297	0.058	270	0.029	240	0.057	170	0.057	210
238.0	Bunia	COD	0.055	102	0.053	309	0.021	326	0.052	202	0.052	251
238.3	Dong Thap	VNM	0.031	278	0.080	126	0.009	470	0.079	79		
238.5	Kaski	NPL	0.029	305	0.059	262	0.039	152			0.054	235
238.7	Barra	GMB	0.033	249	0.063	221	0.029	246				
239.4	BrikamaBa	GMB	0.019	422	0.063	220	0.034	190	0.060	159	0.059	206
239.5	Abomey	BEN	0.020	409	0.066	193	0.041	132			0.055	224
239.5	Bakau	GMB	0.018	435	0.065	196	0.039	146			0.061	181
239.8	Sare Bojo	GMB	0.025	346	0.062	229	0.034	192			0.060	192
240.5	Chittagong	BGD	0.032	256	0.060	246	0.023	310			0.066	150
240.8	Basse Santa su	GMB	0.019	417	0.063	218	0.038	158			0.062	170
241.2	Khammouane	LAO	0.060	81	0.051	328	0.020	334	0.051	211	0.051	252
241.4	Touba	SEN	0.025	352	0.061	244	0.030	225	0.058	169	0.056	217
242.2	BrikamaBa	GMB	0.023	370	0.060	252	0.038	163	0.054	188	0.054	238
242.8	National Average	MDG	0.098	19	0.056	286	0.006	504	0.052	201	0.059	204
243.0	National Average	MDG	0.100	18	0.056	287	0.006	505	0.052	203	0.059	202
243.8	Padang	IDN	0.039	184	0.053	308	0.025	285	0.053	198		
244.0	Port-au-Prince	HTI	0.028	321	0.066	188	0.017	380	0.062	148	0.061	183
244.4	Yogyakarta	IDN	0.042	169	0.055	299	0.023	313	0.053	200	0.054	241
247.0	Wassu	GMB	0.034	236	0.059	264	0.029	241				
248.5	Sare Ngai	GMB	0.024	367	0.060	249	0.035	189			0.060	189
250.3	Sikasso Centre	MLI	0.063	72	0.049	336	0.022	319			0.048	274
250.3	Sare Ngai	GMB	0.039	180	0.053	307	0.028	264			0.052	250
251.6	Pekanbaru	IDN	0.031	277	0.057	278	0.029	239	0.051	209	0.051	255

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... Table A.3 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
252.0	BrikamaBa	GMB	0.018	428	0.056	285	0.029	238	0.055	181	0.070	128
252.3	Louga	SEN	0.024	366	0.086	97	0.011	450			0.080	96
253.8	Lahore	PAK	0.039	187	0.055	293	0.017	367	0.053	193	0.055	229
254.0	SaintLouis	SEN	0.027	335	0.060	247	0.024	296	0.056	180	0.057	212
254.5	Ulaanbaatar	MNG	0.031	285	0.061	232	0.023	316	0.055	185		
255.8	Karachi	PAK	0.043	162	0.065	195	0.010	458	0.043	250	0.057	214
256.8	S.Antao	CPV	0.023	380	0.059	258	0.037	172	0.048	221	0.051	253
257.0	M'Pèssoba	MLI	0.056	101	0.046	360	0.023	307	0.044	245	0.048	272
257.6	Sare Bojo	GMB	0.023	384	0.057	283	0.031	221	0.056	177	0.056	223
257.8	S.Vincente	CPV	0.018	433	0.062	223	0.026	277	0.059	163	0.060	193
258.0	Banjul	GMB	0.035	228	0.060	254	0.024	292				
259.3	Farafenni	GMB	0.031	283	0.056	288	0.033	207				
260.0	Patna	IND	0.022	389	0.055	294	0.035	184	0.053	199	0.054	234
260.8	National Average	CRI	0.020	406	0.057	276	0.040	136			0.055	225
261.4	National Average	CRI	0.019	415	0.054	305	0.042	124	0.051	207	0.050	256
263.8	Thiodaye	SEN	0.033	251	0.054	303	0.026	281	0.052	204	0.047	280
264.8	Mopti	MLI	0.068	61	0.045	375	0.019	348	0.045	239	0.045	301
265.2	Ouanaminthe	HTI	0.029	300	0.057	281	0.021	329	0.055	183	0.054	233
265.2	Kendari	IDN	0.036	211	0.052	315	0.019	350	0.051	206	0.053	244
268.0	Chennai	IND	0.051	121	0.048	350	0.017	375	0.047	226	0.048	268
268.3	Kwinella Nya Kunda	GMB	0.027	329	0.061	242	0.029	234				
268.4	Maxixe	MOZ	0.017	443	0.055	296	0.040	138	0.051	208	0.050	257
270.5	Antananarivo	MDG	0.067	65	0.046	362	0.017	364			0.046	291
270.7	Keur I. Yacine	SEN	0.029	298	0.087	93	0.013	421				
271.4	Gaza Strip	PSE	0.020	413	0.052	317	0.037	164	0.053	196	0.049	267
271.8	Rajshahi	BGD	0.029	302	0.053	312	0.020	332	0.053	194	0.056	219
272.0	Mopti Guangal	MLI	0.053	109	0.044	386	0.024	297	0.043	251	0.042	317
273.8	Samarinda	IDN	0.027	328	0.059	263	0.029	235			0.048	269

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... Table A.3 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
274.8	Ambositra	MDG	0.060	84	0.046	366	0.017	385	0.045	241	0.045	298
274.8	Palangkaraya	IDN	0.019	420	0.056	284	0.030	227	0.053	195	0.052	248
275.5	Koulikoro Ba	MLI	0.047	137	0.046	361	0.024	299			0.044	305
275.6	Dioro	MLI	0.078	41	0.049	342	0.007	500	0.048	224	0.048	271
276.8	South Cotabato	PHL	0.074	47	0.050	332	0.008	478	0.046	237	0.046	290
277.0	Ségou Centre	MLI	0.059	88	0.047	352	0.013	420	0.047	233	0.046	292
277.0	Barra	GMB	0.024	362	0.054	301	0.028	255	0.054	190		
277.2	Kinshasa	COD	0.037	208	0.049	341	0.020	339	0.048	222	0.048	276
278.0	Diourbel	SEN	0.021	396	0.067	184	0.028	254				
278.4	Ségou Château	MLI	0.063	71	0.048	349	0.011	445	0.047	228	0.045	299
279.2	Bandar Lampung	IDN	0.043	158	0.049	343	0.019	353	0.047	230	0.043	312
280.5	Mannar	LKA	0.030	294	0.052	318	0.020	331			0.061	179
281.8	Jakarta	IDN	0.039	181	0.049	338	0.018	360	0.047	234	0.045	296
283.0	Cotonou	BEN	0.011	499	0.059	265	0.039	148	0.049	220		
283.0	Brikama	GMB	0.019	421	0.056	291	0.023	305	0.055	182	0.057	216
285.3	Brikama	GMB	0.017	437	0.058	273	0.033	203			0.055	228
285.5	Panama City	PAN	0.028	319	0.053	311	0.036	179			0.040	333
287.0	Kolda	SEN	0.024	359	0.051	326	0.026	274	0.050	213	0.050	263
287.6	Peshawar	PAK	0.029	303	0.044	379	0.017	372	0.042	254	0.069	130
288.8	Banjarmasin	IDN	0.032	260	0.052	319	0.016	399	0.051	205	0.050	261
289.0	Gao	MLI	0.032	262	0.052	322	0.018	355	0.049	217		
289.0	Lahore	PAK	0.031	274	0.051	324	0.017	365	0.049	218	0.050	264
289.3	Libreville	GAB	0.024	369	0.057	282	0.026	275			0.055	231
290.2	Kaur Wharf Town	GMB	0.024	365	0.054	306	0.019	344	0.053	197	0.054	239
290.8	Farafenni	GMB	0.031	271	0.049	337	0.026	280			0.048	275
291.5	Bansang	GMB	0.025	353	0.056	292	0.024	294			0.055	227
292.3	Colombo	LKA	0.050	128	0.047	357	0.016	391			0.046	293
292.4	Bandung	IDN	0.031	281	0.048	346	0.020	337	0.047	225	0.048	273

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... Table A.3 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
292.5	Diaobe	SEN	0.008	512	0.059	266	0.037	170			0.056	222
294.0	Zguinchor	SEN	0.026	340	0.052	320	0.020	340	0.050	212	0.050	258
295.3	Wellingara	GMB	0.027	333	0.055	300	0.028	253				
297.6	Multan	PAK	0.044	157	0.044	380	0.017	388	0.041	257	0.044	306
297.8	Djougou	BEN	0.019	418	0.051	329	0.028	258	0.050	214	0.048	270
298.5	Davao City	PHL	0.028	315	0.035	434	0.011	444			1.671	1
298.8	Peshawar	PAK	0.043	160	0.047	358	0.016	389			0.046	288
300.8	Dantokpa	BEN	0.018	430	0.047	359	0.034	198	0.046	236	0.047	281
302.2	Latri kunda	GMB	0.015	457	0.051	330	0.029	249	0.049	216	0.050	259
302.8	Nara	MLI	0.069	58	0.037	424	0.010	456	0.036	273		
303.0	Karachi	PAK	0.053	112	0.052	316	0.009	476			0.044	308
304.6	Patna	IND	0.029	306	0.046	367	0.023	308	0.045	238	0.045	304
304.8	Banjul	GMB	0.017	436	0.053	313	0.031	224			0.052	246
305.3	Sibanor	GMB	0.024	363	0.053	310	0.025	283			0.049	265
305.5	Ouanaminthe	HTI	0.028	316	0.059	261	0.010	461	0.055	184		
305.8	South Cotabato	PHL	0.059	87	0.044	378	0.008	484	0.041	256	0.041	324
308.8	Bansang	GMB	0.013	480	0.047	351	0.026	276	0.047	229	0.058	208
310.8	Ouanaminthe	HTI	0.030	291	0.060	250	0.011	453			0.052	249
310.8	Manado	IDN	0.027	336	0.048	344	0.023	304	0.043	247	0.042	323
311.0	Mopti Digue	MLI	0.054	107	0.042	397	0.014	418			0.042	322
311.6	Palu	IDN	0.023	382	0.050	333	0.022	322	0.047	227	0.046	294
313.2	Quetta	PAK	0.025	350	0.047	353	0.019	342	0.047	232	0.046	289
313.5	Gao	MLI	0.036	213	0.042	399	0.023	303			0.039	339
313.6	Ahmedabad	IND	0.016	447	0.050	334	0.024	291	0.049	219	0.048	277
314.2	Bhopal	IND	0.016	453	0.048	348	0.027	268	0.048	223	0.047	279
314.8	Maputo	MOZ	0.017	442	0.047	356	0.030	230	0.047	231		
315.2	Koutiala	MLI	0.053	110	0.038	417	0.014	416	0.036	274	0.034	359
315.2	Peshawar	PAK	0.031	275	0.047	355	0.018	361	0.042	253	0.040	332
316.3	Lahore	PAK	0.019	424	0.057	280	0.029	245				

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... Table A.3 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
317.8	Bansang	GMB	0.016	449	0.053	314	0.028	265			0.053	243
320.3	Kolda	SEN	0.033	253	0.043	390	0.021	325			0.043	313
321.0	Palembang	IDN	0.031	284	0.047	354	0.014	412	0.041	258	0.045	297
321.0	Niarela	MLI	0.040	175	0.035	437	0.016	393	0.035	279		
321.5	Medine	MLI	0.043	161	0.035	433	0.014	414	0.035	278		
321.8	Hirat	AFG	0.035	225	0.051	331	0.007	491	0.044	243	0.042	319
322.8	Davao City	PHL	0.045	149	0.043	389	0.011	448	0.037	271	0.034	357
324.0	Karachi	PAK	0.051	118	0.049	339	0.004	514			0.041	325
324.0	Kayes Centre	MLI	0.042	168	0.039	412	0.000				0.028	392
325.0	Zwedru	LBR	0.025	347	0.042	396	0.022	320	0.043	248	0.043	314
325.2	Jaipur	IND	0.019	414	0.045	374	0.026	278	0.043	249	0.043	311
326.5	Gonaives	HTI	0.017	440	0.059	267	0.017	373			0.055	226
327.7	Boghé	MRT	0.024	368	0.042	400	0.031	215				
328.0	Ouolofobougou	MLI	0.045	144	0.037	422	0.017	386			0.034	360
329.3	Dibida	MLI	0.040	177	0.035	438	0.017	374			0.041	328
331.0	San	MLI	0.045	151	0.040	409	0.012	433			0.040	331
331.3	Davao City	PHL	0.052	114	0.037	423	0.012	436			0.035	352
332.5	Man	CIV	0.021	405	0.046	365	0.028	257			0.045	303
332.6	Sao Paulo	BRA	0.019	425	0.045	376	0.024	300	0.044	246	0.043	316
332.7	National Average	COL	0.017	439	0.026	503	0.000				0.097	56
333.4	Koury	MLI	0.049	132	0.033	460	0.014	419	0.033	285	0.032	371
333.7	Kwinella Nya Kunda	GMB	0.022	387	0.056	290	0.021	324				
333.8	Mumbai	IND	0.020	410	0.044	387	0.019	347	0.045	240	0.047	285
335.3	Farafenni	GMB	0.023	376	0.046	364	0.023	314			0.046	287
335.5	Lamin	GMB	0.015	459	0.050	335	0.027	270			0.048	278
337.8	Sare Yoba	SEN	0.016	451	0.049	340	0.017	368	0.046	235	0.046	295
337.8	Lahore	PAK	0.021	404	0.045	371	0.017	370	0.045	242	0.045	302
339.6	Multan	PAK	0.028	322	0.042	395	0.012	443	0.043	252	0.047	286

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... Table A.3 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
340.8	Hirat	AFG	0.030	292	0.052	321	0.010	466			0.047	284
340.8	Aizwal	IND	0.018	432	0.048	345	0.019	341			0.053	245
341.8	Nouakchott	MRT	0.024	360	0.051	327	0.009	471	0.044	244	0.044	307
342.2	Bla	MLI	0.032	255	0.036	428	0.017	387	0.035	277	0.034	364
342.3	Ouolofobougou	MLI	0.015	462	0.033	464	0.013	428			0.144	15
342.3	Matam	SEN	0.030	295	0.046	369	0.016	395			0.043	310
343.3	Sikasso Médine	MLI	0.055	105	0.037	425	0.007	493			0.036	350
343.5	Semarang	IDN	0.027	330	0.046	368	0.018	356			0.042	320
343.8	Gonaives	HTI	0.018	431	0.056	289	0.015	408			0.052	247
345.0	Surabaya	IDN	0.031	287	0.045	370	0.016	396			0.041	327
345.0	Hyderabad	IND	0.013	475	0.040	403	0.024	293			0.058	209
345.5	Fadjiguila	MLI	0.039	183	0.035	432	0.016	390			0.031	377
345.8	S.Antao	CPV	0.022	385	0.045	372	0.024	290			0.040	336
346.6	Dougouolo	MLI	0.034	232	0.036	430	0.012	441	0.037	269	0.034	361
346.8	Multan	PAK	0.032	263	0.039	414	0.011	447	0.038	265	0.038	345
346.8	National Average	ZAF	0.026	338	0.043	388	0.014	410	0.039	260	0.039	338
347.4	Denpasar	IDN	0.021	393	0.045	377	0.016	397	0.041	255	0.043	315
347.5	National Average	WSM	0.028	313	0.044	384	0.018	363			0.041	330
348.8	Djikoroni	MLI	0.032	261	0.035	436	0.014	413	0.038	267	0.033	367
351.0	Santiago	CPV	0.023	377	0.039	411	0.020	333	0.035	281	0.035	353
351.0	Niamey	NER	0.015	458	0.040	405	0.025	284	0.039	264	0.038	344
351.0	San Salvador	SLV	0.021	403	0.040	402	0.020	336	0.039	263		
353.0	Kita	MLI	0.027	334	0.045	373	0.019	352				
354.5	Agadez Commune	NER	0.021	397	0.042	394	0.024	298			0.041	329
356.0	Quetta	PAK	0.020	408	0.046	363	0.017	371			0.047	282
356.8	Badalabougou	MLI	0.036	217	0.034	454	0.013	430			0.041	326
359.0	Maradi	NER	0.011	494	0.040	408	0.026	279	0.037	268	0.037	346
359.3	Quetta	PAK	0.024	364	0.044	382	0.017	382			0.044	309

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... Table A.3 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
360.5	Kolkata	IND	0.012	484	0.043	391	0.027	267			0.045	300
361.4	Agartala	IND	0.017	441	0.036	427	0.022	318	0.036	272	0.036	349
361.7	Garoua	CMR	0.015	464	0.043	393	0.030	228				
362.0	Jambi	IDN	0.026	344	0.038	420	0.014	417	0.036	275	0.035	354
362.3	Sirakorola	MLI	0.028	320	0.034	442	0.015	405	0.034	282		
362.3	Lafiabougou	MLI	0.033	246	0.035	439	0.014	409			0.035	355
363.5	S.Vincente	CPV	0.026	343	0.041	401	0.011	449	0.039	261		
363.5	Dosso	NER	0.016	446	0.037	421	0.022	317	0.037	270		
363.8	Touna	MLI	0.026	339	0.040	407	0.017	366			0.038	343
366.3	National Average	ZAF	0.013	476	0.051	323	0.015	406			0.050	260
366.3	Magnambougou	MLI	0.031	269	0.034	456	0.013	422			0.042	318
369.0	Sogoniko	MLI	0.033	254	0.034	450	0.015	403				
370.4	Lucknow	IND	0.008	511	0.038	418	0.025	287	0.035	280	0.034	356
370.7	Niamakoro	MLI	0.033	245	0.034	452	0.014	415				
370.8	Zamboanga City	PHL	0.044	154	0.032	469	0.008	481			0.030	379
371.3	Iloilo	PHL	0.039	189	0.033	459	0.010	465			0.032	372
372.0	Faladié	MLI	0.031	272	0.034	447	0.013	427			0.039	342
372.4	Vientiane Capital	LAO	0.022	390	0.044	383	0.007	496	0.040	259	0.040	334
374.6	Koulikoro Gare	MLI	0.031	270	0.031	473	0.010	459	0.032	289	0.030	382
374.8	Pleebo	LBR	0.022	388	0.042	398	0.019	351			0.034	362
380.7	Natitingou	BEN	0.014	469	0.044	385	0.025	288				
381.0	Gaza Strip	PSE	0.015	463	0.039	416	0.017	379	0.038	266		
386.2	Santiago	CPV	0.015	460	0.036	426	0.014	411	0.035	276	0.034	358
386.3	Dhaka	BGD	0.025	354	0.040	410	0.012	440			0.039	341
386.8	Santo Domingo	DOM	0.013	478	0.034	448	0.020	338	0.034	283		
388.3	Kayes Plateau	MLI	0.018	434	0.048	347	0.017	384				
388.6	Chennai	IND	0.021	395	0.031	472	0.015	407	0.031	291	0.031	378
388.8	Bhubaneshwar	IND	0.021	392	0.034	455	0.019	343			0.034	365
389.5	Guwahati	IND	0.014	467	0.033	458	0.019	346	0.032	287		

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... Table A.3 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
390.0	Vientiane Capital	LAO	0.016	452	0.043	392	0.006	507	0.039	262	0.039	337
390.4	Santo Domingo	DOM	0.014	466	0.032	465	0.018	362	0.032	286	0.032	373
391.0	National Average	MDG	0.031	280	0.040	404	0.005	512			0.033	368
391.3	Basse Santa su	GMB	0.011	492	0.044	381	0.024	301				
391.8	National Average	URY	0.022	391	0.035	435	0.011	452	0.029	292	0.028	389
392.0	Agadez	NER	0.007	517	0.033	457	0.021	327	0.034	284	0.032	375
392.8	Adel Bagrou	MRT	0.021	399	0.036	429	0.016	392			0.036	351
393.4	Aceh	IDN	0.018	427	0.035	440	0.013	431	0.032	288	0.030	381
398.0	Mumbai	IND	0.006	522	0.034	446	0.025	289			0.040	335
398.8	National Average	MDG	0.028	312	0.040	406	0.005	511			0.034	366
400.2	Montevideo	URY	0.023	383	0.034	449	0.010	463	0.025	300	0.026	406
400.3	National Average	IDN	0.032	265	0.021	516	0.000				0.021	420
401.5	Vientiane Capital	LAO	0.017	445	0.038	419	0.016	394			0.036	348
402.0	Port-de-Paix	HTI	0.012	485	0.039	415	0.011	446			0.050	262
402.6	Iloilo	PHL	0.023	375	0.028	495	0.012	435	0.025	298	0.025	410
413.4	Douala	CMR	0.011	500	0.027	502	0.017	369	0.026	296	0.026	400
415.0	Lafiabougou	MLI	0.011	497	0.030	481	0.010	467	0.031	290	0.039	340
415.2	Shimla	IND	0.010	503	0.029	489	0.015	401	0.029	293	0.028	390
417.4	National Average	NIC	0.012	490	0.031	477	0.013	432	0.028	294	0.027	394
417.7	Sikasso Centre	MLI	0.023	379	0.034	445	0.013	429				
420.0	Cebu	PHL	0.020	407	0.028	497	0.009	477	0.025	299		
421.0	Badinko	MLI	0.025	345	0.032	467	0.011	451				
421.3	Kayes Centre	MLI	0.023	378	0.033	461	0.013	425				
423.7	Yaundé	CMR	0.012	486	0.036	431	0.019	354				
423.8	Managua	NIC	0.007	518	0.034	444	0.018	357			0.031	376
425.5	Trivandrum	IND	0.009	509	0.031	474	0.019	349			0.033	370
426.0	Pontianak	IDN	0.011	496	0.039	413	0.013	426			0.033	369
427.0	Shillong	IND	0.010	501	0.033	462	0.016	398			0.037	347
427.4	Nueva Ecija	PHL	0.016	455	0.030	487	0.007	495	0.027	295	0.026	405

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... Table A.3 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
429.3	Vientiane Capital	LAO	0.012	487	0.034	443	0.013	424			0.034	363
431.3	Managua	NIC	0.009	508	0.034	451	0.017	381			0.029	385
434.5	Chennai	IND	0.011	493	0.030	485	0.017	377			0.030	383
436.3	Abalak	NER	0.018	429	0.021	512	0.001	521			0.047	283
437.3	Zinder	NER	0.012	488	0.027	498	0.018	359			0.026	404
440.0	Medine	MLI	0.016	456	0.035	441	0.013	423				
440.3	Medan	IDN	0.019	426	0.032	470	0.010	457			0.026	408
440.3	Koury	MLI	0.021	402	0.029	491	0.009	475			0.028	393
442.0	Managua	NIC	0.007	515	0.031	471	0.015	402			0.030	380
443.0	National Average	COL	0.023	373	0.029	493	0.004	515			0.028	391
443.3	Cebu	PHL	0.021	394	0.030	484	0.007	492			0.026	403
443.3	National Average	PHL	0.028	323	0.024	509	0.002	518			0.018	423
444.0	Diallassagou	MLI	0.013	472	0.020	519	0.008	483	0.020	302		
444.8	New Delhi	IND	0.007	516	0.021	515	0.009	473	0.021	301	0.021	419
445.8	Sikasso Médine	MLI	0.012	483	0.026	506	0.007	497	0.026	297		
446.0	Niarela	MLI	0.013	479	0.032	468	0.012	442			0.027	395
446.7	Koulikoro Ba	MLI	0.019	419	0.032	466	0.011	455				
447.0	Kita	MLI	0.012	491	0.031	476	0.012	434			0.028	387
448.0	Dibida	MLI	0.016	454	0.034	453	0.012	437				
450.8	National Average	RUS	0.009	507	0.019	520	0.006	503	0.019	303	0.019	421
452.8	National Average	ZAF	0.010	502	0.033	463	0.010	460			0.029	386
453.5	Lima	PER	0.014	468	0.026	504	0.010	468			0.032	374
455.3	Fadjiguila	MLI	0.015	461	0.030	482	0.009	469			0.026	409
456.3	National Average	MMR	0.020	411	0.027	500	0.005	513			0.026	401
457.5	Bankass	MLI	0.017	444	0.024	510	0.011	454			0.019	422
457.5	Koulikoro Gare	MLI	0.014	465	0.030	480	0.007	501			0.030	384
459.8	Magnambougou	MLI	0.013	477	0.031	478	0.008	482			0.026	402
461.0	Sogoniko	MLI	0.013	474	0.030	483	0.008	489			0.027	398
461.5	National Average	PHL	0.022	386	0.021	518	0.003	517			0.015	425

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... Table A.3 continued

Average rank	Market	ISO3	SD Season	Rank Season	SD log Δ	Rank log Δ	SD Irreg	Rank Irreg	SD GARCH	Rank GARCH	SD EGARCH	Rank EGARCH
461.5	Badalabougou	MLI	0.011	495	0.031	475	0.008	479			0.027	397
462.3	Koulogon	MLI	0.012	489	0.024	508	0.012	438			0.023	414
462.3	MetroManila	PHL	0.014	470	0.029	492	0.008	480			0.026	407
462.8	Djikoroni	MLI	0.014	471	0.029	490	0.007	502			0.028	388
465.5	Jayapura	IDN	0.008	513	0.030	479	0.009	474			0.027	396
465.8	Bankass	MLI	0.010	505	0.021	517	0.002	520			0.042	321
466.0	Faladié	MLI	0.013	473	0.030	486	0.007	494			0.025	411
466.8	Niamakoro	MLI	0.013	481	0.030	488	0.008	486			0.025	412
471.8	Delhi	IND	0.006	520	0.023	511	0.012	439			0.023	417
472.8	Mumbai	IND	0.009	506	0.027	499	0.008	487			0.026	399
473.0	Nueva Ecija	PHL	0.013	482	0.028	496	0.007	498			0.023	416
473.0	National Average	TUN	0.009	510	0.026	505	0.010	462			0.023	415
475.7	Zangasso	MLI	0.017	438	0.027	501	0.008	488				
477.3	West Bank	PSE	0.016	448	0.029	494	0.008	490				
477.8	National Average	NIC	0.007	519	0.026	507	0.009	472			0.024	413
478.3	West Bank	PSE	0.010	504	0.017	521	0.010	464			0.016	424
482.0	Lima	PER	0.011	498	0.021	513	0.007	499			0.022	418
494.8	Luanda	AGO	0.006	521	0.013	525	0.006	506			0.013	427
496.3	National Average	GTM	0.003	525	0.014	523	0.006	508			0.010	429
497.0	Lima	PER	0.003	524	0.014	522	0.004	516			0.014	426
497.3	National Average	GTM	0.003	526	0.014	524	0.006	509			0.010	430
499.0	National Average	CHN	0.005	523	0.011	526	0.002	519			0.010	428
512.7	MetroManila	PHL	0.008	514	0.021	514	0.006	510				

Source: Source: Author’s computation based on ZEF [2014].

Appendix B

Appendix: Supplementary tables chapter 4

Table B.1: List of countries and crops in sample

Country	Maize	Rice	Sorghum	Wheat	Millet	Country	Maize	Rice	Sorghum	Wheat	Millet
Afghanistan		√		√		Lao, PDR		√			
Argentina	√			√		Madagascar		√			
Armenia				√		Malawi	√	√			
Azerbaijan				√		Mali	√	√	√		√
Bangladesh		√		√		Mauritania	√	√	√	√	
Benin	√	√	√			Mexico	√	√			
Bhutan		√		√		Moldova	√			√	
Bolivia	√	√		√		Mongolia		√		√	
Brazil		√		√		Mozambique	√	√			
Burkina Faso	√	√	√		√	Myanmar		√			

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... Table B.1 continued

Country	Maize	Rice	Sorghum	Wheat	Millet	Country	Maize	Rice	Sorghum	Wheat	Millet
Burundi	√		√			Namibia	√				
Cambodia		√				Nepal		√		√	
Cameroon	√	√		√	√	Nicaragua	√	√			
Cape Verde	√	√				Niger		√	√	√	√
Chad	√	√	√			Nigeria	√	√	√	√	
China		√		√		Pakistan		√		√	
Colombia	√	√				Panama	√	√			
Congo (D.R.)	√	√		√		Peru	√	√		√	
Costa Rica	√	√				Philippines	√	√			
Cote d'Ivoire	√	√				Russian Federation		√		√	
Djibouti		√		√		Rwanda	√	√			
Dominican Republic	√	√				Senegal	√	√	√		√
Egypt		√		√		Somalia	√	√	√		
El Salvador	√	√	√	√		South Africa	√	√		√	
Equador	√					Sri Lanka		√			
Ethiopia	√		√	√	√	Sudan			√	√	√
Gabon		√		√		Tajikistan	√	√		√	
Gambia		√				Tanzania	√	√	√		
Georgia				√	√	Thailand	√				
Ghana	√	√	√			Togo	√	√	√		
Guatemala	√	√		√		Tunisia		√		√	
Guinea		√				Turkey		√		√	
Haiti	√	√	√	√		Uganda	√		√		√
Honduras	√	√				Uruguay		√		√	
India		√		√		Viet Nam		√			

Continued on next page...

... Table B.1 continued

Country	Maize	Rice	Sorghum	Wheat	Millet	Country	Maize	Rice	Sorghum	Wheat	Millet
Indonesia	√				√	Zambia	√	√		√	
Kenya	√		√	√		Zimbabwe	√			√	
Kyrgyzstan				√							

Source: Own illustration.

Table B.2: Country classification

	countries	N
importers	Afghanistan[bd], Armenia[d], Azerbaijan[d], Bangladesh[d], Benin[b], Bhutan[bd], Bolivia[d], Brazil[d], Burkina Faso[b], Burundi[ad], Cameroon[bd], Cape Verde[ab], Chad[b], Colombia[a], Congo, D.R.[bd], Costa Rica[abd], Cote d'Ivoire[b], Dem. Republic[a], Djibouti[bd], Dominican Republic[a], Equador[a], Egypt[d], El Salvador[abd], Ethiopia[d], Gambia, the[b], Gabon[ab], Georgia[d], Ghana[b], Guinea [b], Guatemala[abd], Haiti[bd], Honduras[ab], Indonesia[d], Kenya[cd], Kyrgyzstan[bd], Mauritania[ab], Mexico[ab], Malawi[b], Mauritania[abd], Mongolia[bd], Mozambique[b], Namibia[a], Nicaragua[ab], Niger[abd], Nigeria[bd], Panama[ab], Peru[ad], Russia[b], Rwanda[ab], Senegal[b], Somalia[abc], Sudan[d], Sri Lanka[d], Togo[b], Tajikistan[d], Tunisia[bd], Turkey[b], South Africa[bd], Zambia[b], Zimbabwe[ad]	92

Continued on next page...

... *Table B.2 continued*

	countries	N
trade-switchers	Burundi^{bc}, Benin^{c}, Burkina Faso^{ce}, Bangladesh^{b}, Bolivia^{ab}, Brazil^{b}, China^{bd}, Cote d'Ivoire^{a}, Congo, D.R^{a}, Colombia^{b}, Dominican Republic^{b}, Egypt^{b}, Ethiopia^{ace}, Ghana^{ace}, Haiti^{ac}, Indonesia^{b}, India^{d}, Kenya^{ae}, Lao, PDR^{b}, Sri Lanka^{b}, Moldova^{ad}, Madagascar^{b}, Mali^{ab}, Mozambique^{a}, Mauritania^{c}, Malawi^{a}, Namibia^{e}, Niger^{ce}, Nigeria^{a}, Nepal^{bd}, Pakistan^{d}, Peru^{b}, the Philippines^{ab}, Sudan^{ce}, Senegal^{ce}, El Salvador^{c}, Chad^{a}, Togo^{c}, Tajikistan^{ab}, Turkey^{d}, Tanzania^{abc}, Uganda^{ce}, South Africa^{a}, Zambia^{a}	66
exporters	Argentina^{ad}, Benin^{a}, Burkina Faso^{a}, Cameroon^{a}, India^{b}, Cambodia^{b}, Mali^{ce}, Myanmar^{b}, Nigeria^{c}, Pakistan^{b}, Russia^{d}, Chad^{e}, Togo^{a}, Thailand^{b}, Uganda^{a}, Uruguay^{bd}, Vietnam^{b}	21
high intervention	Burkina Faso, Bangladesh, Brazil, China, Egypt, Ethiopia, India, Indonesia, Kenya, Cambodia, Mali, Myanmar, Malawi, Nepal, Pakistan, Philippines, Russia, Thailand, Turkey, Vietnam, Zambia, Zimbabwe	47

Note:^{a}maize,^{b}rice,^{c}sorghum,^{d}wheat,^{e}millet; non-importers are exporters plus trade-switchers.

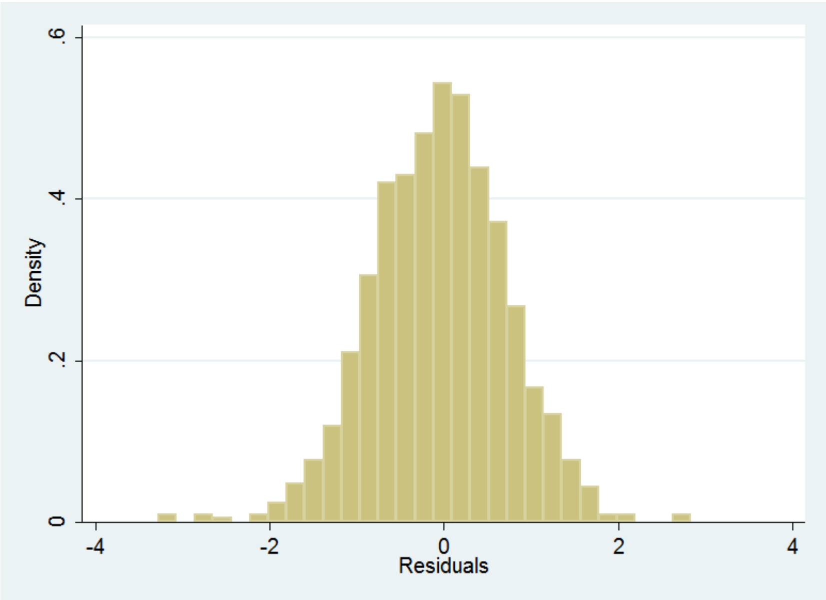

FIGURE B.1: Residuals from the GMM regression with logged price volatility

Appendix C

Appendix: Survey details

Table C.1: Survey details

market	date	id	1st important crop	2nd important crop	3rd important crop
Accra	2-Sep-13	3.01	Imported rice	White maize	
Accra	2-Sep-13	3.02	White maize	Local rice	
Accra	6-Sep-13	3.03	White maize	Local rice	Yellow maize
Accra	9-Sep-13	3.04	Imported rice	Local rice	
Accra	23-Sep-13	3.05	White maize	Local rice	Soyabeans
Tamale	7-Sep-13	4.01	Soyabeans	Local rice	White maize
Tamale	7-Sep-13	4.02	White maize	Soyabeans	
Tamale	7-Sep-13	4.03	Soyabeans	Local rice	White maize
Tamale	8-Sep-13	4.04	Soyabeans	White maize	Millet
Tamale	9-Sep-13	4.05	White maize	Local rice	Soyabeans
Tamale	10-Sep-13	4.06	White maize	Local rice	
Kumasi	7-Sep-13	5.01	Local rice		
Kumasi	7-Sep-13	5.02	White maize		
Accra	23-Oct-13	3.06	Imported rice		
Kumasi	24-Oct-13	5.03	White maize		

Continued on next page...

... *Table C.1 continued*

market	date	id	1st important crop	2nd important crop	3rd important crop
Accra	8-Oct-13	3.1	White maize	Local rice	
Accra	25-Oct-13	3.07	Imported rice		
Accra	28-Oct-13	3.08	Imported rice		
Accra	28-Oct-13	3.09	White maize	Imported rice	
Kumasi	29-Oct-13	5.04	Soyabeans	Millet	White maize
Kumasi	30-Oct-13	5.05	Imported rice		
Kumasi	31-Oct-13	5.06	Local rice	White maize	
Techiman	1-Nov-13	6.01	Imported rice		
Techiman	1-Nov-13	6.02	White maize		
Techiman	2-Nov-13	6.04	White maize	Soyabeans	
Techiman	2-Nov-13	6.03	White maize	Soyabeans	
Wenchi	4-Nov-13	7.01	White maize		
Wenchi	4-Nov-13	7.02	White maize		
Wenchi	4-Nov-13	7.03	White maize		
Ejura	7-Nov-13	8.01	White maize		
Ejura	7-Nov-13	8.02	White maize		
Wa	6-Nov-13	9.01	White maize	Local rice	
Accra	4-Dec-13	3.11	White maize	Yellow maize	
Tamale	9-Nov-13	4.07	White maize	Local rice	Soyabeans
Tamale	9-Nov-13	4.08	White maize	Local rice	
Tamale	18-Nov-13	4.09	White maize	Soyabeans	Sorghum

Appendix D

Appendix: Trader survey questionnaire

TRADER SURVEY QUESTIONNAIRE

Institute of Statistical, Social and Economic Research (ISSER),
University of Ghana (Legon)
Center for Development Research (ZEF), University of Bonn

To be completed by the interviewer.

Market name: ________________

Respondent's ID Code: __ __ __ __ __

Interview Date: __ __ __ __ -2013 (ddmm-2013)

Begin Interview: __ __ __ __ (hhmm)

End interview: __ __ __ __ (hhmm)

Gender of respondent: ☐ Male ☐ Female

Good morning/afternoon. My name is ______________________. I am conducting this survey on behalf of ISSER and ZEF on the structure of agricultural marketing in Ghana.

The information provided by you in this interview about your trading activities will contribute to understand the causes and impacts of seasonal price dynamics in Ghana. Your response to these questions will be anonymous and will be treated with the strictest confidentiality. Your participation is voluntary and you can choose not to answer any or all of the questions if you wish; however we hope you will participate since your views are important. The research is aiming at improving the functioning of grain markets in Ghana.

Thank you in advance for your time to participate in this study.

Company profile

1. What is the full name of the company?

____

2. Is the company registered?

☐ Yes ☐ No ☐ No answer

3. When was the company registered? ________________

4. What is the legal status of this company?

1	Sole ownership	2	Subsidiary (or branch) of another enterprise
3	Partnership	4	Cooperative
5	Shareholding company	6	State-owned enterprise
7	Others: ________________	.	No answer

5. Is the company operating in any other businesses than grain trading

if any: ____

6. Where is the legal seat of the company?

____

7. Where is the company having branches?

if any: ____

8. What is the position of the respondent in the business?

1 Owner(CEO)/Manager

2 Manager only

3 Others: ____________________________

.

No answer

General Information - wholesale business

9. What year did you/ this company start operating as a grain trading business? ______________

10. From which market actors are you buying?

☐ Purchase from traders ☐ Purchase from farmers

☐ Purchase from NAFCO ☐ Purchase from aggregators

☐ Others: ______________________

11. To which market actors are you selling to?

☐ Sell to traders ☐ Sell to processors

☐ Sell to NAFCO ☐ Sell to retailers

☐ Sell to consumers ☐ Others: ______________________

12. Please indicate the three most important commodities you are trading?

1. for the most important commodity

2. for the second most important commodity

3. for the third most important commodity

White maize	
Yellow maize	
Local rice/Paddy rice	
Imported rice	
Soy beans	
Millet	
Sorghum	

if Q.5=yes:

13. What is the income share you obtain from your grain trading activities (during the peak period of grain sales)?

____________ %

14. Please describe your challenges when you started your grain trading business, did you face any entry barriers caused by competitors?

____

____

____

____

____

____

____

____

____

Stocking strategy

15. What is your maximum storage capacity?

______________________________ unit: __________________

16. During last production year (2012-2013), what was the total quantity you purchased [for three most important commodities]?

	Loc. Rice	Millet	Sorghum	White Maize	Yellow Maize	Imp. Rice	Soya
Quantity							
Unit							

17. Please one [unit from above] is how much in kg?

most important ____________________ unit: __________________

2nd most imp.____________________ unit: __________________

3rd most imp. ____________________ unit: __________________

18. Please indicate the best time to start stocking/ release stocks [for three most important commodities]

	best time to start stocking							best time to release stocks						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Jan	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Feb	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Mar	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Apr	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
May	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Jun	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Jul	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Aug	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sep	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Oct	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Nov	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Dec	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
1:Local rice, 2:Millet, 3:Sorghum, 4:Y.Maize, 5:W.Maize, 6:Imp.Rice, 7:Soya														
Explanation:														

19. What is the risk of losing business partners if you stop supplying them for 3 months?

No risk	Low risk	Medium risk	High risk

20. How much stocks do you have?

Maize				Soya		
Time	Quantity	Unit		Time	Quantity	Unit
Sep				Sep		
Oct				Oct		
Nov				Nov		
Dec				Dec		
Jan				Jan		
Feb				Feb		
Mar				Mar		
Apr				Apr		
May				May		
Jun				Jun		
Jul				Jul		
Aug				Aug		
right now				right now		
next Dec				next Dec		

Sorghum				Millet		
Time	Quantity	Unit		Time	Quantity	Unit
Sep				Sep		
Oct				Oct		
Nov				Nov		
Dec				Dec		
Jan				Jan		
Feb				Feb		
Mar				Mar		
Apr				Apr		
May				May		
Jun				Jun		
Jul				Jul		
Aug				Aug		
right now				right now		
next Dec				next Dec		

Loc. Rice				Imp. Rice		
Time	Quantity	Unit		Time	Quantity	Unit
Sep				Sep		
Oct				Oct		
Nov				Nov		
Dec				Dec		
Jan				Jan		
Feb				Feb		
Mar				Mar		
Apr				Apr		
May				May		
Jun				Jun		
Jul				Jul		
Aug				Aug		
right now				right now		
next Dec				next Dec		

21. What is the largest quantity [of your three most important commodities] you ever had in stock within the last five years?

	Loc. Rice	Millet	Sorghum	White Maize	Yellow Maize	Imp. Rice	Soya
Quantity							
Unit							

Stocking commodities over time involves uncertainty about future prices. You can either lose or gain. Please evaluate the following statements:

	No risk	Low risk	Medium risk	High risk
22a. Stocking commodities for more than 3 months involves				
	No advantage	Low advantage	Medium advantage	High advantage
22b. Stocking commodities for more than 3 months involves				

Do you agree with the following statement.

23. I am willing to take more risk with respect to stockholding than other wholesale traders?

1 strongly agree
2 agree
3 disagree
4 strongly disagree

24. How long do you averagely keep your stocks and how often do you deplete them?

Market information

25. Did you ever experience a wholesale trader trying to push a competitor out of business

☐ Yes ☐ No

☐ No answer

26. Are food aid agencies affecting your business?

☐ Yes ☐ No ☐ No answer

27. Please indicate your main purchase and sales markets for your two major products (origin of business partners):

Major agriculture product	Main purchase market /region	Main sales market /region

28. How important are long term business relationships with clients for your business?

No importance	Low importance	Medium importance	High importance

29. Please explain your choice

____

____

____

____

Price prospects

30. Where do you get price information from?

☐ Radio	☐ TV
☐ Newspaper	☐ Other traders/cooperatives
☐ Business partners	☐ Friends/relatives
☐ Agriculture information system (Mobile)	☐ NAFCO
☐ Others: ____________	☐ No answer

31. How frequent do you update information about prices?:

1 several times a day	2 daily
3 ___ days	4 weekly
5 monthly	. No answer

Price prospects [most important commodity]: ____________

32. How frequently do prices change?:

1 several times a day	2 daily
3 ___ days	4 weekly
5 monthly	6 seasonally
	. No answer

33a. What is today's sales price?[most important commodity]: ____________ in GHC per unit ___

33b. What price do you expect in one month?: ____________ in GHC per unit ___

33c. ... three months?: ______________ in GHC per unit ___

33d. ... six months?: ______________ in GHC per unit ___

34. How often do you experience a major drop in prices whilst you are stocking?[three most important commodities]:

1	every week	2	every month
3	multiple times a year	4	once a year
5	every other year	6	

never
.
No answer

	Loc. Rice	Millet	Sorghum	White Maize	Yellow Maize	Imp. Rice	Soya
Quantity							
Unit							

Please indicate whether you agree or disagree on the following statement:

35. Compared to the last year, there was much rain in this year's main rainy season.

1	strongly agree	2	agree
3	disagree	4	strongly disagree

36. What is the NAFCO minimum guaranteed price for [the most important com from above] this production year?

__________________ ☐ Dont know

Only if respondent trades imported rice:

37. What is the current import duty for perfumed rice from Non-ECOWAS countries?

__________________ ☐ Dont know

38. Which region in Ghana produces most in terms of quantity?[three most important commodities]:

1 Greater Accra	2 Ashanti
3 Brong-Ahafo	4 Volta
5 Central	6 Eastern
7 Northern	8 Upper East
9 Upper West	10 Western
	. No answer

	Loc. Rice	Millet	Sorghum	White Maize	Yellow Maize	Imp. Rice	Soya
Region							

Transaction costs

39. Over the last 12 months, did you hire a transporter or did you transport yourself?

□ Did not transport □ Only with my own vehicle □ Only with a transporter

□ Both

40. Over the last 12 months, did you use your own storage facilities or did you rent them from someone?

□ Did not store □ Only own facilities □ Only rented facilities

□ Both

Secret market information

41. Who are the three largest trader in the market (other than you)?

____

____

42. How much storage capacity do they have?

____

____

____

43. How much do you believe they have in stocks at the moment?

____ commodity: ____________________

____ commodity: ____________________

____ commodity: ____________________

Appendix E

Appendix: Telephone interview questionnaire

TRADER SURVEY QUESTIONNAIRE

Institute of Statistical, Social and Economic Research (ISSER),

University of Ghana (Legon)

Center for Development Research (ZEF), University of Bonn

To be filled by the contractee.

Name of the company:________________________

Name of the respondent:________________________

Telephone Number: ________________________

[Additional information on the respondent is provided here in order to establish rapport; e.g. location of the first meeting, special incidents during the meeting]

____

____

Commodities of the company ______________________________

To be completed by the interviewer.

Interview Date: __ __ __ __ -2014 (ddmm-2014)

Good morning/afternoon. My name is ____________________. I am conducting this survey on behalf of ISSER and ZEF on the structure of agricultural marketing in Ghana.

The information provided by you in this interview about your trading activities will contribute to understand the causes and impacts of seasonal price dynamics in Ghana. Your response to these questions will be anonymous and will be treated with the strictest confidentiality. Your participation is voluntary and you can choose not to answer any or all of the questions if you wish; however we hope you will participate since your views are important. The research is aiming at improving the functioning of grain markets in Ghana.

Thank you in advance for your time to participate in this study.

1. Please evaluate the following factors according to their impact on price movements:

	No impact	Low impact	Medium impact	High impact
Quantity harvested				
Timing of harvest				
Change in market supply				
Change in market demand				
Trade policies Ghana				
Market activity NAFCO				
Trade policies in neighbouring countries				
Price changes in neighbouring countries				
International price changes				
Others:__________________				

2. Please evaluate the following factors according to their risk for profits from your stocks:

	No risk	Low risk	Medium risk	High risk
Bumper harvest				
Bad harvest				
Timing of harvest				
Export prohibition				
Change in import duties				
Market activity of NAFCO				
Export prohibition in neighbouring country				
Import stop in neighbouring country				
Price changes in neighbouring country				
International price changes				
Others:__________________				

3. Please evaluate your competitiveness for the following cost components?

	Lower costs	Sames costs	Higher costs
	than other traders		
Loading			
Transportation			
Capital/interest payment			
Storage costs			
Costs due to losses while storing			

How much do you need to add to the purchase price to not make any loses?: ______________ for most important crop ___

4a. if you buy and immediately sell: ______________ in GHC per unit ___

4b. if you buy and store for three months and sell: ______________ in GHC per unit ___

Appendix F

Appendix: Derivation of the optimal linear stocking rule

Let supply be a random variable and ϵ the deviation from its mean:

$$Q_t + IM_t = E[Q + IM] + \epsilon \tag{F.1}$$

According to the market identity, consumption C_t equals total supply plus changes in stocks ΔS_t:

$$C_t = Q_t + IM_t + \Delta S_t \tag{F.2}$$

$$\text{with } \Delta S_t = S_{t-1} - S_t \tag{F.3}$$

In each year a constant portion γ of total available supply $Q_t + IM_t + S_{t-1}$ is carried to the next period. Thus,

$$S_{t-1} = \gamma(S_t + Q_t + IM_t) \tag{F.4}$$

Inserting (F.4) in (F.3) yields:

$$\Delta S_t = \gamma(S_t + Q_t + IM_t) - S_t \tag{F.5}$$

$$= (\gamma - 1)S_t + \gamma(Q_t + IM_t) \tag{F.6}$$

Then, consumption can be written as:

$$C_t = Q_t + IM_t - \gamma(Q_t + IM_t) + (1-\gamma)S_t \quad \text{(F.7)}$$
$$= (1-\gamma)Q_t + (1-\gamma)S_t \quad \text{(F.8)}$$

In steady state $E[S_t] = E[S_{t-1}] = S^*$, therefore in expectation (F.4) changes to:

$$E[S_{t-1}] = \gamma(E[S_t] + E[Q + IM]) \quad \text{(F.9)}$$
$$S^* = \frac{\gamma E[Q + IM]}{(1-\gamma)} \quad \text{(F.10)}$$

The variance of consumption is given by:

$$\text{Var}(C_t) = (E[C_t] - C_t)^2 \quad \text{(F.11)}$$
$$= (1-\gamma)^2[\text{Var}(S_t + (Q_t + IM_t))] \quad \text{(F.12)}$$
$$= (1-\gamma)^2[\text{Var}(S_t) + \text{Var}(Q_t) + 2\text{Cov}(S_t, Q_t + IM_t)] \quad \text{(F.13)}$$

$Q_t + IM_t$ i.i.d. and S_t depends on $Q_{t-1} + IM_{t-1}$ only $\rightarrow \text{Cov}(S_t, Q_t + IM_t) = 0$

$\text{Var}(C_t)$ can be expressed dependent on S_t and S_{t-1}. In both cases $\text{Var}(C_t)$ is equal. Therefore:

$$= (1-\gamma)^2[\gamma^2\text{VAR}(S_{t-1}) + (1+\gamma^2)\text{VAR}(Q_t + IM_t)] \quad \text{(F.14)}$$
$$! = (1-\gamma)^2[\text{VAR}(S_t) + \text{VAR}(Q_t + IM_t)] \quad \text{(F.15)}$$

Solving for $\text{VAR}(S_t)$ yields:

$$\text{VAR}(S_t) = \frac{\gamma^2}{(1-\gamma^2)}\text{VAR}(Q_t + IM_t) \quad \text{(F.16)}$$

Inserting (F.16) in (F.13) allows to write $\text{VAR}(C_t)$ as a function of $\text{VAR}(Q_t + IM_t)$:

$$\mathrm{VAR}(C_t) = (1-\gamma)^2[\frac{\gamma^2}{(1-\gamma^2)}\mathrm{VAR}(Q_t + IM_t) + \mathrm{VAR}(Q_t + IM_t)] \tag{F.17}$$

$$= \frac{1-\gamma}{(1+\gamma)}\mathrm{VAR}(Q_t + IM_t) \tag{F.18}$$

or

$$\mathrm{CV}(C_t) = \sqrt{\frac{1-\gamma}{(1+\gamma)}}\mathrm{CV}(Q_t + IM_t) \tag{F.19}$$

with

$$\mathrm{VAR}(Q_t + IM_t) = \frac{1}{T}\sum_t^T (E[Q+IM] - (Q_t + IM_t))^2 \tag{F.20}$$

$$E[Q+IM] : \text{Trendvalue from HP-filter} \tag{F.21}$$

Appendix G

Appendix: Supplementary tables and figures chapter 6

Table G.1: Stock levels in 2014 for target consumption of 99 %

	Production				Supply			
	P_i	S_i^*	$\hat{S}_i$	$\tilde{S}_i$	P_i	S_i^*	$\hat{S}_i$	$\tilde{S}_i$
Benin	40%	141,604	120,137	100,356	37%	152,677	127,265	116,424
Burkina Faso	40%	631,234	368,174	447,361	40%	593,667	351,453	452,700
Cameroon	49%	214,049	236,879	151,698	26%	203,148	281,713	154,911
Cape Verde	49%	8,101	524	5,741	52%	15,455	1,701	11,785
Chad	49%	368,209	139,960	260,953	46%	357,082	141,125	272,293
Cote d'Ivoire	37%	127,531	97,789	90,382	43%	181,273	187,327	138,229
Gambia, the	43%	79,208	16,839	56,135	55%	48,382	23,208	36,894
Ghana	43%	357,196	207,853	253,148	43%	477,451	263,042	364,079
Guinea	43%	90,030	174,930	63,805	46%	124,296	186,109	94,782
Guinea-Bissau	43%	26,771	13,318	18,973	46%	26,092	20,706	19,896
Liberia	40%	27,477	13,978	19,473	49%	53,601	34,774	40,873
Mali	58%	419,760	429,367	297,487	55%	417,047	383,615	318,019
Mauritania	49%	56,683	16,814	40,172	46%	111,038	49,237	84,672
Niger	37%	779,525	360,017	552,456	37%	681,052	350,313	519,335
Nigeria	43%	1,786,527	1,674,944	1,266,127	43%	2,167,705	1,943,323	1,652,981
Senegal	49%	477,554	100,173	338,447	52%	308,029	204,087	234,887
Sierra Leone	37%	128,728	62,996	91,231	46%	149,723	73,652	114,171

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... Table G.1 continued

	Production				Supply			
	P_i	S_i^*	$\hat{S}_i$	$\tilde{S}_i$	P_i	S_i^*	$\hat{S}_i$	$\tilde{S}_i$
Togo	43%	95,910	87,226	67,972	40%	117,762	94,081	89,800
Region	100%	5,816,099	4,122,000	4,122,000	100%	6,185,480	4,716,730	4,716,730

Source: Author's computation based on USDA [2014].

Note: Stocks in mt. P_i is the probability of intervention when production and supply are below the target consumption (99%). S_i^*, $\hat{S}_i$, and $\tilde{S}_i$ are stocks without cooperation, with equal, and relative contributions.

Table G.2: Stock levels in 2014 for target consumption of 97 %

	Production				Supply			
	P_i	S_i^*	$\hat{S}_i$	$\tilde{S}_i$	P_i	S_i^*	$\hat{S}_i$	$\tilde{S}_i$
Benin	34%	120,218	93,057	79,668	37%	127,936	96,089	91,907
Burkina Faso	34%	546,502	285,182	362,163	37%	500,825	265,358	359,785
Cameroon	29%	189,018	183,483	125,260	17%	170,363	212,702	122,386
Cape Verde	49%	7,836	406	5,193	40%	14,800	1,285	10,632
Chad	43%	334,871	108,411	221,916	40%	317,808	106,554	228,308
Cote d'Ivoire	23%	106,025	75,746	70,262	31%	139,631	141,438	100,309
Gambia, the	37%	74,719	13,043	49,515	54%	41,486	17,523	29,803
Ghana	37%	317,677	161,000	210,522	34%	422,149	198,605	303,265
Guinea	34%	74,009	135,498	49,045	31%	87,947	140,519	63,179
Guinea-Bissau	34%	24,150	10,316	16,004	40%	23,423	15,634	16,827
Liberia	40%	23,892	10,827	15,833	37%	48,902	26,255	35,130
Mali	46%	309,623	332,581	205,185	49%	303,936	289,642	218,342
Mauritania	49%	53,175	13,024	35,238	37%	101,159	37,175	72,671
Niger	34%	693,576	278,864	459,627	34%	585455	264,498	420,581
Nigeria	34%	1,285,869	1,297,387	852,134	34%	1,572,822	1,467,271	1,129,890
Senegal	43%	453,584	77,593	300,586	43%	258,230	154,092	185,508
Sierra Leone	34%	117,360	48,796	77,773	40%	134,597	55,609	96,692

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... Table G.2 continued

	Production				Supply			
	P_i	S_i^*	$\hat{S}_i$	$\tilde{S}_i$	P_i	S_i^*	$\hat{S}_i$	$\tilde{S}_i$
Togo	31%	85,791	67,564	56,853	29%	105,888	71,035	76,069
Region	100%	4,817,894	3,193,000	3,193,000	97%	4,957,355	3,561,283	3,561,283

Source: Author's computation based on USDA [2014].

Note: Stocks in mt. P_i is the probability of intervention when production and supply are below the target consumption (97%). S_i^*, $\hat{S}_i$, and $\tilde{S}_i$ are stocks without cooperation, with equal, and relative contributions.

Table G.3: Stock levels in 2014 for target consumption of 90 %

	Production				Supply			
	P_i	S_i^*	$\hat{S}_i$	$\tilde{S}_i$	P_i	S_i^*	$\hat{S}_i$	$\tilde{S}_i$
Benin	11%	49,479	31,300	20,578	11%	42,379	17,315	15755
Burkina Faso	23%	271,876	95,923	113,071	20%	203,667	47,818	75,717
Cameroon	9%	101,408	61,716	42,175	9%	94,852	38,329	35,263
Cape Verde	34%	6,910	137	2,874	34%	12,505	231	4,649
Chad	23%	218,190	36,465	90,743	23%	180,347	19,201	67,048
Cote d'Ivoire	6%	30,755	25,478	12,791	3%	35,635	25,487	13,248
Gambia, the	29%	59,007	4,387	24,540	31%	22,209	3,158	8,257
Ghana	14%	257,176	54,153	106,957	11%	228,592	35,789	84,984
Guinea	6%	17,936	45,576	7,460	6%	10,864	25,322	4,039
Guinea-Bissau	17%	14,974	3,470	6,227	14%	14,084	2,817	5,236
Liberia	26%	15,564	3,642	6,473	23%	32,455	4,731	12,066
Mali	11%	110,280	111,866	45,864	14%	78,210	52,194	29,076
Mauritania	37%	40,894	4,381	17,007	17%	66,580	6,699	24,753
Niger	20%	392,751	93,798	163,341	20%	345,241	47,663	128,351
Nigeria	3%	497,369	436,384	206,851	9%	128,646	264,404	47,827
Senegal	29%	369,686	26,099	153,749	9%	83,935	27,768	31,205
Sierra Leone	23%	77,571	16,413	32,261	20%	81,657	10,021	30,358
Togo	14%	50,373	22,726	20,950	11%	64,329	12,800	23,916
Region	89%	2,582,200	1,074,000	1,074,000	89%	1,726,187	641,747	641,747

Source: Author's computation based on USDA [2014].

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... Table G.3 continued

	Production				Supply			
	P_i	S_i^*	$\hat{S}_i$	$\tilde{S}_i$	P_i	S_i^*	$\hat{S}_i$	$\tilde{S}_i$

Note: Stocks in mt. P_i is the probability of intervention when production and supply are below the target consumption (90%). S_i^*, $\hat{S}_i$, and $\tilde{S}_i$ are stocks without cooperation, with equal, and relative contributions.

Table G.4: Regression results: beginning stocks$_t = \gamma$ l.supply$_t + \epsilon_t$

	Coef.	Std. Err.	t	$P > \|t\|$	R^2
Benin	0.1052916	0.0095475	11.03	0	91
Burkina Faso	0.0826153	0.0070421	11.73	0	92
Cameroon	0.177977	0.015548	11.45	0	92
Cape Verde	0.1686828	0.0196476	8.59	0	86
Chad	0.1927932	0.0120751	15.97	0	96
Cote d'Ivoire	0.0951646	0.0106122	8.97	0	87
Gambia, the	0.2392599	0.0254189	9.41	0	88
Ghana	0.0891409	0.0051898	17.18	0	96
Guinea	0.1377254	0.0091712	15.02	0	95
Guinea-Bissau	0.1638711	0.0088481	18.52	0	97
Liberia	0.144342	0.0145824	9.9	0	89
Mali	0.116585	0.0102389	11.39	0	92
Mauritania	0.1589412	0.0157148	10.11	0	90
Niger	0.0574701	0.0099975	5.75	0	73
Nigeria	0.0626637	0.0056854	11.02	0	91
Senegal	0.1403502	0.0075525	18.58	0	97
Sierra Leone	0.0626151	0.0062673	9.99	0	89
Togo	0.132223	0.0060911	21.71	0	98

Table G.5: Optimal stock-to-use ratio for various levels of consumption variability

	CV Supply	γ for CV_C=3.4	γ for CV_C=3.1	γ for CV_C=5.4	α for CV_C=3.4	α for CV_C=3.1	α for CV_C=5.4
Benin	7.6	0.67	0.71	0.33	200%	251%	49%
Burkina Faso	9.1	0.76	0.79	0.48	308%	381%	92%

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... Table G.5 continued

	CV Supply	γ for CV_C=3.4	γ for CV_C=3.1	γ for CV_C=5.4	α for CV_C=3.4	α for CV_C=3.1	α for CV_C=5.4
Cameroon	6	0.51	0.58	0.10	106%	137%	12%
Cape Verde	30.3	0.98	0.98	0.94	3921%	4727%	1524%
Chad	13.3	0.88	0.90	0.72	715%	870%	253%
Cote d'Ivoire	5.7	0.48	0.54	0.05	91%	119%	6%
Gambia, the	14.4	0.89	0.91	0.75	847%	1029%	306%
Ghana	10.2	0.80	0.83	0.56	400%	491%	128%
Guinea	5.6	0.46	0.53	0.04	86%	113%	4%
Guinea-Bissau	10.3	0.80	0.83	0.57	409%	502%	132%
Liberia	14.8	0.90	0.92	0.77	897%	1090%	326%
Mali	9.4	0.77	0.80	0.50	332%	410%	102%
Mauritania	9.6	0.78	0.81	0.52	349%	430%	108%
Niger	12	0.85	0.87	0.66	573%	699%	197%
Nigeria	5.4	0.43	0.50	0.00	76%	102%	0%
Senegal	8.3	0.71	0.76	0.41	248%	308%	68%
Sierra Leone	11.1	0.83	0.86	0.62	483%	591%	161%
Togo	8.1	0.70	0.74	0.38	234%	291%	63%
Region	3.4	0.00	0.09		0%	10%	

Source: Author's computation based on USDA [2014] and FAO CBS [2014].

Note: $\gamma = \frac{CV_S^2 - CV_C^2}{CV_S^2 + CV_C^2}$ (which is derived from equation 6.28; α is computed by (see equation 6.26).

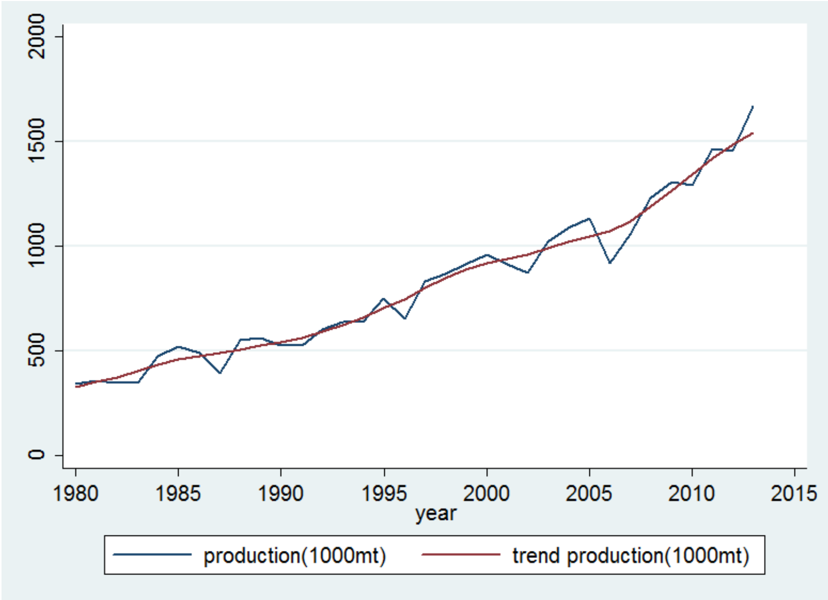

Figure G.1: Grain production in Benin 1980-2014.

Source: Author's illustration based on USDA [2014].

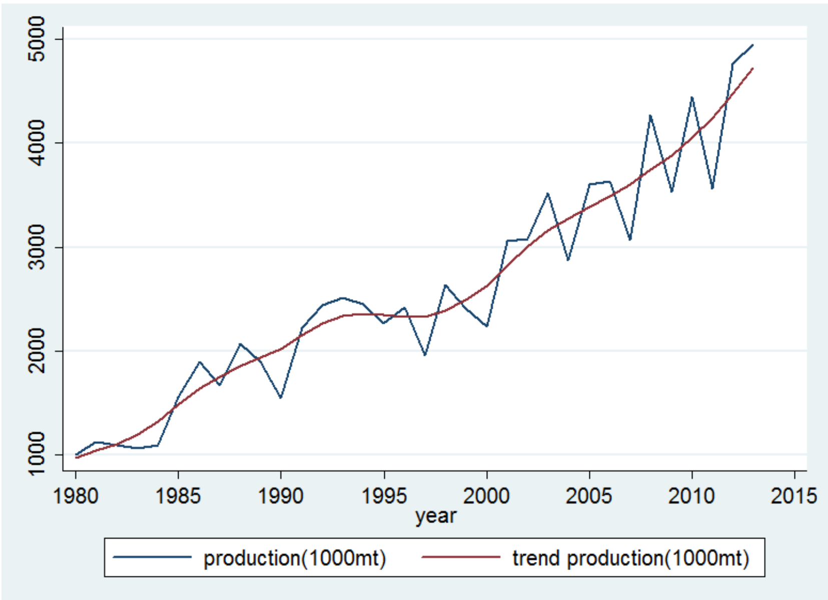

Figure G.2: Grain production in Burkina Faso 1980-2014.

Source: Author's illustration based on USDA [2014].

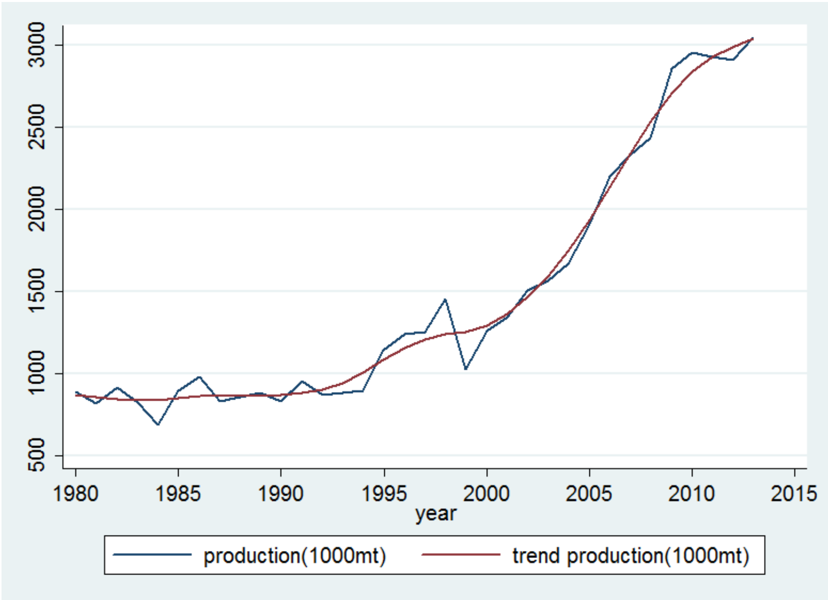

Figure G.3: Grain production in Cameroon 1980-2014.

Source: Author's illustration based on USDA [2014].

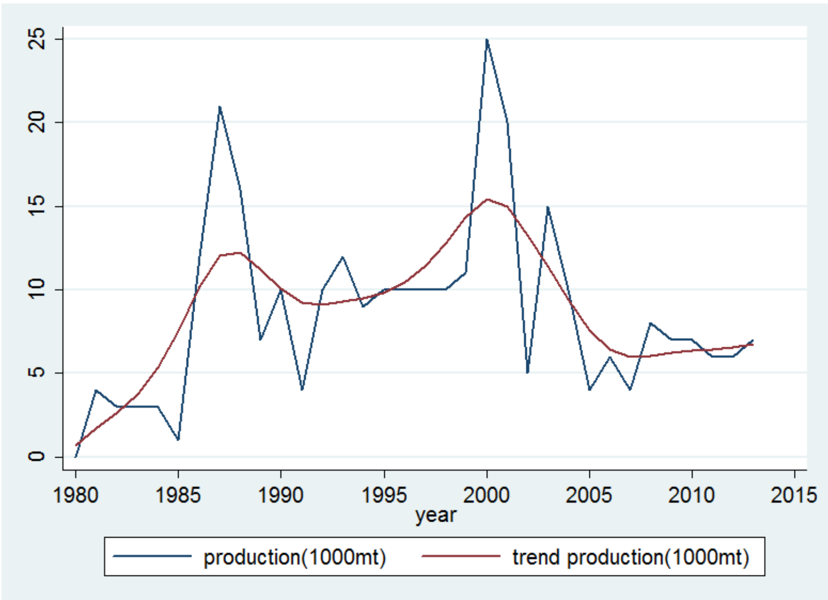

Figure G.4: Grain production in Cape Verde 1980-2014.

Source: Author's illustration based on USDA [2014].

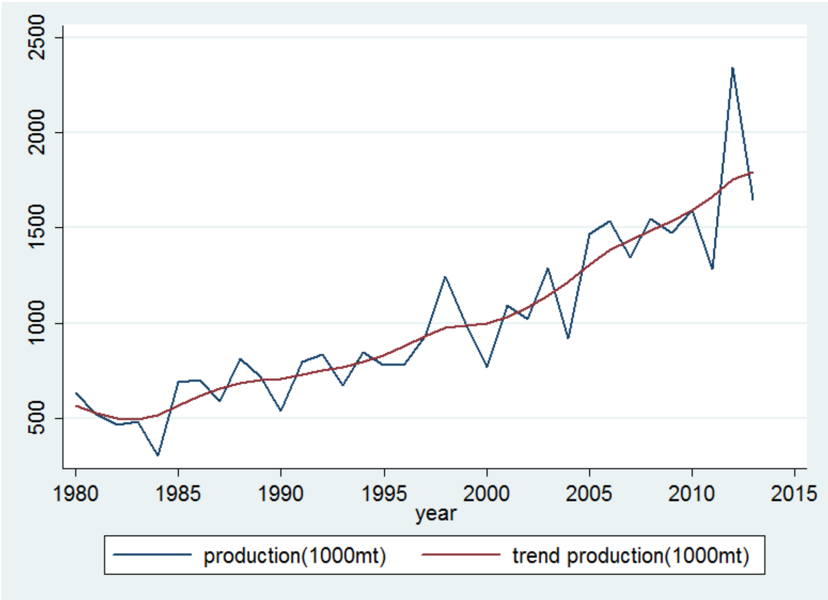

Figure G.5: Grain production in Chad 1980-2014

Source: Author's illustration based on USDA [2014].

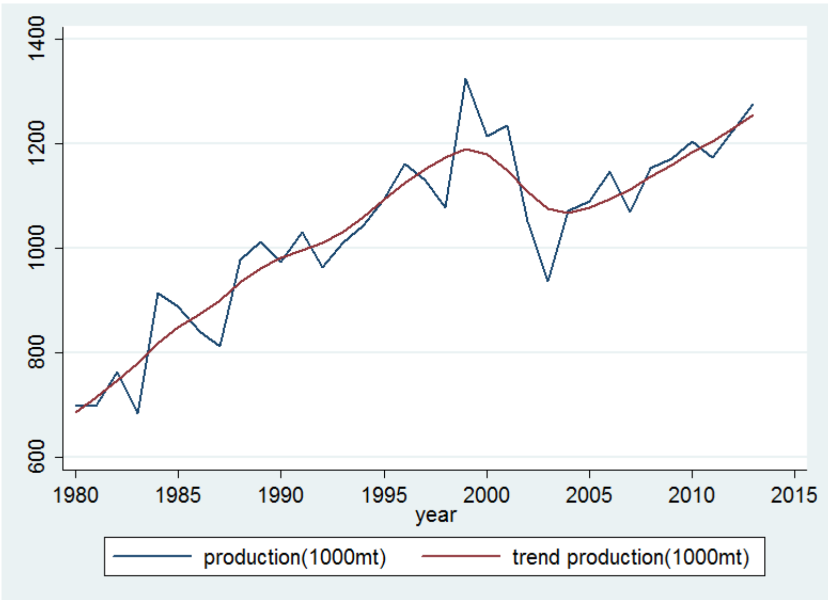

Figure G.6: Grain production in Cote d'Ivoire 1980-2014

Source: Author's illustration based on USDA [2014].

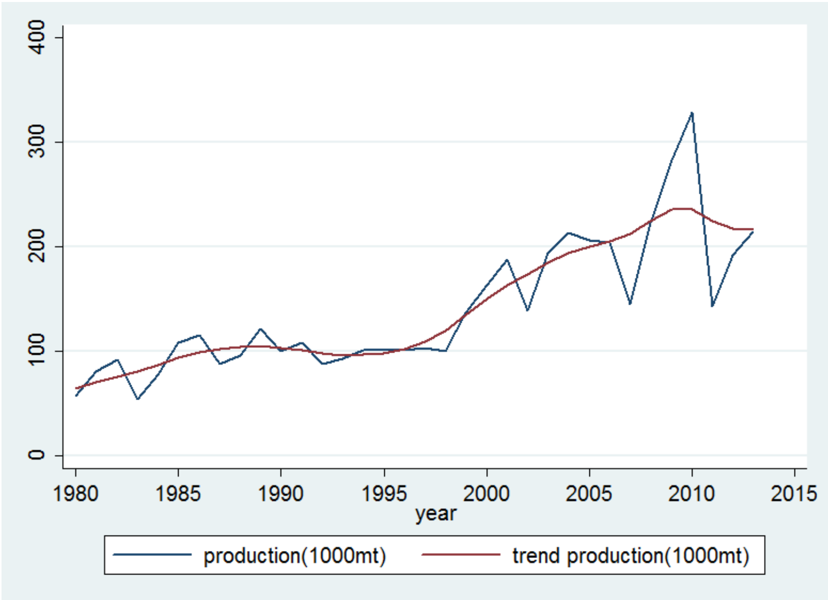

Figure G.7: Grain production in The Gambia 1980-2014

Source: Author's illustration based on USDA [2014].

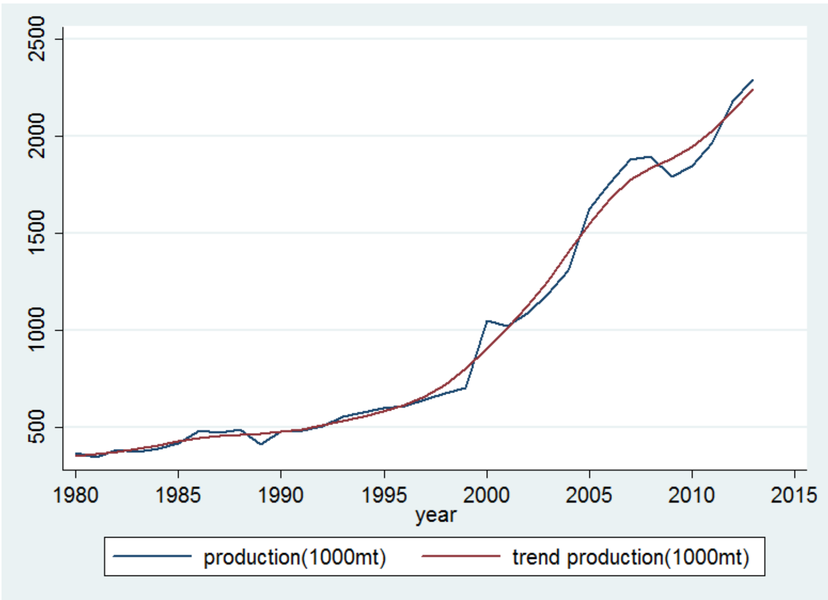

Figure G.8: Grain production in Guinea 1980-2014

Source: Author's illustration based on USDA [2014].

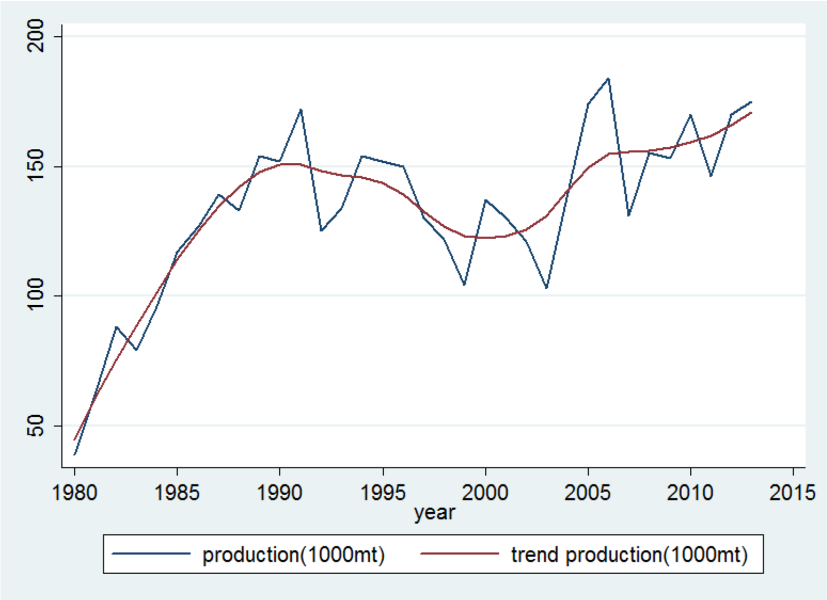

FIGURE G.9: Grain production in Guinea-Bissau 1980-2014

Source: Author's illustration based on USDA [2014].

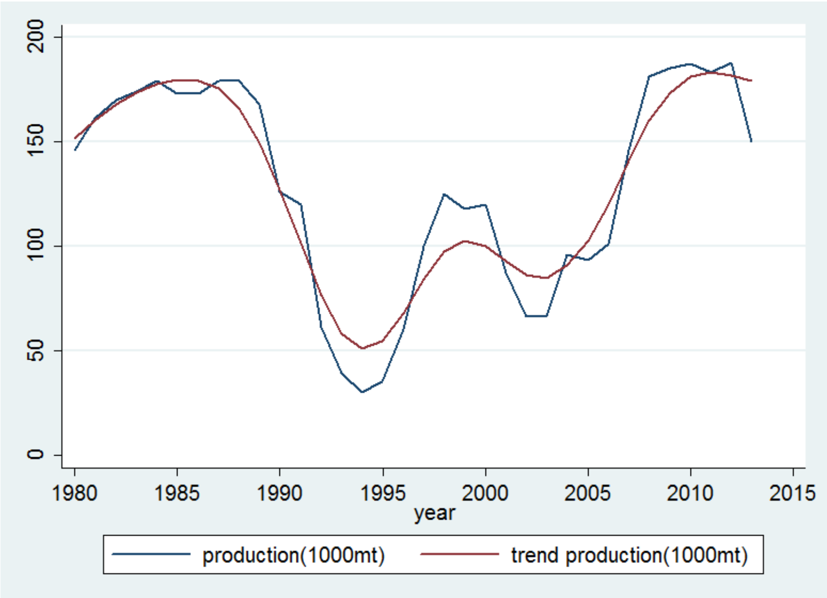

FIGURE G.10: Grain production in Liberia 1980-2014

Source: Author's illustration based on USDA [2014].

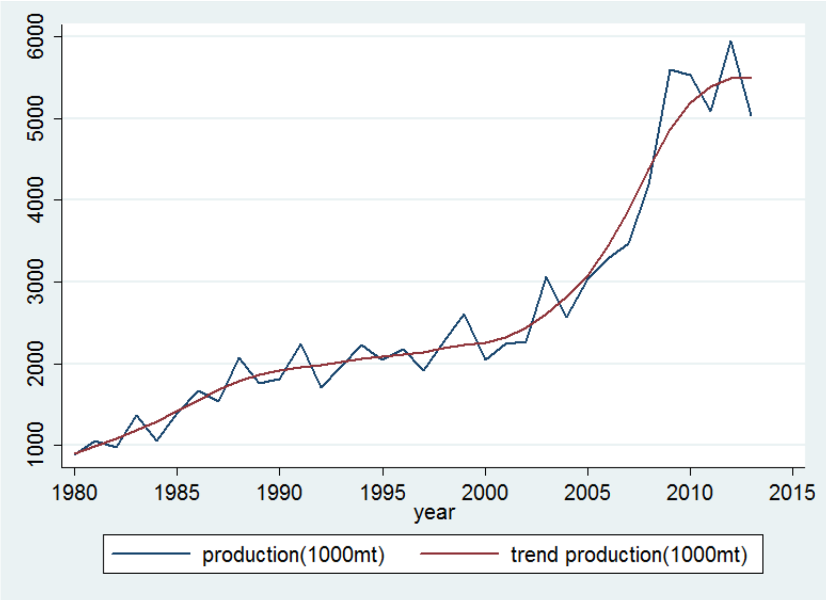

Figure G.11: Grain production in Mali 1980-2014

Source: Author's illustration based on USDA [2014].

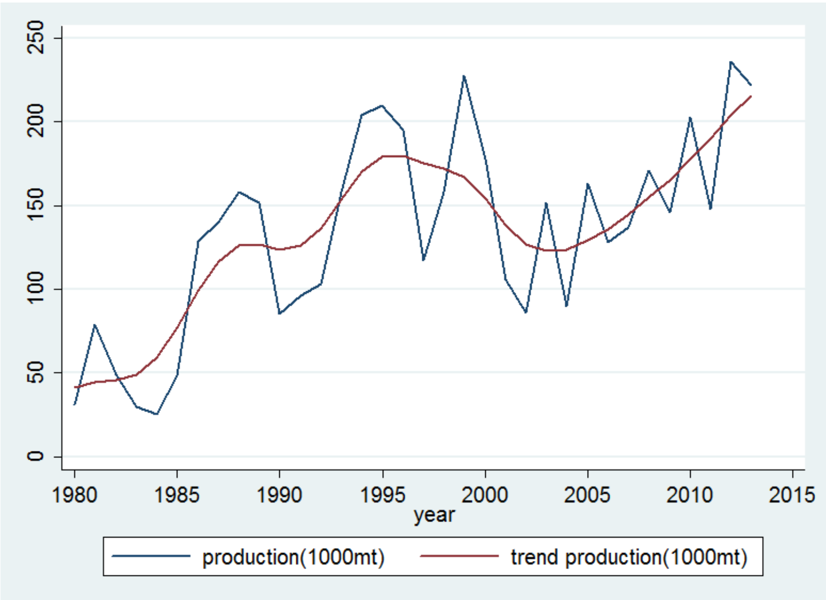

Figure G.12: Grain production in Mauritania 1980-2014

Source: Author's illustration based on USDA [2014].

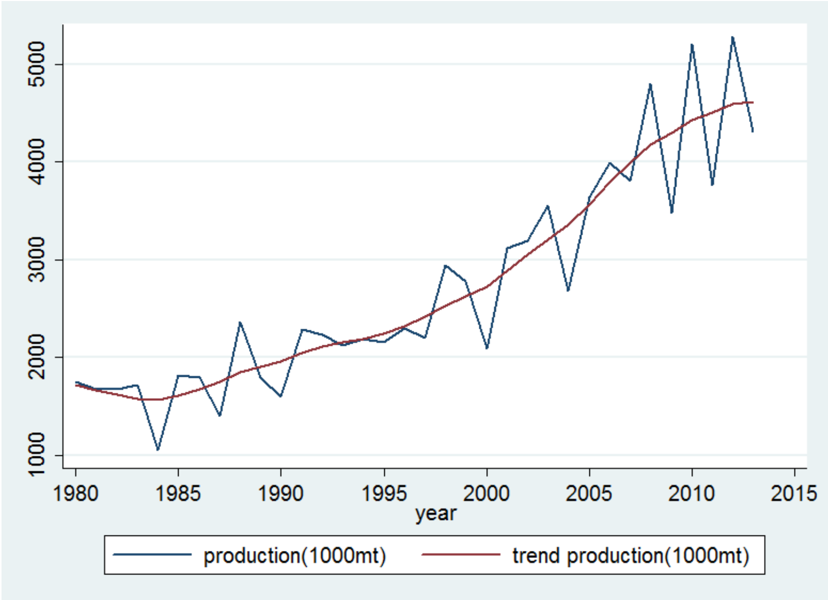

Figure G.13: Grain production in Niger 1980-2014

Source: Author's illustration based on USDA [2014].

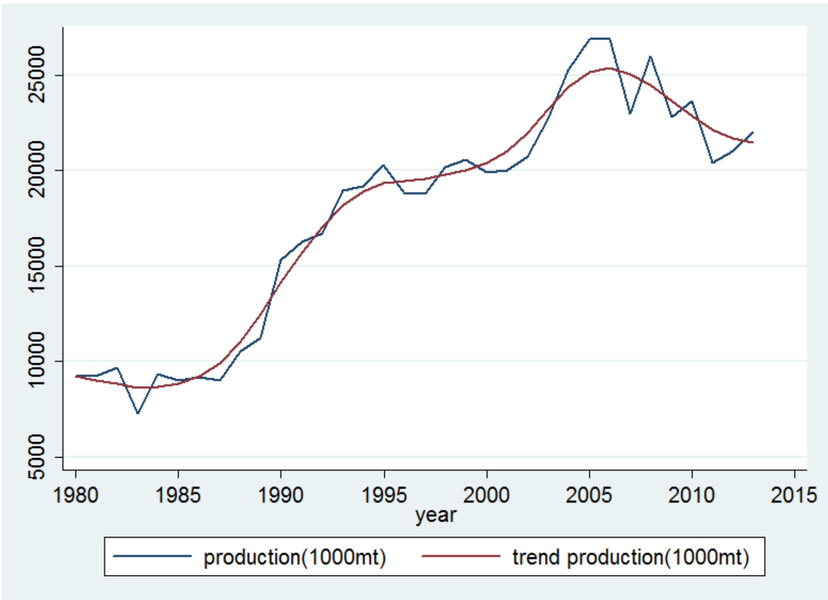

Figure G.14: Grain production in Nigeria 1980-2014

Source: Author's illustration based on USDA [2014].

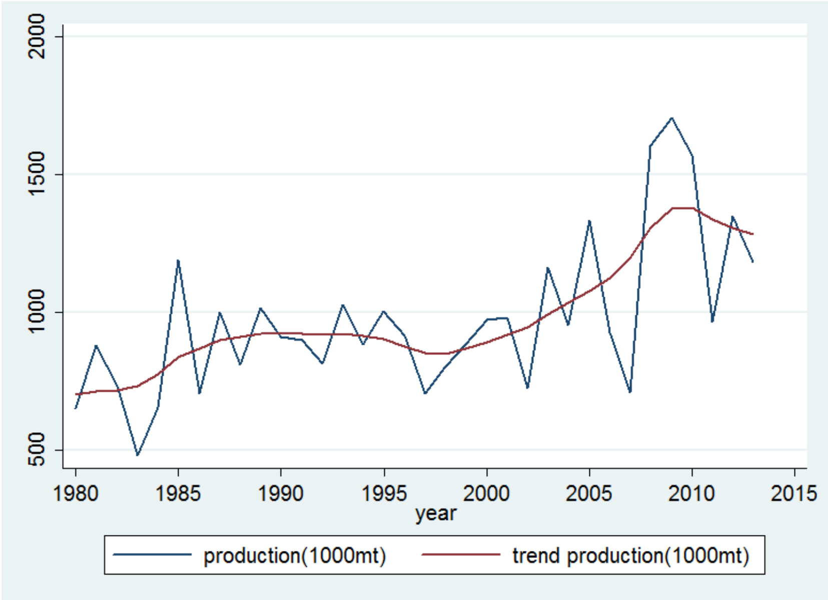

Figure G.15: Grain production in Senegal 1980-2014

Source: Author's illustration based on USDA [2014].

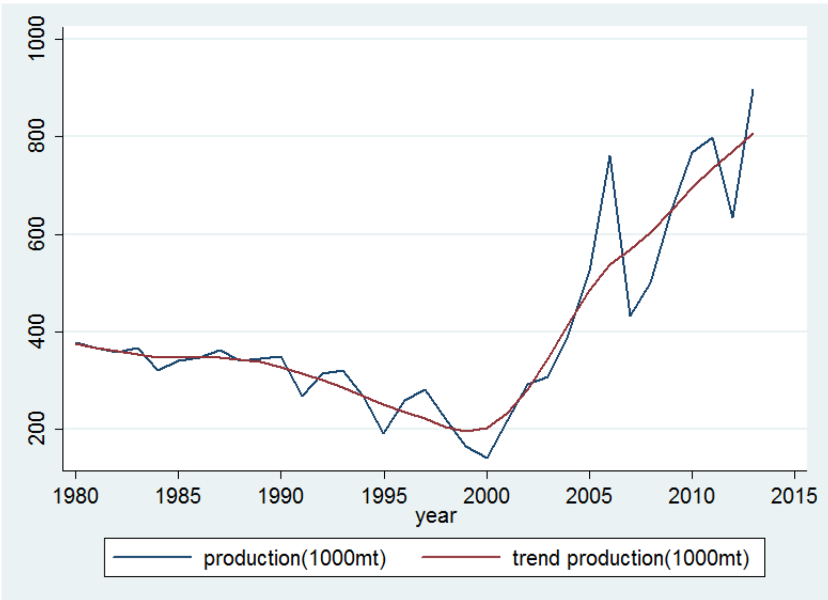

Figure G.16: Grain production in Sierra Leone 1980-2014

Source: Author's illustration based on USDA [2014].

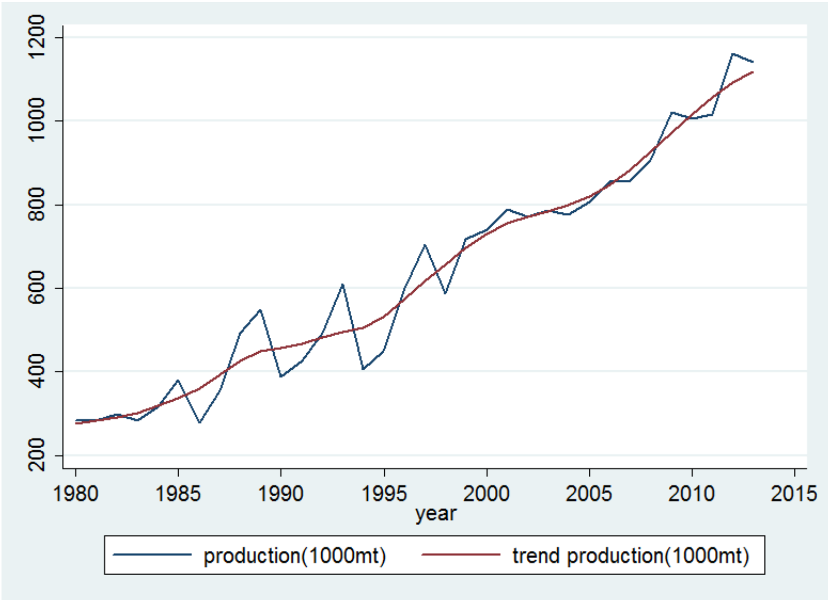

Figure G.17: Grain production in Togo 1980-2014

Source: Author's illustration based on USDA [2014].

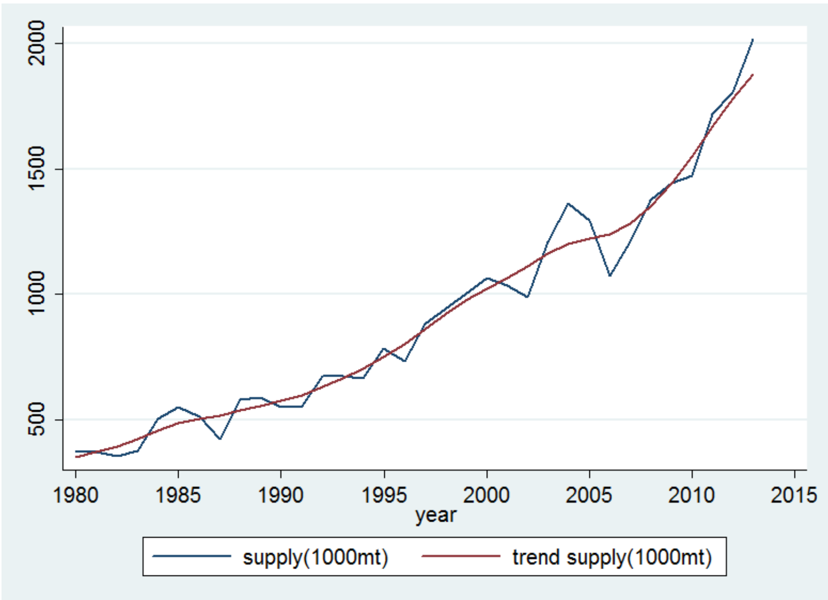

Figure G.18: Grain supply in Benin 1980-2014

Source: Author's illustration based on USDA [2014].

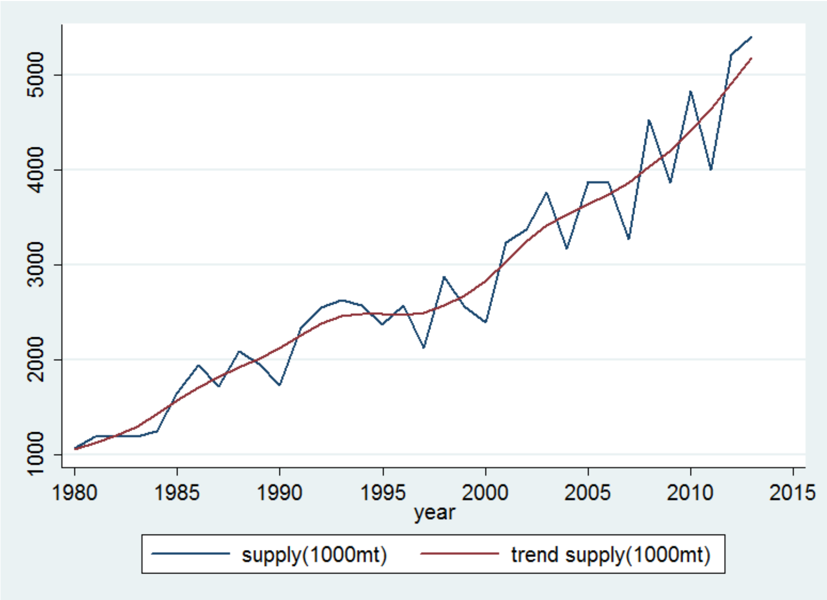

Figure G.19: Grain supply in Burkina Faso 1980-2014

Source: Author's illustration based on USDA [2014].

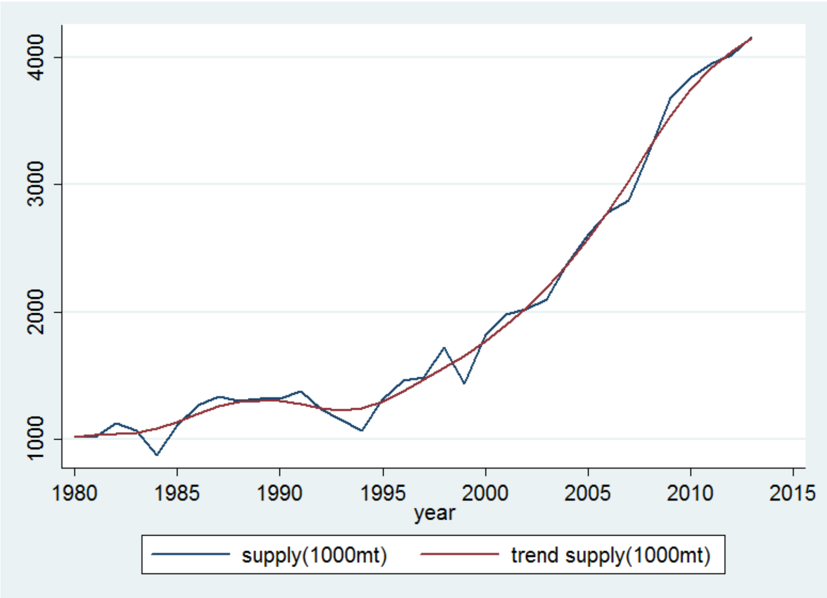

Figure G.20: Grain supply in Cameroon 1980-2014

Source: Author's illustration based on USDA [2014].

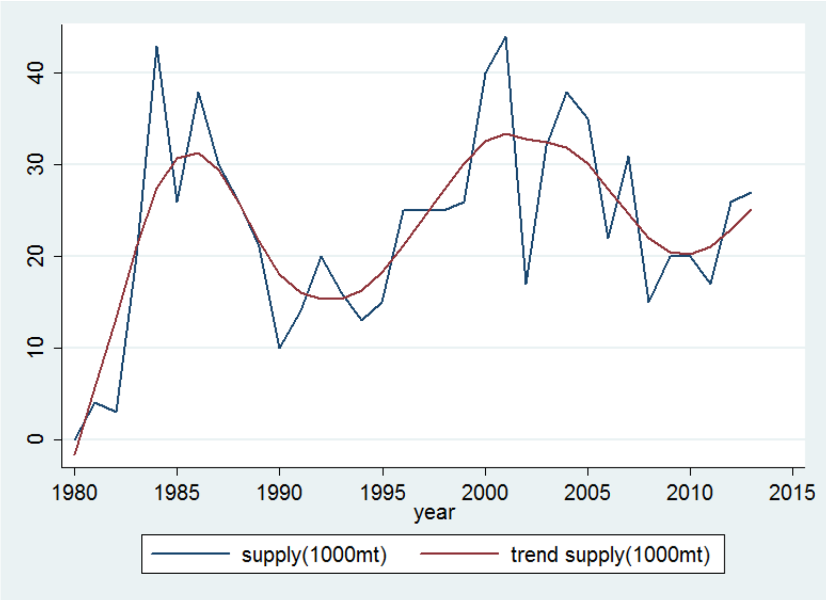

FIGURE G.21: Grain supply in Cape Verde 1980-2014

Source: Author's illustration based on USDA [2014].

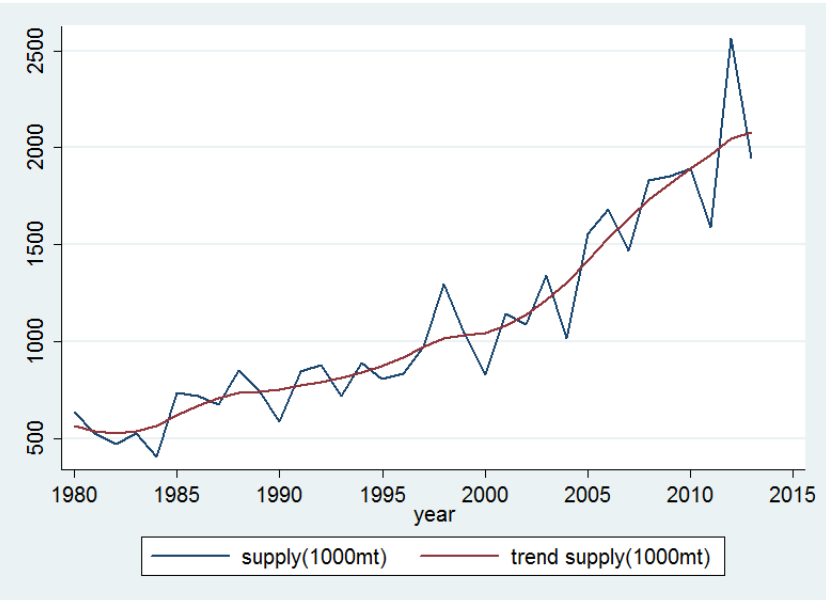

FIGURE G.22: Grain supply in Chad 1980-2014

Source: Author's illustration based on USDA [2014].

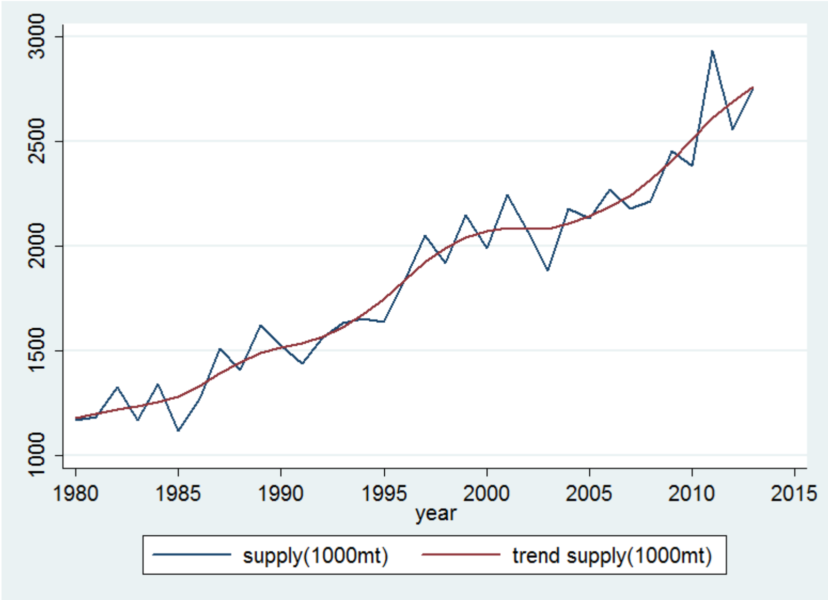

FIGURE G.23: Grain supply in Cote d'Ivoire 1980-2014

Source: Author's illustration based on USDA [2014].

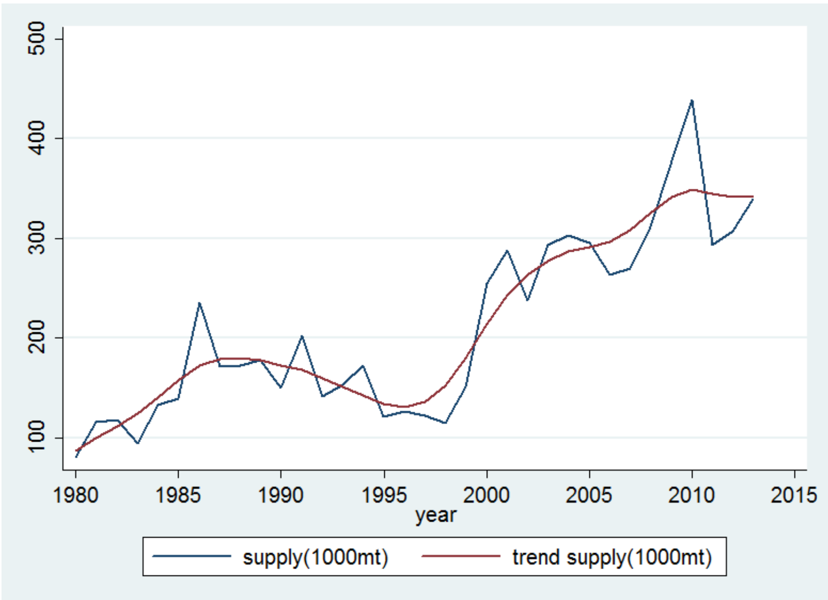

FIGURE G.24: Grain supply in The Gambia 1980-2014

Source: Author's illustration based on USDA [2014].

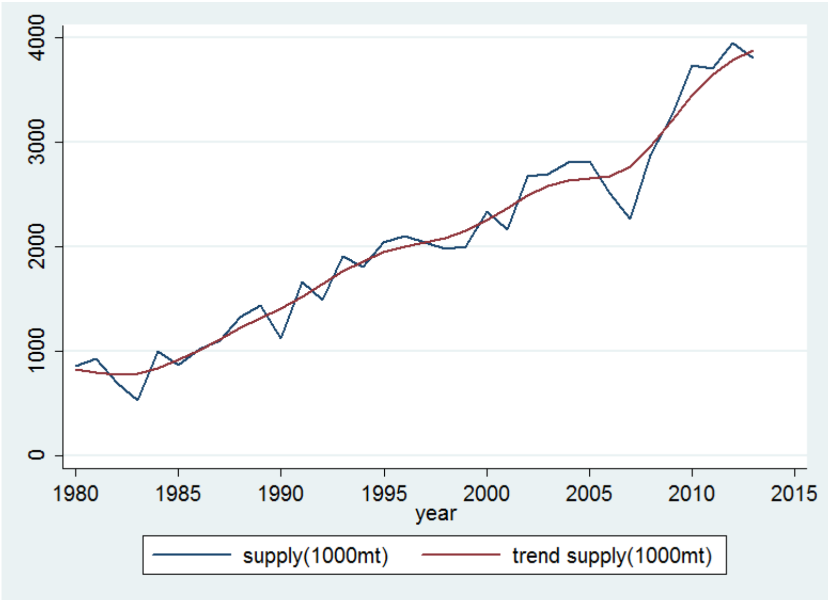

FIGURE G.25: Grain supply in Ghana 1980-2014

Source: Author's illustration based on USDA [2014].

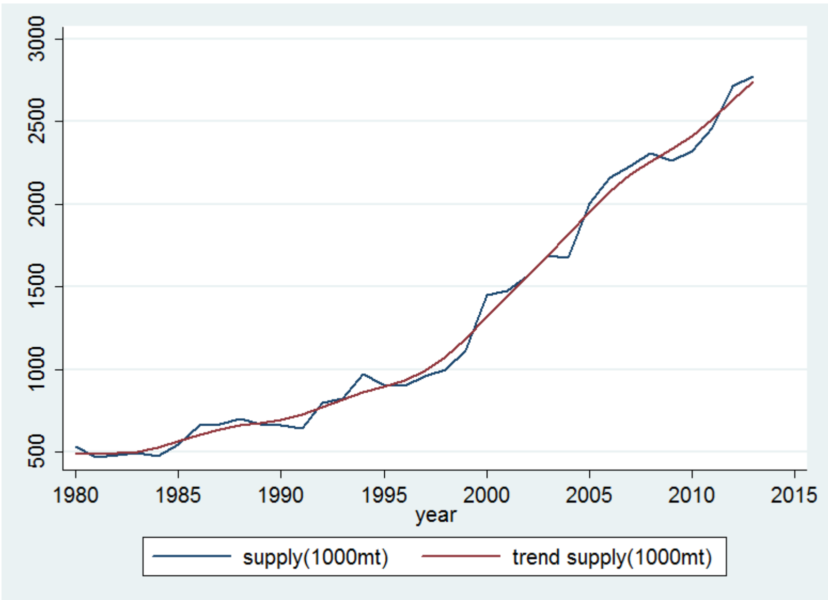

FIGURE G.26: Grain supply in Guinea 1980-2014

Source: Author's illustration based on USDA [2014].

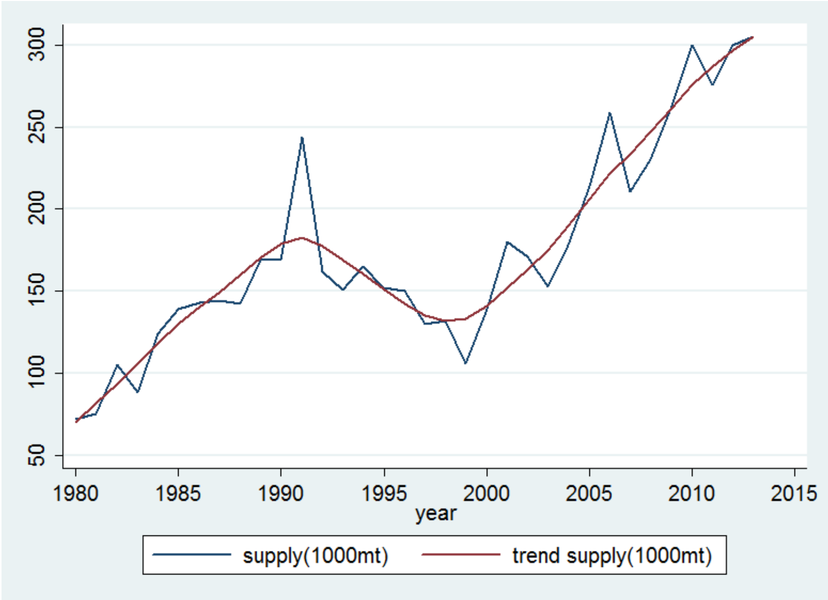

Figure G.27: Grain supply in Guinea-Bissau 1980-2014

Source: Author's illustration based on USDA [2014].

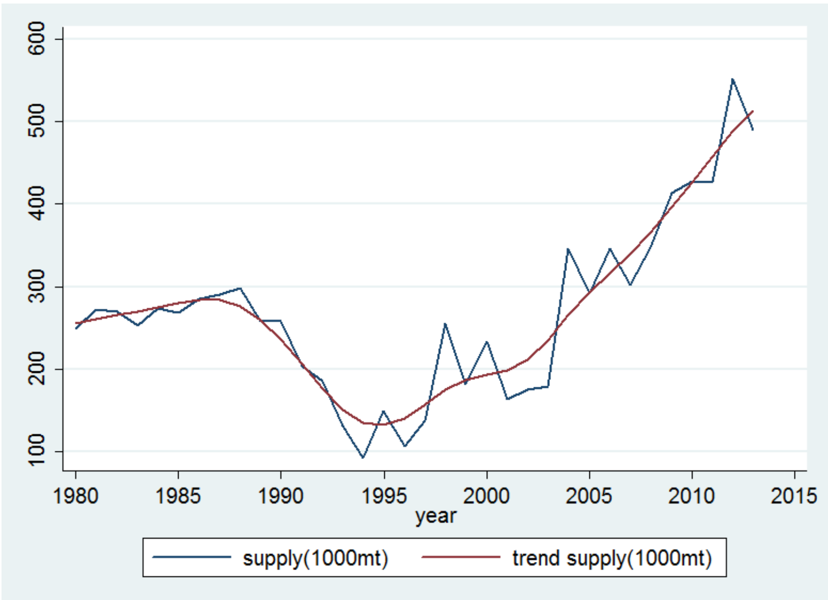

Figure G.28: Grain supply in Liberia 1980-2014

Source: Author's illustration based on USDA [2014].

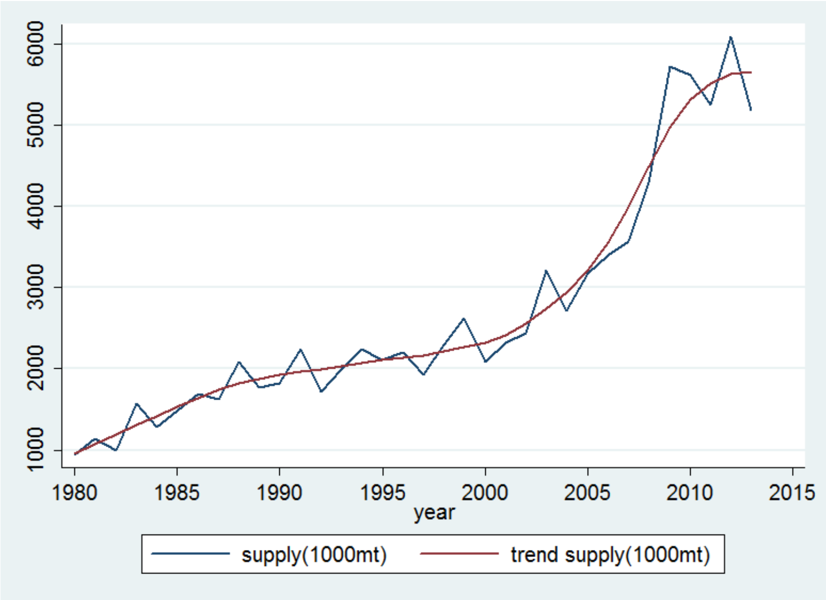

Figure G.29: Grain supply in Mali 1980-2014

Source: Author's illustration based on USDA [2014].

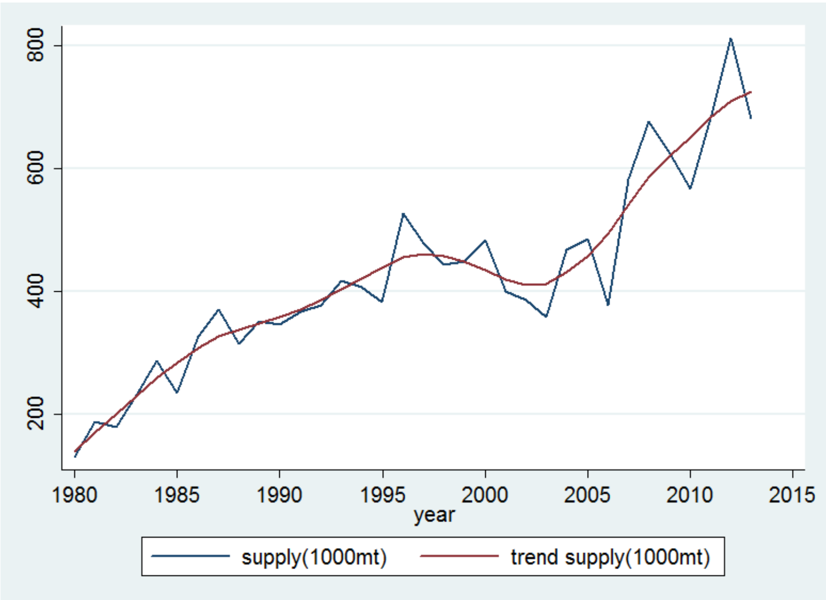

Figure G.30: Grain supply in Mauritania 1980-2014

Source: Author's illustration based on USDA [2014].

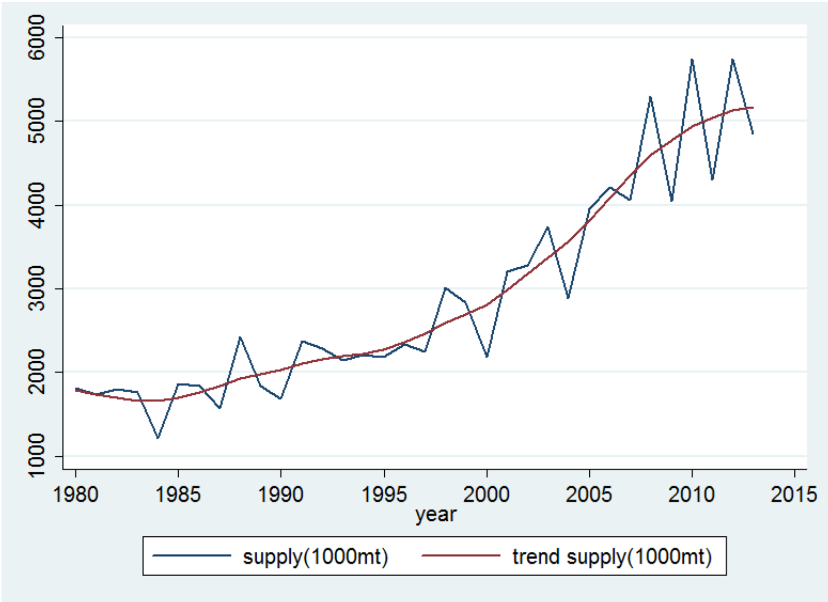

FIGURE G.31: Grain supply in Niger 1980-2014

Source: Author's illustration based on USDA [2014].

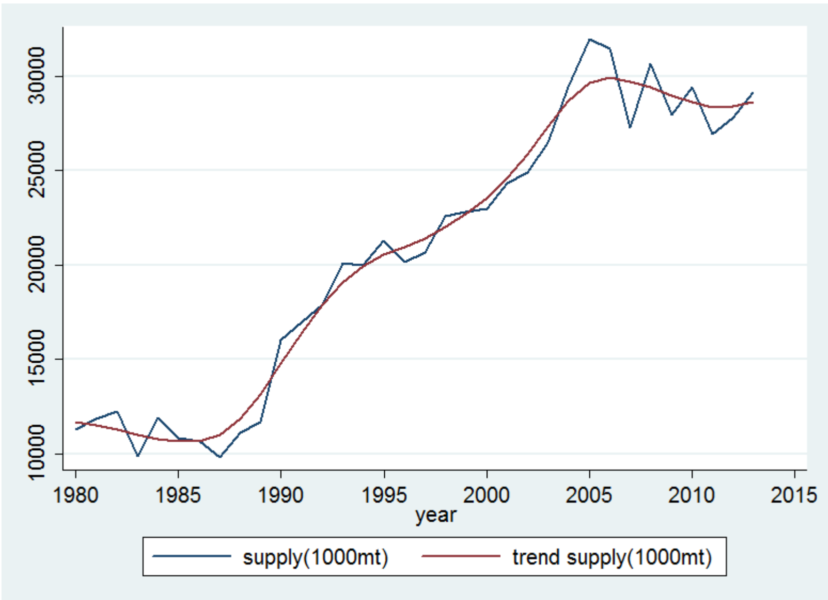

FIGURE G.32: Grain supply in Nigeria 1980-2014

Source: Author's illustration based on USDA [2014].

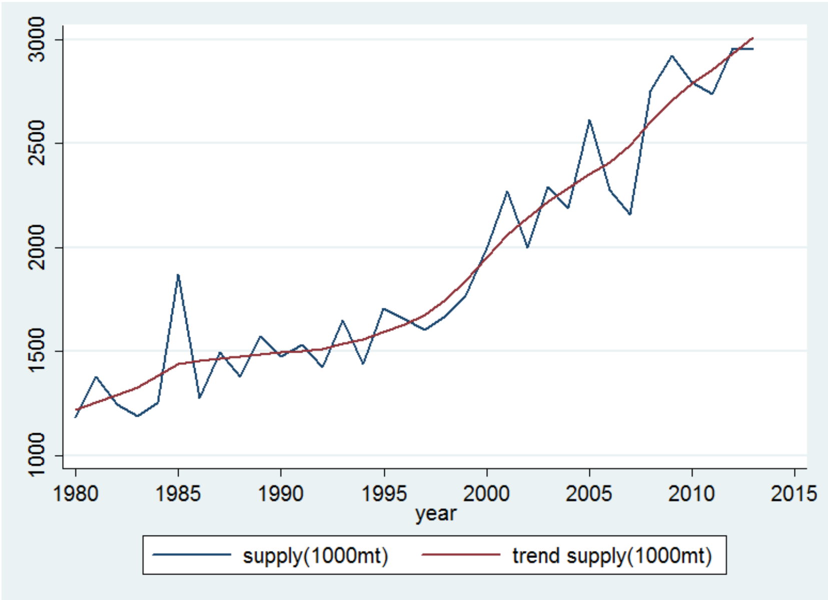

FIGURE G.33: Grain supply in Senegal 1980-2014

Source: Author's illustration based on USDA [2014].

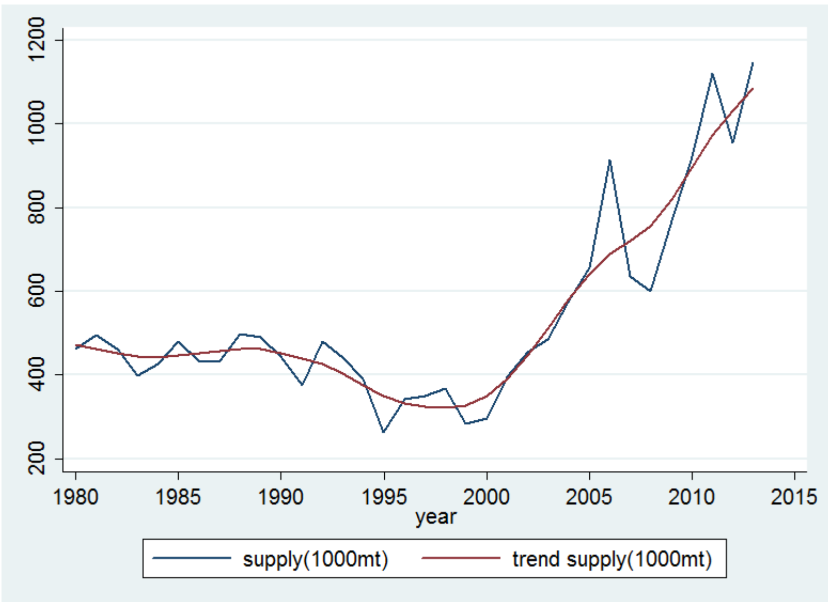

FIGURE G.34: Grain supply in Sierra Leone 1980-2014

Source: Author's illustration based on USDA [2014].

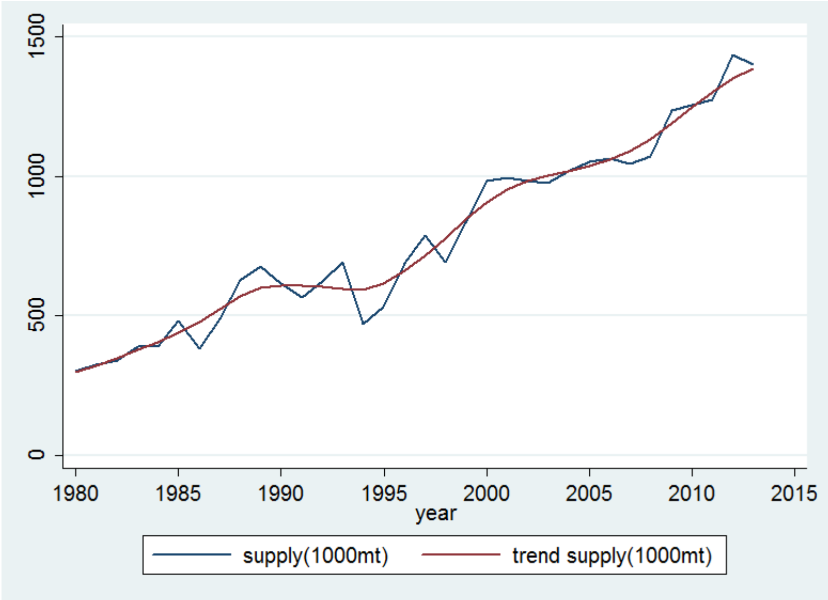

FIGURE G.35: Grain supply in Togo 1980-2014

Source: Author's illustration based on USDA [2014].

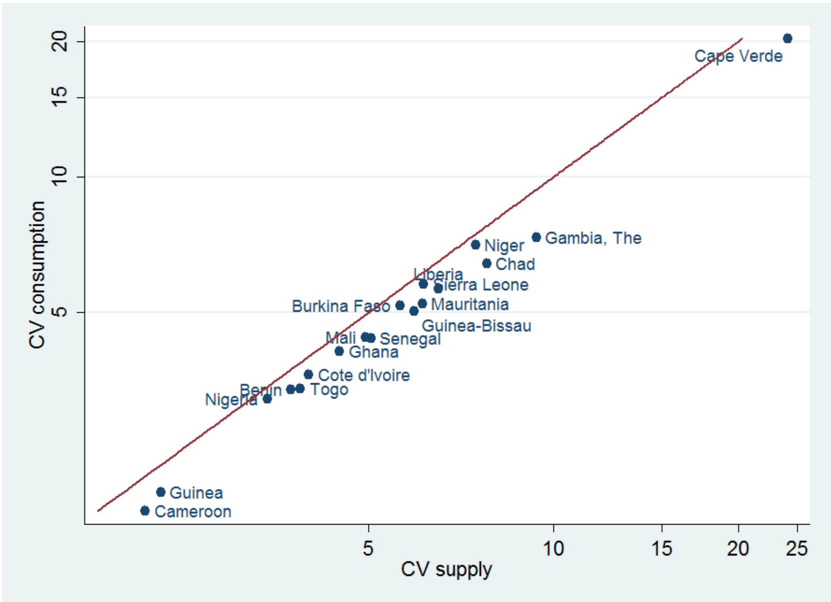

FIGURE G.36: Consumption and supply variability across study countries (log scale)

Source: Author's illustration based on USDA [2014] and FAO CBS [2014].

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