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Three Essays on Price Instability and Agents' Behaviour

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CHAPTER 1

Three essays on price instability and agents' behaviour: an introduction

The ability of a country to grow at non-increasing food prices is a fundamental pre-condition for economic growth. In fact when food commodity prices are high and volatile, they can impair the political and economic stability of a developing country, as they have significant impacts at both micro and macro level. What happened over the last decade in the world agricultural commodity markets, can largely be explained by analyzing the trends in global supply and demand for these commodities. However, these markets are not isolated from the rest of the economy and other factors play a role as well. In particular, since the summer of 2007, a shift of a huge amount of resources from financial markets raised new investment opportunities. These resources were large enough - especially as compared to those in the real economy - to easily cause significant price movements, sometimes with explosive effects. It is probably not by chance that commodity food prices increased as a result of the international financial volatility, triggered by the breakdown in the US sub-prime mortgage market. As reported by the UNCTAD Policy Brief (2008), "speculators looking for assets with raising returns may have well sensed the strains in world food markets and re-oriented their portfolios towards food commodities".

The recent and vast literature on this topic came to different and contrasting conclusions on the transmission mechanisms of the crisis. However, there are doubts about the key role played by price movements and their increased volatility. Therefore, the general aim of the thesis is to provide some insights into recent price instability and its role in spurring the crisis and its consequences.

1.1. Background and justification

1.1.1. Topic 1 - Economic agents' behaviour, price dynamics and market stability

The understanding of financial markets as channels of transmission of economic crisis behaviour is essential. In the last decades, indeed, the huge movement of resources from the productive to the financial sector has characterized the evolution of economic systems. This financialization of the economy is one of the major reasons of the latest financial instability, characterized by periodic crises of increasing intensity that ended up in the recent global crisis (see Orhangazi, 2008; Rochon and Rossi, 2010).

Recently, much attention has been devoted to financial markets psychology. This is perhaps a consequence of the failure of the conventional approaches used to study financial markets, basically grounded on the hypothesis of perfectly rational agents, keystone of the so-called efficient markets hypothesis (Fama, 1965). This strand of research was dramatically unsuccessful in anticipating and explaining how financial bubbles initiate, inflate and eventually burst (Shiller, 2005). The consequences of the bursts of such bubbles can be dramatic, since they may have huge effects on the real economy, giving rise to profound recessions.

However, there are many stylized facts[1] other than bubbles and crashes that the mainstream approach is not able to describe convincingly. Tversky and Kahneman (1974) were among the first ones who analysed and classified the irrationalities that influence human decisions making behaviour. They demonstrated that people formulate their decisions following simple heuristics, or said differently, rules of thumb, which can be in a certain sense a simple way to cast a decision. However, sometimes they may lead to systematic deviations from the decision that a perfectly rational agent should do. Financial investors and market makers decide for example which strategy to pursue, whether to buy or sell a financial asset, following simple heuristics too.

Models with heterogeneous agents (HAMs henceforth) have provided some insights into trader strategies and their impact on aggregate variables, demonstrating to be a promising unconventional alternative that can successfully explain some stylized anomalies of financial markets, such as high prices, excess volatility, fat tails and boom and bust cycles. These models have shown that the interactions at the micro-level are crucial in comprehending macro-economic dynamics, revealing the similarities and differences between the overall system and its parts (see Delli Gatti *et al.* 2011). This is fundamental because agents acting in financial markets are often involved in asset speculation, which in turn has strong repercussions on commodity and real estate markets, strongly linked between each other (Chan *et al.*, 2011).

For this reason it is crucial to provide new insights on the dynamics behind financial markets stylized facts, and on how the behaviour of investors and market makers contributes to generate instability within the financial system. To do this, we will build an heterogeneous agents dynamic model of asset price and inventory. We include a market maker who manages her inventory on the basis of the excess demand of two groups of agents, which employ the same trading rule but have different beliefs on the fundamental value.
Indeed, commodity price instability has significant drawbacks both at macro and at micro-levels. In the former case it can generate a significant deterioration of the balance of pay-

[1] Such as volatility clustering, long memory effects, excess volatility, fat tails in the distribution of returns.

ments, of public finance and worsen the long-term growth, while in the latter case it may have severe impacts on the most vulnerable households. In both cases, the effect of price upswing and volatility is harmful both on the supply and on the demand side. These are the additional aspects we want to investigate further.

1.1.2. Topic 2 - The impact of price spikes and increased volatility on agricultural supply response

Concerning the supply side, individual agricultural producers, as well as food exporting countries can take advantage from high prices, whereas low prices and increased price volatility may reduce producers welfare.

Higher food prices provide in fact an incentive and opportunity for many developing countries to strengthen the agricultural sector contribution to economic growth and poverty reduction (Arias *et al.*, 2013). At the same time, some farmers can be hit by the consequences of higher prices, in particular livestock farmers who face increasing costs for fodder and stock for animal feeding operations, in particular in intensive animal farming. This negative effect is often worsened by the fact that usually farmers have little or no choice about the coping strategies to be adopted to protect themselves against large income fluctuations.

On the other hand, low prices can also harm agricultural producers with worsening effects on both production and investment decisions (OECD-FAO, 2011). Because of their unpredictability, strong price fluctuations may be particularly harmful for producers, especially when occurring between the planting decisions and harvest/sale time. Supply response to high prices is likely to be reduced when prices are volatile.

Hence, the second objective of the thesis is to shed new light on the global potential effect of food prices upsurges and their volatility on staple food supply. This assessment is treated in a context where also the macro-environment is taken into consideration.

1.1.3. Topic 3 - The impacts of price shocks on food and nutrition security

Looking at the impact of price instability on food and nutrition security of developing country households is another relevant issue. In particular, developing a thorough understanding about the links between prices and food and nutrition security is an extremely delicate and complex problem, being prices only one of the underlying causes of food and nutrition insecurity. Moreover, the effect of their dynamics on households welfare is not always easily measurable and can seldom be generalized, since it is strongly influenced by the different economic and social contexts (Headey and Fan, 2010). Specifically, the regions most at risk are those that, are not only characterized by low income, but also have a severe food deficit: Sub-Saharan countries represent one of the most vulnerable areas.

Taking into account that in less developed economies food consumption expenditure is a significant share of households' budget, it is important to assess whether price shocks have had a negative impact on their level of food and nutrition security and poverty, especially for the urban poor, the landless and those ones with a lower level of assets. Moreover, it is frequently argued in the literature (Brinkman *et al.*, 2010) that the increase in staple food prices has led to a comprehensive reduction in the quantity and quality of food consumed among vulnerable households, and to an erosion of the few available coping mechanisms.

In order to understand what are the effects of price surges on households welfare and to assess the determinants of vulnerability, further studies are needed. The third aim of the thesis is thus to evaluate whether the food price crisis has had a harmful effect on the food intake and dietary composition of poor households.

1.2. Structure of the thesis and research questions

This work is composed by three papers, each addressing one of the issues highlighted in the previous section.

In the first paper[2], *Heterogeneous Fundamentalists and Market Maker Inventories*, we contribute to the development of financial market modelling and asset price dynamics by employing heterogeneous agents. It provides a better understanding of the instability arising in financial markets by the interaction of different agents. Starting from Naimzada - Ricchiuti framework (2008, 2009, 2012) we develop a model of asset price and inventory in a scenario where a market maker sets the price to clear the market. In doing so, the market maker considers the excess demand of two groups of agents that employ the same trading rule (i.e. two fundamentalists) but with different beliefs about the fundamental prices.

The research questions addressed in this paper are the following:

- Does the market maker stabilize or destabilize the market?
- Which is the relationship between the fraction of inventory the market maker holds from the previous period and the market stability?
- Do the different beliefs about the fundamentals influence the market stability in this framework?
- Is the model able to replicate important stylized facts, such as the excess volatility, price increments or fat tails?

The second paper, entitled *Modelling acreage, production and yield supply response to domestic price volatility*, is grounded on the Nerlovian framework (Nerlove, 1971) and proposes an empirical analysis of the effects of domestic food commodity prices and their volatility on the supply response of wheat, rice and maize. In particular we will focus on different response indicators, such as yield, production and acreage.

The research questions addressed in this paper are the following:

[2]Presented at the 8th Workshop MDEF, 18-20 September 2014, held in Urbino (Italy) and at the 55th RSA Italian Economics Association, 23-25 October 2014 in Trento (Italy).

- To what extent domestic food commodity prices and their volatility influence supply response of wheat, rice and maize?
- Do non-price factors, namely inputs use, financial deepening and climatic factors, have an incidence on agricultural supply response?
- What is the role played by financial deepening in a context of domestic price volatility?

Finally, in the third paper entitled *Price Shocks, Vulnerability and Food and Nutrition Security among Rural and Urban Households in Tanzania* we examine the impact of the recent food price shocks on food consumption across households in urban and rural Tanzania. This analysis contributes to the debate on the relative importance of the different sources of risk on poor and vulnerable households, as they have important implications for social protection and other policies. In order to do that we will assess their effect on both food caloric intake and dietary diversity, controlling for other idiosyncratic and covariate shocks that the vulnerable households could experience.

The research questions addressed in this paper are the following:

- What is the effect of food price shocks as well as idiosyncratic and covariate shocks on Tanzanian households' food caloric intake?
- Which types of households in rural and urban Tanzania are most vulnerable to shocks in terms of a decline in total food caloric intake?
- Is there any effect of such shocks in terms of dietary diversity?
- Which areas experienced a more substantial change in terms of macro and micronutrients?

1.3. Data and methods

Since the price instability issue is tackled from different viewpoints, data and approaches adopted are quite different among the three papers. The first article, being a theoretical work, does not employ any specific dataset. We developed a model with heterogeneous agents and then, making use of *E & F Chaos* software, through which we were able to show the complex dynamic features of the model by simulations, we extrapolated time series of prices. These are useful in understanding the stylized facts arising from the financial markets as well as (economic) mechanisms causing cycles and fluctuation.

The empirical model used in the second paper envisaged the construction of a macro-panel dataset, consisting of countries and commodities over the period ranging between 2005 and 2012. Specifically, data relative to acreage, yield and production at country-commodity level, have been extracted from FAOSTAT. Monthly domestic price data referring to wheat, maize and rice in each country were obtained from WFP-VAM, FAO GIEWS and kindly

FEWS-NET. We coped with the lack of data on domestic prices at farm-gate level by using wholesale and retail prices as proxies. Additionally, data on fertilizers consumption were downloaded from the Fertilizers Archive Domain of FAOSTAT, while international prices of fertilizers were obtained from the World Bank Commodities Price Data (The Pink Sheet). Finally, data on financial deepening and agricultural share over GDP were drawn from World Development Indicators dataset, provided by the World Bank. The analysis has been performed adopting the System Generalized Method of Moments (SYS-GMM) introduced by Blundell and Bond (1998).

Data used in the third paper were obtained from the three waves (2008/09, 2010/11 and 2012/13) of the Tanzanian Living Standard Measurements Study - Integrated Surveys on Agricolture (LSMS - ISA) dataset. It is a nationally representative household survey, structured in three questionnaires: household, community and agriculture. We used the household and agriculture modules, achieving a final size of 58,022 observations. To assess the impact on food and nutrition security we employed a panel fixed effect model, based on the Vulnerability as Uninsured Exposure to Risk (VER) (Hoddinott and Quisumbing, 2003) framework.

1.4. Main Findings

The model introduced in the first paper offers an important contribution to the economic literature about market price determination in replicating cluster volatility, price increments and other financial markets stylized facts. Also, we demonstrated that the interaction between different groups of agents with the same trading strategy led to market instability. Moreover, by modifying the share of inventory held, market makers have an active role in causing instability.

Concerning the second paper, several conclusions can be drawn. Firstly, we found that farmers are strongly responsive to high domestic prices and to domestic price volatility. Secondly according to our estimates high expected prices determine an increase of the quantity produced and a raise in maize acreage and rice yields, while price instability generates more uncertainty on the price that farmers are going to be paid, with negative implications on production investment decisions. Financial deepening in part mitigates the negative effect of price instability on the producers' welfare.

Findings from the third paper confirm the initial hypotheses about the negative implications of price shocks on food caloric intake of the Tanzanian households. The effects of shocks are more pronounced for urban households in the basic model; however, interacting shocks with the household market position shows that rural households are affected, i.e. rural food buyers are negatively impacted by price surges. As regards food dietary diversity, we found that price surges had a negative impact on it, with significant deficiencies of micro and macro nutrients, particularly fats, calcium and vitamin A.

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CHAPTER 2

Heterogeneous Fundamentalists and Market Maker Inventories

2.1. Introduction

The market price determination has been historically a crucial issue in the economic literature. Views about the different roles of the so called "specialists" have intensely changed through time since they have been performing increasingly complex functions. On the one hand, the market maker is originally described as 'the broker's broker' and inserted in the "Walrasian auctioneer" framework to describe the price formation process. On the other hand, a "market maker mechanism" has been extensively used to describe the financial markets, when out of the equilibrium exchanges are possible.

Beja and Goldman (1980) are among the first authors that introduced a stylized representation of the market maker[1]. Day and Huang (1990) give also an important contribution on this literature, developing a non-linear behavioral model which achieves chaotic fluctuations around a benchmark fundamental price that may be seen as the bull and bear fluctuations. The market maker reacts to the excess demand by setting the price. She behaves in two different ways: she accumulates (decumulates) stocks in (out) of her inventory in presence of excess supply (demand), like the so-called dealers or liquidity providers, or rather behaves as an active investor maximizing her profits by actively controlling her inventory. These two behaviors may be consistent with each other if a target level of inventory is introduced (Bradfield, 1979).

Madhavan and Smidt (1993) shed new light on the role of specialists' inventory: their basic idea is that when the specialists act as dealers, their quotes induce mean reversion towards a target inventory level, while when they behave as active investors they choose a long-term desired inventory based on portfolio considerations, and may periodically revise this target. Also, they extend the market maker inventory control models incorporating the "asymmetric information effects" combined with level shifts in the target inventory. The existence of a target level redefines the market maker figure as an agent who has a degree of decision on its future market positions.

[1]Hereafter we use indifferently either specialists or market makers.

Since the seminal contribution of Day and Huang (1990), the market maker has been extensively analysed in the framework of the heterogeneous agent models (HAMs). This theoretical approach shows that the behavior of heterogeneous agents may generate complex price dynamics (Kirman, 1991, Lux, 1995, Brock and Hommes, 1997, 1998; Chiarella and He, 2001 or Farmer and Joshi, 2002; Westerhoff and Dieci, 2006) that may replicate stylized facts such as bubbles and crashes, fat tails for the distribution of the returns and volatility clustering.

However, in the HAM's framework, some contributions focus on the impact of the market maker inventory on the price (Gu, 1995; Sethi, 1996; Day, 1997; Franke and Asada, 2008), but none of these seeks to model the market maker as an active investor. To the best of our knowledge, Westerhoff (2003a) is the first that analyses how inventory management of foreign exchange dealers may affect exchange-rate dynamics. Later on, Zhu *et al.* (2009) develop a model consisting in a market with two different groups of agents (fundamentalists and chartists) plus a market maker acting both as a dealer and an active investor, showing that *'the market maker does not necessarily stabilize the market when actively manages his/her inventory to maximize the profit'* (Zhu *et al.*, 2009, p. 3165). Modelling market makers may make the dynamics much easier because a parameter, the market maker reaction coefficient, is added. However we believe it makes models much closer to the real markets (Farmer and Joshi, 2002) and may simplify the analysis (i.e. Hommes *et al.*, 2005).

Most of the HAMs models are characterized by a framework with two assets (a risky and a risk-free asset), different types of traders (i.e. fundamentalists, chartists, noise traders and so on) and sometimes a market maker (for a survey see Hommes, 2006; LeBaron, 2006). By definition, fundamentalists are convinced that prices will return toward their long-run equilibrium values. Hence, if the price is below (above) its fundamental value, they will buy (sell) the asset. Such a trading strategy tends to stabilize the market since prices are pushed towards their equilibrium values. The market impact of fundamental traders is constant over time. Recently, in contrast with the canonical HAM's models, Naimzada and Ricchiuti (2008, 2009, 2012) developed a framework in which the source of instability resides in the interaction of two different groups of agents that use the same trading strategy (all traders are fundamentalists) but have heterogeneous beliefs about the fundamental asset value. We may think about the two different agents' beliefs also within a system that lies outside the financial markets, for example at macro level, which is the case reported for inflation expectations by Mankiw *et al.* (2003). For instance, the beliefs about the future have a subjective dimension: hardly agents reach the true fundamental value and it is really unlikely that agents have the same beliefs (Naimzada and Ricchiuti, 2014).

The goal of the present paper is twofold. Firstly, starting from the framework developed by Naimzada and Ricchiuti (2009) and in line with the market maker inventory introduced by Zhu *et al.* (2009), we develop a simple model in which two groups of fundamentalists trade in a financial market with a market maker who actively manages her inventory. Secondly, we study in such a framework the role of heterogeneity and whether the market maker is a stabilizer or not, analysing through simulations both the cases with fixed and endogenously determined fractions.

The remainder of this paper is organized as follows. In section 2.2 we discuss the asset pricing model with two fundamentalists and the market maker inventory. Section 2.3 briefly presents the necessary conditions for the existence and local stability of fixed points. In section 2.4 we use simulations to study the role of heterogeneity also in the case with endogenous fractions of agents. The last section contains the final remarks and suggestions for further investigations.

2.2. The model

Naimzada and Ricchiuti model (2009) includes a market maker and two archetypal groups of fundamentalists *'who may use one of a number of predictor which they might obtain from financial gurus'* (experts) as in Föllmer et al. (2005). There are two different assets: agents can either invest in a risky asset or in a risk-free asset. The risky asset (e.g stock or stock market index) has a price per share ex-dividend at time t equal to X_t and a (stochastic) dividend process y_t. The risk-free asset is perfectly elastically supplied at the gross return $(R = (1 + r/k) > 1)$, where r is equal to the constant risk free rate per annual and k is the frequency of the trading period per year. We define $i = 1, 2$ the *two* groups of agents, and we assume that all the investors choose their own portfolio in a way such that they maximize their expected utility. We denote as z_s the total fixed risky asset supply. The portfolio wealth at $(t + 1)$ is given by:

$$W_{i,t+1} = RW_{i,t} + R_{t+1}q_{i,t} = RW_{i,t} + (X_{t+1} + y_{t+1} - RX_t)\, q_{i,t} \tag{2.1}$$

where $R_{t+1} = (X_{t+1} + y_{t+1} - RX_t)$ corresponds to the excess return (capital gain/loss) of the risky asset over the trading period $t + 1$[2], while $q_{i,t}$ represents the number of shares of the risky asset held in the trading period t by the investor i.

Now, let $E_{i,t}(X_{t+1})$ and $V_{i,t}(X_{t+1})$ be the beliefs or forecasts about the future dividends and the conditional variance of the quantity X_{t+1} respectively. It follows from (2.1) that:

$$E_{i,t}(W_{t+1}) = RW_{i,t} + E_{i,t}\,(X_{t+1} + y_{t+1} - RX_t)\, q_{i,t}, \tag{2.2}$$

$$V_{i,t}(W_{t+1}) = q_{i,t}^2 V_{i,t}(R_{t+1}). \tag{2.3}$$

Let's assume for agents of group i a constant absolute risk aversion utility function equal to $U_i(W) = -e^{-a_i W}$, where a_i represents the - strictly positive and constant - risk

[2]which is conditionally normally distributed

aversion coefficient equal for both groups of agents, we assume that $a_i = 1 \; \forall \; i \in [0, \infty]$. By maximizing the expected utility of wealth in trading period $t+1$

$$Max_{q_{i,t}}\Big[E_{i,t}(W_{i,t+1}) - \frac{a}{2}V_{i,t}(W_{i,t+1})\Big], \tag{2.4}$$

we obtain the optimal demand function for each group

$$q^*_{i,t} = \frac{E_{i,t}(R_{t+1})}{aV_{i,t}(R_{t+1})} = \frac{E_{i,t}(X_{t+1} + y_{t+1} - RX_t)}{aV_{i,t}(R_{t+1})}. \tag{2.5}$$

We assume that agents have common expectations on dividends ($E_{i,t}(y_{t+1}) = E_t(y_{t+1}) = \bar{y}$) but different expectations on future prices $E_{i,t}(X_{t+1}) = E_i(X^*_{t+1}) = F_i$ with $i = 1, 2$, where F_i is the belief about the fundamental value.

Therefore, to model the excess demand we rewrite the equation (2.5) adopting the formulation of Day and Huang (1990):

$$q_{i,t} = \delta(F_i - P_t), \tag{2.6}$$

where $P_t = RX_t - \bar{y}$ and $\delta = \frac{1}{a\sigma^2}$ is the positive coefficient of the reaction of investors, a measure of both risk aversion and reaction to mis-pricing of the fundamentalists which we assume, without loss of generality, being equal to 1.

2.2.1. Inventory

In Naimzada and Ricchiuti (2009), the market maker intervenes clearing the price but she does not manage both her own portfolio and the inventory. In this paper, we consider the two market maker functions - dealer and active investor - as completely segmented. Following Madhavan and Smidt (1993), the market maker - *active investor* - aims to maintain a long-term desired *target inventory position* I^d by demanding in each period the desired inventory plus a share of the previous value of inventory. Let I_t be the specialist's inventory position at time t, then the desired position (I^d_{t+1}) in each period is anything but a share κ of I_t plus the fixed long term target inventory position:

$$I^d_{t+1} = \kappa I_t + I^d, \quad with \quad \kappa \in [0, 1) \tag{2.7}$$

Eq. (2.7) represents the market maker demand function.

On the other hand, acting as *dealer*, the market maker provides a required amount of liquidity to the security's market. The market maker inventory at $t+1$ is the desired inventory position in the next trading period plus the total supply of the risky asset minus the investors aggregate optimal demand of the assets at time t:

$$I_{t+1} = I^d_{t+1} + (z_s - z^*_t). \tag{2.8}$$

Substituting (2.7) in (2.8), the equality becomes

$$I_{t+1} = \kappa I_t + I^d + (z_s - z_t^*) \tag{2.9}$$

with the traders aggregate demand z_t^* at time t being equal to

$$z_t^* = n_1 q_1 + n_2 q_2 + \epsilon_t, \quad with \quad n_1 + n_2 = 1, \tag{2.10}$$

where ϵ_t is the demand error term[3], and n_i is the fraction of agents that follow the expert i. Fractions can be fixed or they can vary according to an adaptive system such as Brock and Hommes (BH, henceforth)(1998). For the analytical results, as in Zhu et al. (2009), we will assume fixed fractions. This assumption will be relaxed in the simulations where we will employ the BH switching mechanism.

Given our assumptions, the market excess demand ED_t for the risky asset in trading period $t+1$ is as follows:

$$ED_t = z_t^* + I_{t+1}^d - z_s \tag{2.11}$$

where z_t represents the market demand, I_{t+1}^d the *market maker* demand and z_s the supply of the market maker to the outside investors. The other investors adjust their holdings to their optimal demand in trading period $t+1$ by submitting market orders at price P_{t+1}. The market maker adjusts the price so that the return is an increasing function of the market excess demand. If the excess demand ED_t is positive (negative), she increases (decreases) the price:

$$P_{t+1} = P_t + P_t \gamma ED_t = P_t + P_t \gamma [z_t^* + I_{t+1}^d - z_s] \tag{2.12}$$

where P_t is the asset price at time t and $\gamma > 0$ is the sensitivity of market maker to the excess demand. Finally, the relation that determines the dynamics of the model is obtained by substituting (2.7) and (2.10) into (2.12) and adding the market maker demand:

$$P_{t+1} = P_t + P_t \gamma [n_1 q_1 + n_2 q_2 + \kappa I_t + I^d - z_s] + \epsilon_t \tag{2.13}$$

where ϵ_t is a white noise term, i.i.d. normally distributed with mean 0 and variance σ_ϵ^2. The asset price and the inventory dynamics are determined by the following stochastic discrete non-linear dynamical system of equations:

$$\begin{cases} P_{t+1} = P_t[1 + \gamma[n_1(F_1 - P_t) + n_2(F_2 - P_t) + \kappa I_t + I^d - z_s]] + \epsilon_t \\ I_{t+1} = \kappa I_t + I^d + [z_s - [n_1(F_1 - P_t) + n_2(F_2 - P_t)]] + \epsilon_t \end{cases} \tag{2.14}$$

[3] i.i.d. random variable normally distributed with mean 0 and variance σ_μ^2

2.3. The Deterministic Model: Dynamic Analysis

Let us assume that the system is deterministic. We first calculate the steady states and afterwards we qualitatively work out some properties including the fixed points stability conditions.

2.3.1. Fixed Points

Proposition 1. *The map (2.14) has two steady states:*

$$(P_1^*, I_1^*) = \left(0, \frac{z_s + I^d - G}{1-\kappa}\right) \tag{2.15}$$

and

$$(P_2^*, I_2^*) = \left(G - z_s + \frac{I^d}{1-2\kappa}, \frac{2I^d}{1-2\kappa}\right) \tag{2.16}$$

with $G = n_1 F_1 + n_2 F_2$

Proof. The proof is in the Appendix 2A. □

2.3.2. Local Stability Analysis

The study of the local stability of the equilibria starts with the determination of the Jacobian matrix of the two-dimensional map. The Jacobian matrix of system (2.14) has the form:

$$J = \begin{bmatrix} 1 + \gamma(G - 2P_t + \kappa I_t + I^d - z_s) & \gamma\kappa P_t \\ 1 & \kappa \end{bmatrix} \tag{2.17}$$

Thus, using straightforward algebra the Jacobian matrix of the system (2.14) at the equilibrium point $E_1(P_1^*, I_1^*)$ is:

$$J(P_1^*, I_1^*) = \begin{bmatrix} 1 + \gamma\left(\frac{G+I^d-2\kappa I^d - z_s}{1-\kappa}\right) & 0 \\ 1 & \kappa \end{bmatrix} \tag{2.18}$$

and from the resulting matrix (2.18) we work out the following trace and determinant:

$$Tr(J^1) = 1 + \gamma\left(\frac{G + I^d - 2\kappa I^d - z_s}{1-\kappa}\right) + \kappa \tag{2.19}$$

$$Det(J^1) = \kappa + \gamma\frac{\kappa}{1-\kappa}\left(G + I^d - 2\kappa I^d - z_s\right) \tag{2.20}$$

Finally, by using Jury's conditions (2.21) (Jury, 1974) we have conditions for local stability:

$$\begin{cases} 1 - TrJ^* + DetJ^* > 0 \\ 1 + TrJ^* + DetJ^* > 0 \\ DetJ^* < 1 \end{cases} \tag{2.21}$$

By substituting trace (2.19) and determinant (2.20) in (2.21) and rearranging the system inequalities we obtain the following stability conditions (2.22):

$$\begin{cases} \gamma(G + I^d - 2G\kappa + (2\kappa - 1)z_s) < 0 \\ (\kappa^2 - 1)(2 * (\kappa - 1) - \gamma(G + I^d - 2G\kappa + (2\kappa - 1)z_s)) > 0 \\ (\kappa - 1)(1 + \kappa(\kappa - 2 - \gamma(G + I^d - 2G\kappa + (2\kappa - 1)z_s))) < 0 \end{cases} \tag{2.22}$$

Moreover, the Jacobian evaluated at the second fixed point (P_2^*, I_2^*) is given by:

$$J(P_2^*, I_2^*) = \begin{bmatrix} 1 + \gamma\left(z_s - G - \frac{I^d}{1-2\kappa}\right) & \left(G - z_s + \frac{I^d}{1-2\kappa}\right)\kappa\gamma \\ 1 & \kappa \end{bmatrix}, \tag{2.23}$$

trace and determinant are thus:

$$Tr(J^2) = 1 + \gamma\left(z_s - G - \frac{I^d}{1 - 2\kappa}\right) + \kappa \tag{2.24}$$

$$Det(J^2) = \kappa + 2\kappa\gamma\left(z_s - G - \frac{I^d}{1 - 2\kappa}\right). \tag{2.25}$$

The stability conditions for the second fixed point are reported in (2.26)

$$\begin{cases} \gamma(G + I^d - 2G\kappa + (2\kappa - 1)z_s) > 0 \\ (2\kappa - 1)(2 - 2\kappa - 4\kappa^2 + G\gamma(4\kappa^2 - 1) - \gamma(1 + 2\kappa)(I^d + (2\kappa - 1)z_s)) < 0 \\ \frac{\kappa(2\kappa - 1 + 2\gamma(G + I^d - 2G\kappa + (2\kappa - 1)z_s))}{2\kappa - 1} < 1 \end{cases} \tag{2.26}$$

We do not have a clear analytical outcome for the stability of the two steady states. Therefore we proceed in the following section through simulations.

2.4. Numerical analysis

The main purpose of this section is to show the complicated dynamic features of the model through simulations. We calibrate the model according to the characteristics highlighted in our framework and replicate the parameters reported by Zhu *et al.* (2009). Table 2.1 shows our initial parameter settings for the simulations. Moreover, we focus our analysis on the steady state with a positive price as shown in eq. (2.16).

We describe how the stability changes as both (i) the sensitivity of the market maker γ

Table 2.1: Parameter settings for the simulations

γ	z_s	κ	n_1	n_2	F_1	F_2	I^d
0.18	1	0.1	0.5	0.5	2	3	10

and (ii) the distance between the two beliefs F_1 and F_2 (i.e. the degree of heterogeneity) increase.

2.4.1. Fixed Fractions

Figures 2.1 and 2.2 show respectively the phase plots in price and inventory space and the bifurcation diagram for an increasing γ. The steady state of equation (2.16) is stable for small values of γ (i.e. $\gamma \leq 0.127$), while for increasing values of γ there is a cascade of period-doubling bifurcations that leads to chaos.

To better evaluate the difference between the two beliefs, it is worth highlighting the evolution of the system from the situation in which there is complete homogeneity ($F_1 = F_2 = F$) with a low γ (0.1) showing the effects of an increasing heterogeneity (an increasing F_2). In Fig. 2.3 we show the bifurcation diagram of P_t: an increase in the degree of heterogeneity generates instability. When beliefs are homogeneous $F_1 = F_2 = 2$ the system is stable. A flip bifurcation arises for $F_2 \approx 12$ and two stable steady states arise. From this points onwards, a cascade of period doubling bifurcations leads the system to chaos. Fig. 2.4 supports this evidence showing how the inventory fraction held by the market maker plays a key rule for the stability of the system. The parameter space shows that there is an inverse relationship between k and the degree of heterogeneity (an increasing F_2): a larger (smaller) distance between the two beliefs leads to instability for a smaller (larger) κ.

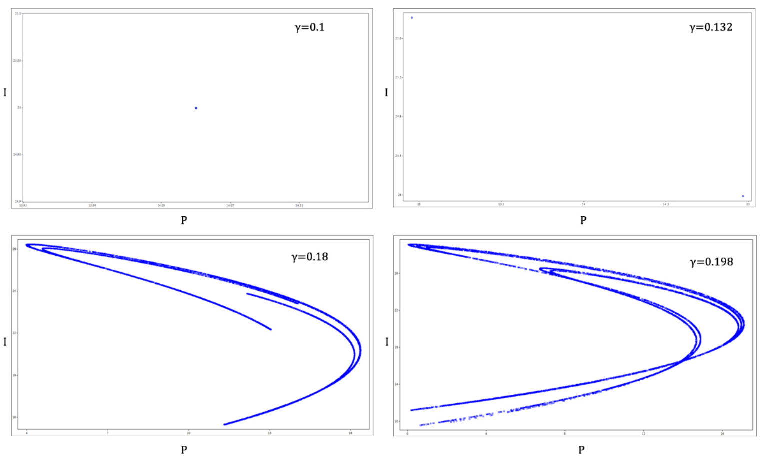

Figure 2.1: Phase plots of (P_t, I_t) for different values of γ

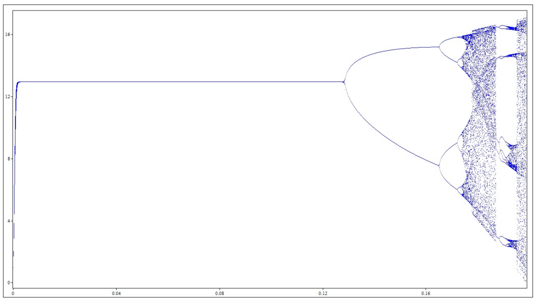

Figure 2.2: Bifurcation diagram of P_t with $0 < \gamma < 0.196$

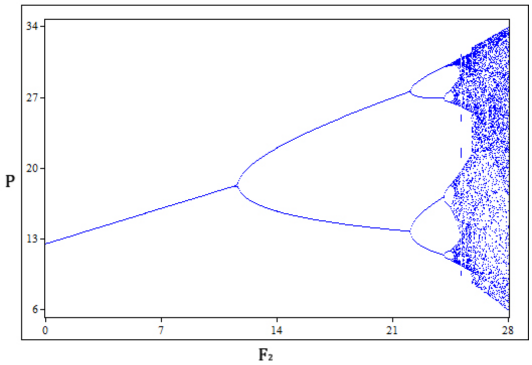

Figure 2.3: Bifurcation diagram of the degree of heterogeneity variation, for $\gamma = 0.1$

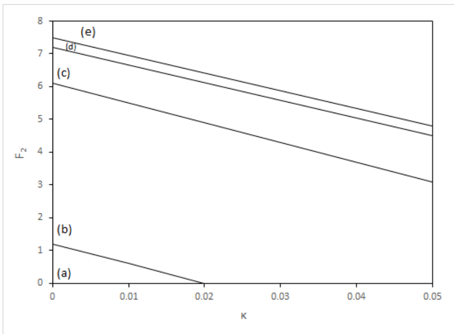

Figure 2.4: Qualitative parameter space of κ and F_2. Local stability region (a), Period-2 cycle (b), further period-doubling cycles (c), (d), (e)

We try to better understand both the activity of the market maker and the incidence of an increasing degree of heterogeneity on the system stability, by analysing time series plots obtained through the simulations (Fig. 2.5) and summarizing the main descriptive statistics (Tab. 2.2). In these graphs we add an i.i.d positive stochastic error. In fig 2.5, we consider the following combinations of parameters $(\gamma,\ \sigma_\epsilon) = (0.127,\ 0)$, $(0.127,\ 0.1)$, $(0.196,\ 0)$, $(0.196,\ 0.1)$ holding $F_1 = 2$ and $F_2 = 3$, plotting time series of the price when the system is stable/unstable both in the deterministic (σ_ϵ=0) and stochastic (σ_ϵ=0.1) case. In the top panel (2.5 (a)) there is a period 2-cycle, when the noise is added (2.5 (c)) the two fundamentalist beliefs about the price become more complex, generating larger and irregular fluctuations around the fundamental price. When the activity of the market maker becomes increasingly stronger (2.5 (b), 2.5 (d)), the market displays much more complicated dynamics characterized by irregular time series and showing a higher volatility.

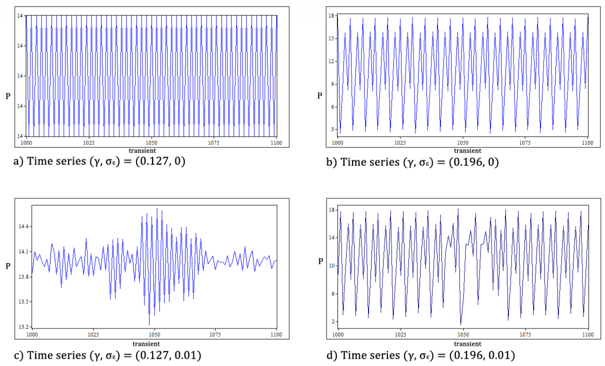

Figure 2.5: Time series of fundamental price for the specified parameters with noise:(a) and (b); (time series of fundamental price for the specified parameters and without noise: (c) and (d).

Increasingly complex dynamics are shown also in Fig. 2.6 where 100 consecutive values of the price are plotted for three different sets of values of $(F_1, F_2, \gamma, \sigma_\epsilon)$. In panel (a) F_1, F_2 are equal and time series quasi periodically fluctuate around the mean value of the price. The variability of the time series reflects the increase of the degree of heterogeneity, this is observable in panel 2.6 (c-d) and (e-f) for a much higher degree of heterogeneity. This is the most interesting scenario, because the dynamics shown in Figure 2.6 are perfectly comparable with those obtained by employing more sophisticated stochastic models. Our simple model is able to generate simulations of some of the most crucial issues happening in the financial markets, in particular the excess volatility. Table 2.2 summarizes some of the descriptive statistics related to the simulations run over $t = 10,000$ periods. As expected an increasing degree of heterogeneity leads to an increase in the mean and median of the time series as the two fundamental values act as focal points. Compared to the variance of $(F_1; F_2) = (2, 2), (2, 3)$ the variance of $(F_1; F_2) = (2, 8)$ is almost double, this clearly reflects strong excess volatility. Since the kurtosis is always lower than 3 (i.e. the theoretical value of a Normal distribution), the computed time series do not possess fat tails.

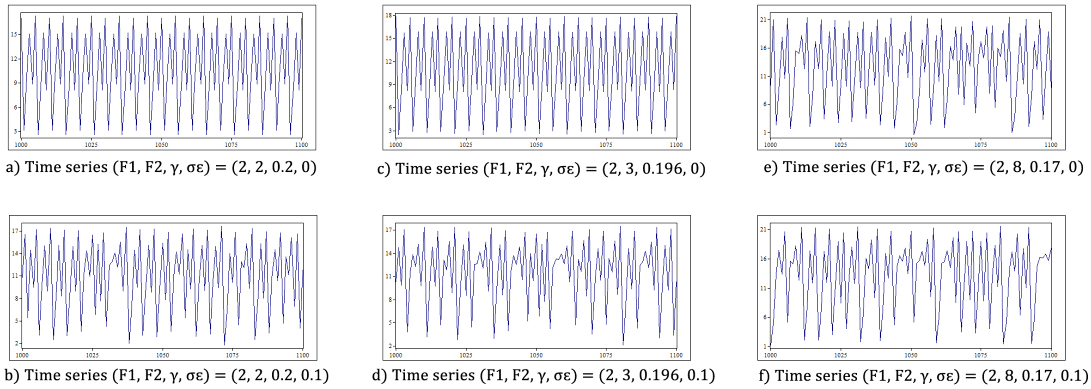

Figure 2.6: Price charts for different degrees of heterogeneity (F_1, F_2), γ values, and in presence (absence) of noise (σ_ϵ=0.1;0)

Table 2.2: Descriptive statistics of the simulated time series

		$(F_1; F_2)$		
		(2; 2)	(2; 3)	(2; 8)
Mean	$\sigma_\epsilon = 0.1$	10.91	10.97	12.79
	$\sigma_\epsilon = 0$	10.58	10.73	12.69
Median	$\sigma_\epsilon = 0.1$	10.38	10.11	13.49
	$\sigma_\epsilon = 0$	10.58	10.73	12.69
Variance	$\sigma_\epsilon = 0.1$	24.08	28.27	41.1
	$\sigma_\epsilon = 0$	26.07	29.56	41.59
Kurtosis	$\sigma_\epsilon = 0.1$	1.85	1.74	1.82
	$\sigma_\epsilon = 0$	1.73	1.63	1.78
Skewness	$\sigma_\epsilon = 0.1$	-0.29	-0.19	-0.31
	$\sigma_\epsilon = 0$	-0.13	-0.06	-0.26

As suggested by Westerhoff and Franke (2009), in order to determine the ability of the model to replicate empirical long memory effects, we include the correlograms plots for all the combination of prices, inventory and fundamental values introduced before. Figure 2B.1 and 2B.2 in Appendix 2B depict the autocorrelation functions of prices and inventories. In most of the plots it is revealed the presence of significant correlation. However, for higher degree of heterogeneity ($F_1 = 2$, $F_2 = 8$) the model successfully reproduces the stylized facts of uncorrelated prices and inventory.

2.4.2. Endogenous Fractions with BH

In this section we analyse "through" simulation a generalized version of the above model when fractions of agents are endogenous. We assume that agents can switch from guru to the other following an adaptive belief system *a la* Brock and Hommes (1997, 1998). Specifically, the fractions of agents n_i is:

$$n_{i,t+1} = \frac{exp[-\beta(F_1 - P_t)^2]}{exp[-\beta(F_1 - P_t)^2] + exp[-\beta(F_2 - P_t)^2]}. \tag{2.27}$$

where β is the so-called intensity of choice, a parameter which assesses how quickly agents *switch* between the two predictions. Substituting (2.27) in (2.13) we obtain the following general map:

$$\begin{cases} P_{t+1} = P_t[1 + \gamma[n_{1,t+1}(F_1 - P_t) + n_{2,t+1}(F_2 - P_t) + \kappa I_t + I^d - z_s]] + \mu_t \\ I_{t+1} = \kappa I_t + I^d + [z_s - [n_{1,t+1}(F_1 - P_t) + n_{2,t+1}(F_2 - P_t)]] + \mu_t \end{cases} \tag{2.28}$$

In Fig. 2.7 we replicate the parameter space of the Fig. 2.4 with a small $\beta = 0.1$. It is worth noting that differently from Fig. 2.4, for a very low κ stability occurs also when fractions are homogeneous. A further increase in the parameters value leads to instability. As we expect, if β increases, the set of parameters for which there is instability is less restrictive (Fig. 2.8). Table 2.3 could be comparable with table 2.2. However, from the statistical point of view the conclusions are the same: the greater the heterogeneity among the agents, the greater the mean / median / variance of the series.

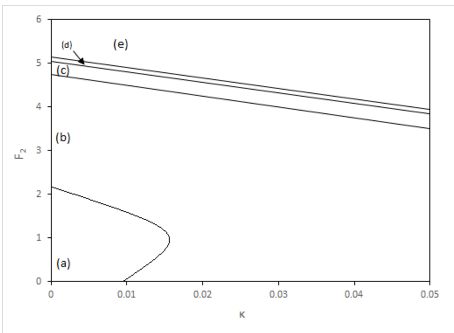

Figure 2.7: Qualitative parameter space for κ and F_2 with BH. Local stability region (a), Period-2 cycle (b), further period-doubling cycles (c), (d), (e)

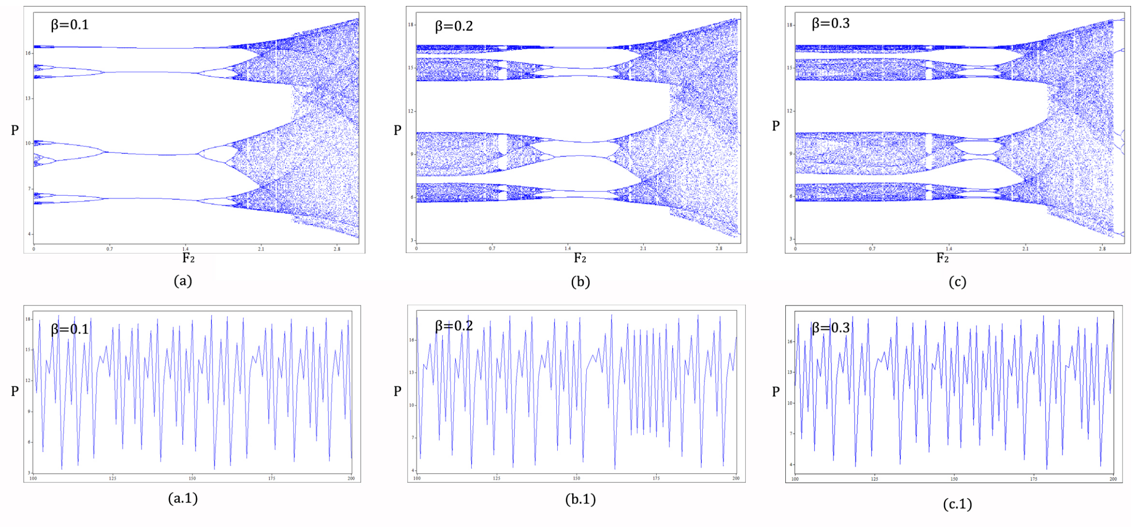

Figure 2.8: P_t Bifurcations plots of degrees of heterogeneity (ΔF) variation for $\beta = (0.1, 0.2, 0.3)$, with n_i endogenous. Time series charts are computed for $(F_1, F_2) = (2, 3)$

Table 2.3: Descriptive statistics of the simulated time series with n_i *a la Brock and Hommes* for different values of β and different agents beliefs

Descriptive Statistic	Noise	$(F_1; F_2)$								
		$\beta = 0.1$			$\beta = 0.2$			$\beta = 0.3$		
		(2;2)	(2;3)	(2;8)	(2;2)	(2;3)	(2;8)	(2;2)	(2;3)	(2;8)
Mean	$\sigma = 0.1$	11.64	11.85	15.7	10.32	11.51	15.65	10.18	11.26	15.48
	$\sigma = 0$	11.65	11.39	15.06	10.21	11.13	14.35	10.39	11.32	15.13
Median	$\sigma = 0.1$	12.36	11.72	16.47	8.04	11.02	16.43	8.75	11.7	16.24
	$\sigma = 0$	12.39	10.06	16.29	10.12	9.38	12.72	10.86	11.63	16.79
Variance	$\sigma = 0.1$	18.15	25.45	49.02	27.59	28.83	49.56	28.59	31.14	51.7
	$\sigma = 0$	18.04	28.77	50.03	29.06	31.29	60.18	27.8	30.61	55.86
Skewness	$\sigma = 0.1$	-0.53	-0.33	-0.24	-0.05	-0.23	-0.23	-0.04	-0.28	-0.24
	$\sigma = 0$	-0.53	-0.15	-0.21	-0.24	-0.07	0.06	-0.27	-0.27	-0.32
Kurtosis	$\sigma = 0.1$	2.16	1.9	1.69	1.62	1.77	1.65	1.62	1.8	1.66
	$\sigma = 0$	2.15	1.75	1.65	1.77	1.65	1.55	1.79	1.79	1.77

2.5. Conclusions

This paper contributes to the development of financial market modelling and asset price dynamics with heterogeneous agents. We develop a model of asset price and inventory in a scenario where a market maker sets the price to clear the market. In doing so, the market maker considers the excess demand of two groups of agents that employ the same trading rule (i.e. two fundamentalists) but with different beliefs about the fundamental prices. Moreover, the market maker has a double role: she provides liquidity and acts as an active investor. When κ is null, the model is equal to Naimzada and Ricchiuti (2014). In contrast with the canonical literature and similarly to Naimzada and Ricchiuti (2008, 2009, 2014) we show that interactions between agents with homogeous trading rules can lead to market instability. The active role of the market maker can be one of the causes of instability in the financial markets: a higher inventory share leads to instability. Finally, buffeted with dynamic noise, this model may also replicate some important stylized facts of financial markets such as excess volatility and volatility clustering.

Further improvements to our behavioural financial model may consist in analysing a case when more actors with a long memory are introduced in the model. This can be pursued by introducing in the model a trend follower. In such a case it will be possible to analyse the interactions between many views within the economic system and their survival in an evolutionary environment based on historical data. In order to control for market distortions and price volatility at the same time it would be interesting to introduce price limiters as attempted by Westerhoff (2003b). Moreover, the model can be improved by comparing this model with others where the market mechanism is different (Walrasian auctioneer for example) as in Anufriev and Panchenko (2009) and observing how the simulated time series behaviour varies across the different specifications.

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Appendix

Appendix 2A

In this appendix, we explain for easy reference the mathematical procedures used in our analysis, in particular we develop a step by step procedure for the fixed points computation.

Step 1) The system of prices and inventory is:

$$\begin{cases} P_{t+1} = P_t[1 + \gamma[n_1(F_1 - P_t) + n_2(F_2 - P_t) + \kappa I_t + I^d - z_s]] + \mu_t \\ I_{t+1} = \kappa I_t + I^d + [z_s - [n_1(F_1 - P_t) + n_2(F_2 - P_t)]] + \mu_t \end{cases} \tag{2.29}$$

Step 2) Setting P^* and I^* as follows:

$P_t = P_{t+1} = P^*$
$I_t = I_{t+1} = I^*$

with $G = n_1F_1 + n_2F_2$

we obtain the following system of equations:

$$\begin{cases} P^* = P^* + P^*\gamma[n_1(F_1 - P_t) + n_2(F_2 - P_t) + \kappa I_t + I^d - z_s]] + \mu_t \\ I^* = \frac{z_s - (n_1F_1 - n_1P_t + n_2F_2 - n_2P_t) + I^d}{1-\kappa} \end{cases} \tag{2.30}$$

Step 3) **fixed points** are obtained by setting $P^* = 0$ and $G = n_1F_1 + n_2F_2$

$$\begin{cases} P_1^* = 0 \\ I_1^* = \frac{z_s + I^d - G}{1-\kappa} \end{cases} \tag{2.31}$$

Step 4) the second solution of the system is computed by solving the system for P^* and I^*.

$$\begin{cases} G - P^* + \kappa I^* + I^d - z_s = 0 \\ I^* = \frac{1}{1-\kappa}\left[I^d + z_s - G + P^*\right] \end{cases} \tag{2.32}$$

Step 5) We substitute I^* in the first equation:

$$\begin{cases} P^* = G + \frac{\kappa}{1-\kappa}\left[I^d + z_s - G + P^*\right] + I^d - z_s \\ I^* = \frac{1}{1-\kappa}\left[I^d + z_s - G + P^*\right] \end{cases} \tag{2.33}$$

Step 6) With further rearrangements we obtain:

$$\begin{cases} \frac{(1-2\kappa)G-(1-2\kappa)z_s+I^d}{1-\kappa} = \left(\frac{1-2\kappa}{2-\kappa}\right) P^* \\ I^*\left(1 - \frac{\kappa}{1-\kappa}\right) = \left(\frac{1}{1-\kappa}\right) 2I^d \end{cases} \tag{2.34}$$

Step 7) which leads to the second set of fixed points:

$$\begin{cases} P_2^* = G - z_s + \frac{I^d}{1-2\kappa} \\ I_2^* = \frac{2I^d}{1-2\kappa} \end{cases} \tag{2.35}$$

Appendix 2B

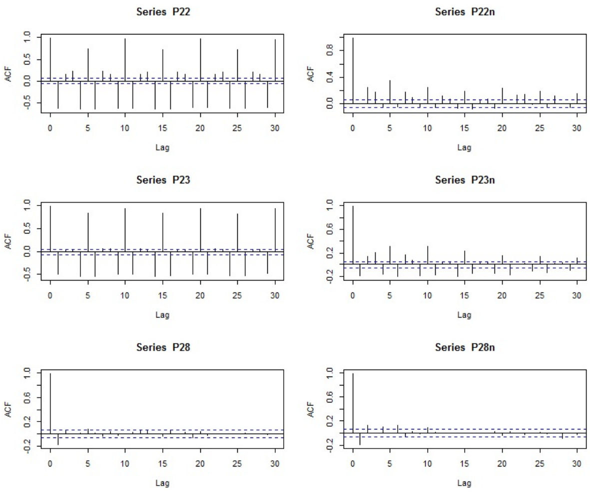

Figure 2B.1: ACF of P_t values, for different (F_1, F_2) combinations and in presence (absence) of noise

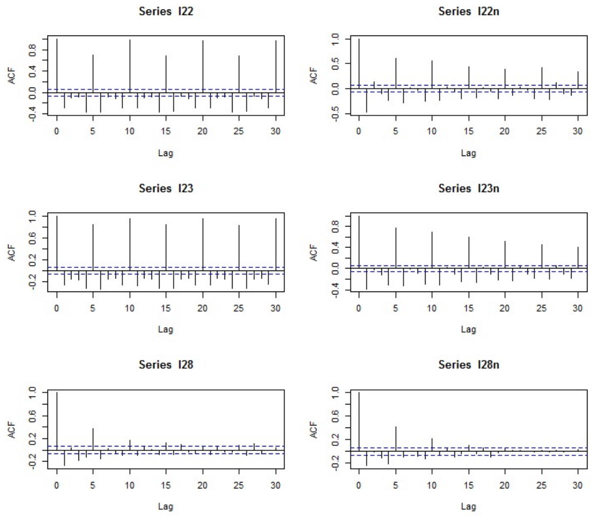

Figure 2B.2: ACF of I_t values, for different (F_1, F_2) combinations and in presence (absence) of noise

CHAPTER 3

Modelling Acreage, Production and Yield Supply Response to Domestic Price Volatility

3.1. Introduction

The food price spikes of 2007-2008 have marked the beginning of a strong international and domestic commodity price dynamics. In 2008, many commodities prices increased by more than 50%[1]. Two further price spikes occurred, in late 2010/early 2011 and mid 2012 leading to unprecedented price movements in the recent history. These shocking boom and bust cycles stimulated an increasing concern by policy makers towards causes and consequences of their formation, especially in terms of national and global food security. Indeed, people with limited coping mechanisms that spend a large share of their income in staple foods were greatly affected by the inflation generated by the international market to domestic market price pass-through (Banerjee and Duflo, 2007; Dorosh *et al.*, 2009).

Predictably, the soaring food prices, their nature and their implications led many researchers to pay increasing attention at their recent dynamics. Authors such as Abbot *et al.* (2009), Piesse and Thirtle (2009), Timmer (2010), Headey and Fan (2010), Gilbert and Morgan (2010), Abbott and De Battisti (2011), gave an important contribution to this literature. In particular, Trostle (2010) highlighted that price fluctuations were driven by many drivers. In this regard authors such as Gilbert and Morgan (2010), Abbott and De Battisti (2011) and OECD-FAO (2011) provided a consolidated discussion of a set of elements that have driven food prices dynamics, identifying among others supply and demand factors, weather climate change, market speculation and stock management, trade restrictions, exchange rates and energy prices (Von Braun and Tadesse, 2012). The relative importance and the impact of these causes have been broadly assessed in the literature[2].

Some of the most questioned drivers affecting food price surges are represented by supply side factors. Many articles and policy briefs referred to climatic factors, high fuel prices and increased land demand for biofuel as responsible of declining production and stocks which in turn are the more immediate causes of the supply-demand imbalance. The

[1] The international prices of maize and wheat roughly doubled, while rice prices became three times higher in few months (Headey and Fan, 2010).

[2] See for instance Headey and Fan (2010) and Headey (2011) for a comprehensive review.

FAO report "*Price Volatility in Food and Agricultural Markets: Policy Responses*" (FAO-IMF-UNCTAD, 2011) highlights climatic factors as one of the main drivers contributing to 2007/2008, 2010 and 2011 soaring food prices and supply shocks. Extreme events like the 2008 drought occurred in Australia - which is one of the main world suppliers of wheat - in Canada and in the Black Sea region induced massive shortages in world wheat supply[3]. Again, between 2010 and 2011, several events such as Australian and Russian federation droughts as well as downward revisions of crops forecasts by US government, caused strong market reactions followed by price bursts. In 2011/2012 an unusually strong *La Niña* created problems in many markets while in 2013 severe weather disruptions worsened staple crops yields in several countries[4]. Price increased also as a result of the increased land competition due to biofuel production subsidies.

However, according to a recent FAO Outlook (OECD-FAO, 2013), food commodity markets are becoming increasingly balanced and less affected by price volatility with respect to recent years thanks to improved supplies and a recovery in global inventories of cereals. Indeed, the prices of most basic crops have decreased in the second half of 2013. This has been due to higher supply capacity, in particular to production increases[5], higher stocks[6] and more export availabilities. OECD-FAO (2013) forecast that the expansion of agricultural production is likely to slow down in the next few years with slower area and productivity growth. This along with increasing demand will likely reduce the speed of stocks renewal making commodity markets more vulnerable to high price fluctuations.

Furthermore, as Schiff and Montenegro (1997) stressed out, it is crucial to consider also the importance of non-price factors or constraints to supply response. Non-price factors, such as environmental conditions or limited access to credit, are among the most binding constraints for agricultural development (Thiele, 2000) and must be considered in any serious policy mix trying to stabilise prices and manage volatility. Therefore, analysing how supply response reacts to expected prices and their volatility is a key research question, as they seriously threat on the food security of millions of individuals and constitute a fundamental issue for policy formulation.

[3]Production shortages created several problems on international markets, as Argentina, Kazakhstan, Russia and Ukraine restricted their exports during the 2007/2008 food crisis. Russia justified its trade measures with the aim to secure sufficient wheat supplies to the domestic market. Ukraine behaved in the same way: wheat export quotas were introduced both in 2007/2008 and 2010/2011 and exports decreased by 77% between 2006 and 2007. As a result, trade restrictions temporarily reduced the degree of integration of both domestic in world wheat markets (Gotz *et al.*, 2013), and most of their clients started to import from other countries. In particular, Ukrainian trade policies affected Russia and Kazakhstan, whose exports became more attractive. To control for stock-to-use depletion Kazakhstan banned wheat exports and Russia raised export taxes.

[4]As reported by Heffernan (2013), severe droughts occurred in USA, Argentina and Brazil with maize yields losses of about 40%, in the Black Sea region with ten millions of hectares of grains being damaged and finally Sub-Saharan Africa, the Horn of Africa and China experienced a huge loss of maize, soybeans, wheat and livestock outputs.

[5]Which for cereals stems from record wheat harvests in CIS and a recovery of maize production in USA.

[6]World cereal stocks expansion will reach the global cereal stocks-to-use ratio of 23 percent by the end of 2014, a value which is well above the historical "floor" of 18.4 percent registered in 2007/08.

While a growing number of studies have examined the impact of prices on agricultural supply response at household and national level (see section 3.2.2), very limited empirical research has been undertaken to assess the impact of price volatility on production, yield and acreage at global level. To the best of our knowledge only Subervie (2008), Haile and Kalkuhl (2013), Haile *et al.* (2014) have tried to address this question in a global perspective framework. Since collecting data on prices in developing countries is difficult, these authors employed international prices as a proxy for domestic prices. However, we believe that this prevents to capture political, social and environmental determinants which contributed to price surging as well as to farmers production decisions in local communities.

Therefore, this paper explores how *domestic* food commodity prices and their volatility influenced supply response of wheat, rice and maize over the last decade. We employ a panel econometric estimation based on a standard version of the Nerlove model (see Nerlove, 1971; Askary and Cummings, 1977) to test (i) how price risk, expressed as domestic price volatility, affects supply response in terms of yield, acreage and production of major food commodities; (ii) whether domestic expected prices and non-price factors, in particular financial deepening and yield shocks, play a role in explaining the agricultural supply response.

The rest of the paper is organized as follows. Section 3.2 presents an overview of the Nerlovian models literature as well as the most recent applications of agricultural supply response models, section 3.3 introduces the empirical model discussing the Difference Generalize Method of Moments (DIFF-GMM) and System Generalized Methods of Moments (SYS-GMM) estimators in conjunction with the problem of endogenous regressors and weak instruments. This section also provides a description of the variables employed in the analyses and source of data. Empirical results are discussed in section 3.4. Section 3.5 summarizes the most important findings and discusses policy implications.

3.2. Literature Review

3.2.1. Models of Agricultural Supply Response

Agricultural supply response has been a fundamental issue in the past and still continues to attract much attention due to the recent food crisis and uncertainty in future food supply. Agricultural economics has a long tradition in estimating Agricultural Supply Response (ASR) models. This literature has gone through many important empirical and theoretical frameworks (see Rao (1989) for a survey).

There are basically two frameworks developed in the literature to conduct supply response analysis, both developed in the 50s. The first is the supply function approach developed by Griliches (1959) for the aggregate supply response. The second is the Nerlovian partial adjustment model which was developed by Nerlove (1956) to assess the supply response of single commodities.

Griliches (1959) developed a model to estimate the aggregate supply elasticity of farm products and it is based on the aggregation of the demand elasticities estimates for all the inputs and estimates of their distributive shares. This approach is less frequently applied since it requires both detailed input prices - which are difficult to get - at which the inputs are supplied to the farmers and simultaneous estimations of input demand and output supply functions.

According to McKay *et al.* (1999), Nerlovian models (Nerlove 1958, 1971) allow to explain dynamic optimization behaviour of farmers, their decisions and their reactions to moving targets. The Nerlove partial adjustment model is based on a one-stage procedure and models the dynamics of agricultural supply by incorporating price expectations and/or adjustment costs, giving at the same time the flexibility to introduce non-price shifters in the model. For instance, the desired quantity to be produced for a given agricultural commodity (Q_t^d)[7] in period t is a function of the expected output prices P_t^e (i.e. the price, at planting time, the farmer expect to get after the harvest), and a vector of other exogenous regressors Z_t.

$$lnQ_t^d = b_0 + b_1 lnP_t^e + b_2 lnZ_t + \epsilon_t \tag{3.1}$$

with b representing the parameters to be estimated and ϵ_t the error capturing unobserved random factors affecting the quantity produced. The major issue in equation (3.1) is that the desired quantity is related to P_t^e and, since the effective price may not be equal to the expected price the desired output adjustment is only partial:

$$lnQ_t - lnQ_{t-1} = \lambda(lnQ_t^d - lnQ_{t-1}) + \mu_t \tag{3.2}$$

where λ is the partial adjustment coefficient and Q_t is the actual output. When λ is close to one the adjustment is almost immediate, whilst a low λ implies a very slow adjustment to variation in exogenous variables (Griliches, 1959). The actual change in output is a fraction of the change required to achieve the optimal output level Q_t^d.

Moreover, quantities are assumed to be driven by price expectations which in Nerlove's model are assumed to be adaptive. It is assumed that farmers adjust their expectations as a fraction γ of the difference between realized and expected price:

$$lnP_t^e - lnP_{t-1}^e = \gamma(lnP_{t-1} - lnP_{t-1}^e) \tag{3.3}$$

that after some manipulation leads to:

$$P_t^e = \gamma lnP_{t-1} + (1-\gamma) lnP_{t-1}^e + \epsilon_t \tag{3.4}$$

Substituting (3.1) in (3.2) and (3.4) in the resulting relation yields

$$lnQ_t = \pi_0 + \pi_1 lnP_{t-1} + \pi_2 lnQ_{t-1} + \pi_3 Z_t + \mu_t \tag{3.5}$$

[7] Agricultural supply response models can be expressed in terms of yield, area, or output response.

with $\pi_1 = \lambda\gamma b_1$ and b_1 representing respectively the short-run and long-run price elasticities of Q_t with respect to P_t.

Over the time, several additional drivers have also been included. These variables consist of output price relative to a variable input price index (Lee and Helmberger, 1985; Tweeten and Quance, 1969), expected net returns per acre (Davison and Crowder, 1991) and acreage value (Bridges and Tenkorang, 2009). Although many variants of the Nerlove formulation have been proposed for the ASR estimation, this model (as well as Griliches model) has always shown some limits on both empirical and theoretical grounds. Firstly, problems associated with the econometric estimation (i.e. the OLS may produce spurious results as series are often $I(1)$, cf. Binswanger, 1989) and secondly the absence of a glaring difference between short-run and long-run elasticities when both adaptive expectations and partial adjustment are present (Schiff and Montenegro, 1997; McKay *et al.*, 1999; Thiele, 2000). Based on the results obtained by authors such as Reca (1980), Bapna (1981), Chhibber (1982) and Bond (1983), which reported downward biased estimates of the short-run and long-run elasticities (approximately around 0.2 and 0.4), Thiele (2003) stated that the "Nerlove method specifies the dynamics of supply in a very restrictive way"(p. 6).

The 60s witnessed an increasing interest towards developing countries. For this reason, several modifications have been introduced to the Nerlovian model to take into consideration self-consumption of food crops. For example, income elasticity of consumption within the households replaced the output in the model (Khrisna, 1962; Behrman, 1966). Later Askari and Cummings (1977) made a comprehensive literature review on supply response to understand the factors lying behind the large differences in supply response elasticities. They found that variables like farm size, access to irrigation, yield risk, literacy level (i.e. non-price variables) had a positive impact on the magnitude of the direct supply price elasticity. Finally, in the last decades the application of dynamic econometric approaches such as cointegration, Error Correction Models (ECM) and the panel data econometrics in the shape of fixed, random effects models and Generalised Method of Moments (GMM) largely contributed to a better estimation of the short run and long run dynamics (Nerlove, 1971; Arellano and Bond, 1991). Cointegration analysis serves to avoid spurious regression when handling non-stationary series, in particular, if combined with ECM it offers reliable long run and short run elasticity estimates. Panel data econometrics has a distinct advantage of providing country and temporal variations for dynamic models. This approach is the most suitable for our analysis and will be discussed in detail in section 3.3.

3.2.2. Country and cross-country level contributions on supply response

This article builds on a broad literature on crops supply response (output, yield or acreage) to prices. A number of earlier studies apply the Nerlovian models to study the crop supply response (Askari and Cummings, 1977; Rao, 1989) whilst others consider both producer and consumer economic behaviors in a more theoretically consistent framework (Lee and

Helmberger, 1985; Chavas and Holt, 1990; Lin and Dismukes, 2007).

In this section we will provide a brief summary of the most recent works on the supply response at country and cross-country/cross-region levels. There is a vast literature on food grain responses to prices. Farooq *et al.* (2001) using a translog profit function approach, finds that basmati paddy rice supply response to own price was inelastic (0.27), and other factors such as the area under paddy and age of basmati varieties are particularly relevant to explain it. Danielson (2002) studied the responsiveness of crop output to farm gate prices in Tanzania, analyzing whether economic reforms have had the expected impact on crop output by controlling for some supply determinants, finding that the structural adjustment of Tanzanian agricultural sector was quite weak in improving the individual crops supply response.

However in the last two decades, most of the existing studies were likely to use either Cointegration/Error Correction Models' approach (when addressing country level supply response) or Generalized Method of Moments models (when dealing with cross-country analyses). Mushtaq *et al.* (2002) with an impulse response and cointegration analysis found that wheat and rice acreage response to prices was not significant, while in the long run, for other crops the results were in line with the downward biased estimates found in the literature.

Direct and indirect pricing policies, macroeconomic distortions and non-price factors can have - in the long run - an impact on agricultural production. In this regard, Thiele (2003) applied a cointegration analysis on time series data from 1965 to 1999 for a set of Sub-Saharan African countries finding that supply elasticities are less than 1 and suggesting new macroeconomic and agricultural reforms. Supply response to price incentives is also a broadly assessed topic. The Vector Error Correction Model (VECM) was used by Olubode-Awosola (2006) to show that agriculture (at aggregate level) is less responsive to price incentives and that, interestingly, capital and credit have an insignificant effect on supply shifts. By contrast, Mose's *et al.* (2007) analysis on maize production in Kenya finds a strong response of farmers to price incentive elasticities: lower than -1 for fertilizers prices and 0.53 and 0.76 for short and long run supply response to maize.

The paper of Vitale *et al.* (2009) represents an example of supply response studies conducted at micro-level. Within a Nerlovian partial equilibrium framework they estimated unconventional determinants for supply response, namely the household subsistence requirements, their fixed endowment of resources and crop rotation. The model, fitted to the choices of a sample of 82 Malian farmers between 2004 and 2007, shows acreage responses lower than those found by the other studies. By focusing on a sample of 10 Asian countries, Imai *et al.* (2011) find that there is a significant yield response to higher farm-gate or wholesale prices, as well as a significant effect of oil prices (-) and other *non-price* factors such as trasportation costs (-) on yield. The most common non-price factors used in supply response empirical analysis include irrigation, investment in research and development (R&D), extension services, access to capital and credit, agro-climatic conditions and rural infrastructure (Yu and Fan, 2011).

Agbola and Evans (2012) employed a Fully Modified Ordinary Least Squares (FMOLS) to analyse the supply response of rice and cotton under water trading in the Murray Darling Basin in Australia. They found inelastic responsiveness to price of water both in the long and the short run, implying that water price impact on the two commodities was basically too low to trigger any significant shift in the production towards a water intensive colture. Gosalamang *et al.* (2012) assess the reaction of beef producers to price incentives for Botwsana between 1993-2005 and found that prices are effective in obtaining the desired output level for beef (1.511 and 1.057 the short and long run elasticities). Panel analysis have been employed for cross-country comparisons but also for cross-region analyses, as for example Ogundari and Nanseki (2013) did for Nigeria. They employed FMOLS, dynamic panel ordinary least squares (DOLS) and one-step Blundell-Bond GMM models to study Nigerian regional acreage and yield supply responses. In a recent study, Boansi (2014) underlines that increasing yield levels and ensuring stability requires an interplay of different forces that range from biophysical factors to socio-economical and structural drivers.

To the best of our knowledge, only few works have been published on supply response to prices at global level (Subervie, 2008; Haile and Kalkuhl, 2013, Haile *et al.*, 2014) and quite surprisingly none of them make use of domestic prices. Moreover, when agricultural supply response analysis to price instability was performed for a specific set of crops (maize, rice, soybean and wheat) in terms of acreage, yield or production level (as in Haile and Kalkuhl, 2013; and Haile *et al.*, 2014), usually the conditions under which price behaves are not specified. Vice-versa, when macroeconomic variables (financial deepening, infrastructure) are included in the model (Subervie, 2008), the analysis of supply response to price instability is performed only on the country production index. Our goal is to fill this gap in the literature, estimating the wheat, maize and rice supply response to price instability using a panel model that includes also non-price variables.

3.3. Empirical framework

3.3.1. The model

Preliminary data investigation, data availability, and the meaningfulness of some variables largely determined our selection of variables. Assuming that there are i countries and j commodities analysed in period t, we substitute our set of variables in the model given in equation (3.5) and estimate the impact of domestic price instability on acreage, yield and production, reported respectively in equation (3.6), (3.7) and (3.8). The general forms of agricultural supply response functions can be written as follows:

$$lnYld_{ij,t} = \gamma_i lnY_{ij,t-1} + \delta_i VOL_{ij,t} + \beta_1 lnE(P_{ij,t-p}) + \mathbf{Z}'_{A,t} + \eta_i + u_{ij,t} \qquad (3.6)$$

$$lnArea_{ij,t} = \gamma_i lnArea_{ij,t-1} + \delta_i VOL_{ij,t} + \beta_1 lnE(P_{ij,t-p}) + \beta_2 \omega_{ij,t-1} + \mathbf{Z}'_{B,t} + \eta_i + u_{ij,t} \quad (3.7)$$

$$lnProd_{ij,t} = \gamma_i lnProd_{ij,t-1} + \delta_i VOL_{ij,t} + \beta_1 lnE(P_{ij,t-p}) + \beta_2 \omega_{ij,t-1} + \mathbf{Z}'_{C,t} + \eta_i + u_{ij,t} \quad (3.8)$$

with $\mathbf{Z}'_{A,t}$=$\mathbf{Z}'_{B,t}$=$\mathbf{Z}'_{C,t}$= $\beta_3 FTC_{i,t} + \beta_4 FTP_t + \beta_5 FiDe_{i,t}$,

where $Yld_{ij,t}$, $Area_{ij,t}$ and $Prod_{ij,t}$ reflect respectively the country i's - commodity j's yield (Kg/Ha), area harvested (Ha) (which is used as proxy of planted area), and production (tonnes) in period t to the j-th crop. The log-lagged acreage variable $Area_{ij,t-1}$, the log-lagged yields and production are part of the relevant information set that the farmer considers in his planting decisions; $VOL_{ij,t}$ represents the price risk variable, which is computed using the annual volatility of own monthly prices (see Appendix 3B for details on this choice); $lnE(P_{ij,t-p})$ is the expected price registered in the month before planting; $\omega_{ij,t-1}$ is the lagged country-crop yield shock occurred in the previous year, which we assume being connected to weather instability; fertilizers consumption $FTC_{i,t}$, and nominal international fertilizers prices $FTP_{j,t}$, are used as proxies for inputs; the financial deepening variable ($FiDe_{i,t}$) is proxied with the domestic credit to private sector by banks as percentage of GDP; η_i represents the country-specific unobserved fixed effects and $u_{i,j,t}$ is the error term. Further, we fine tune the basic model with two further specifications. First, we add an interaction term between the price volatility and the financial deepening in order to investigate whether producers risk management capacity with respect to domestic price volatility may be buffered through the improvement of the financial system; second, we add among controls the relative importance of agriculture in the country's economy ($AGDP_t$) since we are expecting that supply response will differ across countries with a higher share of gross domestic product coming from agriculture: the higher the agricultural share of GDP, the higher the output in terms of production and area but the lower the crop yields. As it is usual in developing countries, higher shares of agriculture over GDP are associated with low yields. This is due to several factors that make the agricultural productive structure less efficient (i.e. lower mechanization, low input adoption, higher incidence of extreme weather events). It is worth noting that since the data on domestic prices were not available for all three commodities in each country, adding the expected prices of the substitute/complementary commodity to the model would have led to a large reduction of the number of observations. For this reason we do not control for the cross-price effect on yield, area and production.

3.3.2. Data and the Econometric Method

The empirical model in this study utilizes country level yearly data to estimate supply responses for three agricultural commodities (wheat, maize and rice) for 66 countries, 25 of which belonging to Africa, 14 to Asia, 11 to Eastern Europe, 16 for Latin and Central America. The countries for which data are available are reported in Appendix 3A. Farmers acreage, production and yield are estimated by pooling time series with cross section data (individual countries). All data were transformed to natural logarithms prior to undertaking the analysis. The period studied spanned from 2005 to 2012[8]. The data employed for the dependent variable (acreage, yield and production at country-commodity level) is obtained from FAOSTAT - the FAO's online agricultural database (FAO, 2014). Monthly domestic price data at country-commodity level for wheat, maize and rice from WFP-VAM, FAO GIEWS and FEWS.NET complement the dataset. Since data on domestic prices at production level are poor, we used wholesale and retail prices as proxies for prices at production level by assuming that prices at wholesale/retail level reflect prices at farm-gate. Following Boansi (2014) we include nitrogen fertilizers consumption (expressed as tons of nutrients) as a proxy for inputs for all the countries in our sample. Phosphate fertilizers consumption is employed for Ethiopia. Cabo Verde, Chad, Central African Republic data on fertilizers are not available. Data on fertilizers consumption was obtained from the Fertilizers Archive Domain of FAOSTAT. International prices of fertilizers were obtained from the World Bank Commodities Price Data (The Pink Sheet). We use as a proxy of financial deepening the "Domestic credit to private sector by banks as percentage of GDP", which is drawn from the World Development Indicators provided by the World Bank.

By taking advantage of domestic monthly data, we decided to consider the seasonality of the different country-crops by picking for each country the prices registered in the month(s) before planting. Indeed pre-planting months contain a good approximation of the information that farmers have when they make their crop investment decisions. For countries harvesting twice per year, we approximate price expectations with the average of prices collected in each pre-planting month. Moreover, similarly to Haile *et al.* (2014) in order to trace the annual planting season we construct a monthly crop calendar using the information on agricultural seasonality for main staple food crops provided by GIEWS Country Briefs (see Appendix 3A)[9].

As mentioned above, this work captures price risk with a measure of domestic price volatility. Following Balcombe (2011) we use the standard deviation of changes in the logarithm of prices (SDLOG). This approach is widely used in agricultural economics as this is a unit free measure[10]. Similarly to Haile *et al.* (2014), yield shocks are captured following the procedure developed by Roberts and Schlenker (2009), which consists in "taking jackknifed residuals from fitting separate yield trends for each crop in each country[11]" (p. 1237).

To estimate the short run dynamic supply responses we employ a panel data regression technique, which is a relevant method of longitudinal data analysis because it allows for a

[8]See Appendix 3A for further information about time length and source of each variable.

[9]cf. http://www.fao.org/giews/countrybrief/.

[10]See Appendix 3B for a brief review of the most common approaches used in literature for volatility calculation.

[11]As noted by Roberts and Schlenker, "OLS residuals give biased estimates of the errors while jackknifed residuals, derived by excluding the current observation when determining the current residual, give unbiased estimates of the error" (p. 1237).

number of regression analyses in both units and time dimensions. It also gives room for data analysis especially when the data come from various sources and the time series are quite short for separate time series analysis (Baum, 2006).

In our context, employing the classic OLS estimators is likely to give a biased result as they do not take into account for possible correlation between the lagged term of dependent variable y_{it-1} and the country fixed effects error component (Baltagi, 2008). In particular OLS overstates the value of the coefficient of the lagged dependent attributing to it the power that belongs to fixed effects. This effect would be particularly emphasized in contexts like ours, with a panel characterized by "small T, and large n".

A suitable solution to this issue could be represented by purging the panel from the fixed effects via the Within Groups estimator (WG). However, as stated by Nickell (1981) and Bond (2002) employing the WG does not resolve this problem, as the dependent variable keeps moving together with the random component[12]. Thus, the use of OLS and WG estimators gives rise to an endogeneity problem, commonly found in the literature under the name of "dynamic panel bias". This leads to coefficients which are biased in opposite directions. Many studies have discussed and proposed a solution to this problem. Kiviet (1995) and Bruno (2005) proposed respectively to estimate balanced and unbalanced panels with Least Square Dummy Variable (LSDV) and then correct for the bias. These two approaches have been criticized as performing badly when endogenous regressors are present in the sample[13].

In cases where T is small and the LSDV estimator is biased and inconsistent, a number of estimators have been proposed. Anderson and Hsiao (1982) suggested to first-differencing the equation, thus eliminating the individual effect μ and using either $\Delta y_{i,t-2}$ or $y_{i,t-2}$ as instruments for $\Delta y_{i,t-1}$.

Despite the consistency of the estimates, the model lacked the use of all the moment conditions. Thus Holtz-Eakin *et al.* (1988) and Arellano and Bond (1991) developed the so called difference Generalized Method of Moments (GMM-diff) estimator, which treated the model as a system of equations, one for each period, making use of a set of additional instruments/moment condition sets. The predetermined and endogenous variables in first differences are basically instrumented with suitable lags, while strictly exogenous regressors enter the matrix of instruments as first differences. Moreover, the GMM estimator does not require any particular distribution of the error term, therefore even in presence of heteroskedasticity it produces consistent estimates of the unknown parameters.

Even if fixed effects are expunged and the endogeneity problem is solved by differencing the data, this approach is however believed to suffer of a weakness of internal instruments

[12]For larger T the dynamic panel bias becomes insignificant and the panel FE returns a better specification of the model.

[13]Other works worth mentioning are the ones of Bun and Carree (2005) and Bun and Carree (2006) which derive the correction of the FE estimator for finite T and large N, in the presence of both time-series and cross-section heteroskedasticity and Everaert and Pozzi (2007) that present another bias correction for the FE estimator based on an iterative bootstrap procedure.

(Blundell and Bond, 1998), because if the dependent variable is persistent (random walk or random walk with drift) or is a near unit-root process then the lagged levels convey little information about future changes and the estimator performs poorly. Binder *et al.* (2005) using a Monte Carlo experiment show that the conventional GMM estimators based on standard orthogonality conditions break down if the underlying time series contains unit roots. Therefore, it is mandatory to perform unit root tests in our series.

These issues have led to the introduction of the system Generalized Method of Moments (GMM-sys) by Blundell and Bond (1998), who show that the biases generated by near unit root processes can be strongly limited by exploiting initial stationary restrictions on the initial condition processes. This method assumes that any correlation between endogenous variables and unobserved or fixed effects are constant over time and allows to add the original equations in level to the system, so that additional moment conditions could both reduce the downward bias and at the same time increase efficiency.

For instance, it considers two different sets of equations. The first one is the GMM-diff, which uses lagged levels as instruments for first difference equations, whilst the second equation takes the first difference of the variables to make them exogenous with respect to the fixed effect and use them as instruments in the first equation (Roodman, 2009).

Prior to start with the analysis we check whether the series are stationary or not by employing two different panel unit root tests: the Levin *et al.* (LLC) panel unit root test, which tests the null hypothesis of non-stationarity and the Hadri (2000) test which tests the null hypothesis of stationarity. If the series are integrated of order 1 we proceed further with the GMM-sys estimation.

The adoption of GMM-sys is supposed to cope with the unit-root problem leading to more asymptotically efficient estimates than the GMM-diff. This is because it explores a higher number of moment conditions. Based on Blundell and Bond (1998) we use the levels and the differences of the explanatory variables as instrumental variables. In order to avoid inconsistent estimates, we check for the correlation of the unit specific effects (that if present may lead to biased GMM-sys estimates) by employing standard Sargan tests, which test the "null hypothesis of instruments validity". Moreover, to evaluate the performance of both the GMMs, we validate our estimates checking for the autocorrelation of residuals by using the AR(1) and AR(2) Arellano-Bond tests.

3.4. Results and Discussion

This section presents and discusses the empirical results of the supply response analysis using GMM-sys approach. We first test for the presence of unit-root processes by means of panel unit root tests. Then we report the system GMM results combined with tests for serial autocorrelation of the residuals and for the validity of the system GMM instruments employed in the model.

3.4.1. Dynamic panel unit root tests results

This section reports the panel tests for the presence of a random walk in the series. It is important to test for the presence of a unit root as it will generate downward biased estimates in the standard GMM estimator. We employ LLC and Hadri panel unit root tests which test respectively for stationarity and non-stationarity of the time series. LLC is commonly used to test for stationarity but since it suffers of the classical type II error (Greene, 2003), it is recommended to test also for the null hypothesis of no unit root. We therefore employ the Hadri's test. The combination of both tests is crucial to confirm or deny conclusions about the presence of unit-root. The results of the two tests are presented in Table 3.1. Under the LLC the null hypothesis of non-stationarity could not be rejected for almost all the series under examination (whether or not a trend is included generates different results), but the null of non-stationarity for the series in differences is rejected. The results for the Hadri test lead us to reject the null hypothesis of no unit root in levels and fail to reject the hypothesis of stationarity under the first-difference. The combination of results obtained from both tests suggests that all the series are $I(1)$ processes.

Table 3.1: Conventional panel unit root tests

	Level				First Difference			
	Levin-Lin-Chu		Hadri		Levin-Lin-Chu		Hadri	
	No Trend	Trend	No Trend	Trend	No Trend	Trend	No Trend	Trend
A_{wheat}	0.2[2]	-2.17[2]	5.92[2]***	8.96[2]***	-4.15[2]***	-5.95[2]***	0.51[0]	-1.284[0]
	(0.528)	(0.02)	(0.000)	(0.000)	(0.000)	(0.000)	(0.305)	(0.905)
A_{maize}	-1.66[2]*	-1.02[2]	6.69[1]***	12.42[1]***	-6.97[2]***	-9.74[2]***	-2[0]	-3.59[0]
	(0.051)	(0.15)	(0.000)	(0.000)	(0.000)	(0.000)	(0.971)	(0.999)
A_{rice}	-1.38[2]	-0.17[2]	10.62[1]***	14.33[1]***	-4.37[2]***	-5.16[2]***	-1.25[0]	-1.08[0]
	(0.08)	(0.43)	(0.000)	(0.000)	(0.000)	(0.000)	(0.899)	(0.869)
Y_{wheat}	1.5[2]	-2.26[2]**	6.3[1]***	6.76[1]***	-4.27[2]***	-6.66[2]***	0.42[0]	-1.66[0]
	(0.938)	(0.012)	(0.000)	(0.000)	(0.000)	(0.000)	(0.333)	(0.959)
Y_{maize}	0.632[2]	-2.84[2]**	7.52[1]***	13.07[1]***	-5.94[2]***	-10.02[2]***	-2.83[0]	-3.8[0]
	(0.732)	(0.02)	(0.000)	(0.000)	(0.000)	(0.000)	(0.999)	(0.999)
Y_{rice}	4.92[2]	1.58[2]***	7.11[1]***	12.15[1]***	-0.31[2]	-4.29[2]***	0.13[0]	-2.25[0]
	(0.999)	(0.943)	(0.000)	(0.000)	(0.37)	(0.000)	(0.451)	(0.988)
$Prod_{wheat}$	2.35[2]	-0.66[2]	5.13[1]***	13.51[1]***	-4.47[2]***	-7.4[2]***	-0.23[0]	-2.42[0]
	(0.999)	(0.252)	(0.000)	(0.000)	(0.000)	(0.000)	(0.591)	(0.999)
$Prod_{maize}$	-0.93[2]	-3.62[2]***	6.7[1]***	14.87[1]***	-6.3[2]***	-10.31[2]***	-2.3[0]	-3.79[0]
	(0.171)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.988)	(0.999)
$Prod_{rice}$	-1.15[2]	-0.63[2]	11.19[1]***	15.65[1]***	-4.78[3]***	-6.81[2]***	0.01[0]	0.13[0]
	(0.124)	(0.263)	(0.000)	(0.000)	(0.000)	(0.000)	(0.499)	(0.445)
ω_{wheat}	2.42[2]	-1.62[2]*	5.89[1]***	5.66[1]***	-3.34[2]***	-5.95[2]***	-1.89[0]	-2.76[0]
	(0.999)	(0.052)	(0.000)	(0.000)	(0.000)	(0.000)	(0.97)	(0.99)
ω_{maize}	2.78[2]	-1.18[2]	6.12[1]***	6.97[1]***	-3.54[2]***	-5.88[2]***	-1.22[0]	-2.55[0]
	(0.991)	(0.881)	(0.000)	(0.000)	(0.005)	(0.000)	(0.85)	(0.999)
ω_{rice}	4.01[2]	2.23[2]	8.83[1]***	10.05[1]***	-3.29[2]***	-5.34[2]***	-1.04[0]	-2.46[0]
	(1.000)	(0.988)	(0.000)	(0.000)	(0.005)	(0.000)	(0.85)	(0.999)
$E(P_{wheat})$	-14.04[2]***	-9.16[2]***	4.56[1]***	5.05[1]***	-8.67[2]***	-12.32[2]***	-0.351[0]	-1.43[0]
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.363)	(0.924)
$E(P_{maize})$	-14.22[2]***	-10.13[2]***	5.21[1]***	8.44[1]***	-32.81[2]***	-19.86[2]***	-0.24[0]	-3.48[0]
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.59)	(0.998)
$E(P_{rice})$	-7.38[2]***	-11.83[2]***	6.86[1]***	9.21[1]***	-17.73[2]***	-7.59[2]***	0.95[0]	-1.439[0]
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.169)	(0.925)
$FiDe$	11.85[2]***	19.04[2]***	11.85[1]***	19.03[1]***	-1.44[2]***	-3.21[2]***	7.38[0]	4.08[0]
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
FTC	-4.72[2]***	-2.67[2]***	11.515[1]***	5.725[1]***	-7.39[2]***	-8.95[2]***	0.199[0]	0.914[0]
	(0.000)	(0.004)	(0.000)	(0.000)	(0.000)	(0.000)	(0.421)	(0.180)
FTP	1.93[2]	-9.19[2]***	12.55[1]***	23.23[1]***	-1.74[2]**	-2.2[2]***	-2.67[0]	-3.75[0]
	(0.973)	(0.000)	(0.000)	(0.000)	(0.041)	(0.013)	(0.996)	(0.999)

Panel unit-root tests are based on Levin *et al.* (2002) and Hadri (2000). Asterisks indicates the level of significance: 1% ***, 5% **, 10%*. The null hypothesis of LLC is the presence of unit root, conversely Hadri's test has under the null hypothesis the stationarity. Figures in parentheses ( ) indicate the p-values. Figures in [ ] indicate the lag length for LLC test (we employ Bartlett kernel) and bandwidth for Hadri test (we use Quadratic Spectral kernel).

3.4.2. GMM-sys estimation

Following the procedure reported in section 3.3 we estimate our model using the generalized method of moments estimator. Since our series are non stationary in levels, the GMM-diff estimator will not be efficient. For instance, the lagged levels would have been used as instruments for the first differences equations, but since all our series are non stationary, these instruments are not suitable in this context. The level instruments for the first differenced equations will tend to be weak because the lagged levels are weakly correlated to subsequent first differences, the consequence of which is finite-sample biases (Blundell and Bond, 1998). In light of this we will employ in this study the GMM-sys estimator. In addition to using lagged levels in the equations for first differences, the lagged differences of variables are also used as instruments in equation for levels.

Table 3.2 describes the GMM-sys estimates for wheat, maize and rice yield response functions. At the bottom of the tables we report tests for the null hypothesis that errors are not correlated at the second order (i.e. dynamics are correctly specified). Of course, the AR(1) hypothesis, i.e. errors not correlated at the first order, is always rejected because in the first difference equations errors are distributed like MA(1). The most relevant test for the validity of the instruments in GMM-sys is the Sargan test, which is χ^2 distributed and tests the validity of the instruments under the null hypothesis.

We are interested in evaluating the response of expected prices, domestic price instability and a set of non-price variables on wheat, maize and rice yield, acreage and production. For each crop we estimate three model specifications which we report in three different columns. In the first column we show the basic specification of the model, in the second column we report the estimates of the model with the interaction term between volatility and credit, while in the third column we include among controls the agricultural GDP expressed as a share of total GDP. All variables have the expected sign, but estimates are not always statistically significant.

Yield responses to own price expectations are positive and statistically significant at 1% for rice showing short-run elasticity values of approximately 0.25. Yield responses to expected prices for wheat and maize are not significant. However, concerning rice the results indicate that as the price of rice increases, yields do so: e.g., farmers are most likely to improve capital investments for example by purchasing new farm equipment or improved seeds. The values obtained are consistent with the range of short run elasticities (0.19 - 0.27) reported by Goodwin *et al.* (2012). According to Berry (2011), the existing research on price-yield response - which relied uniquely on OLS estimates - produced "bad price-yield estimates", with values ranging between 0 (Roberts and Schlenker, 2009) and 0.15 (Huang and Khanna, 2010). As regards acreage response (table 3.3), only the own price elasticity of maize acreage is found to be always significant. The short run maize acreage response with respect to price of maize is estimated to range between 0.397 - when accounting for the relative importance of agriculture in the country's economy - and 0.566.

The results indicate that as the price of maize increases also the area allocated to the production of corn increases. The own price elasticity of maize acreage response reported in this study is slightly higher than the average of the elasticities reported at state level by the Food and Agricultural Policy Research Institute[14]. Though, these measures are particularly sensitive to the estimator used. Abrar *et al.* (2004) reported for the Southern region of Ethiopia an elasticity of acreage to price of maize of about 0.57. Table 3.4 reports the results for the production response. Price coefficients are positive and statistically significant in all the three specifications for both wheat and maize, with short run elasticities ranging between 0.261 and 0.379 for wheat and between 0.396 and 0.542 for maize. Hence, price increments have a positive impact also on the quantity produced, which yields the highest price coefficients.

Table 3.2: GMM-sys estimates of world yield response for wheat, rice and maize

	Wheat (W1)	Wheat (W2)	Wheat (W3)	Maize (M1)	Maize (M2)	Maize (M3)	Rice (R1)	Rice (R2)	Rice (R3)
$\ln Y_{j,t-1}$	-0.091	-0.078	0.134***	-0.079	0.458***	0.440***	0.015	0.005	0.212***
	(0.106)	(0.102)	(0.034)	(0.158)	(0.057)	(0.041)	(0.051)	(0.058)	(0.047)
VOL_j	0.603	1.047	-0.685***	-0.511**	1.316	-0.830**	-0.582***	-0.532	0.067
	(1.104)	(1.487)	(0.170)	(0.191)	(0.702)	(0.280)	(0.139)	(1.959)	(0.594)
$\ln E(P_{t-p})$	-0.210	-0.177	-0.034	0.241	0.023	0.039	0.248***	0.245***	0.243***
	(0.126)	(0.110)	(0.018)	(0.160)	(0.052)	(0.072)	(0.019)	(0.022)	(0.027)
$\ln(FTC)$	0.055***	0.058***	0.056**	0.144***	0.060**	0.028	0.053***	0.059***	0.016***
	(0.012)	(0.010)	(0.016)	(0.031)	(0.020)	(0.020)	(0.004)	(0.005)	(0.005)
$\ln(FTP_t)$	0.046	0.051	-0.059**	-0.228*	-0.082*	0.046	-0.128***	-0.160***	-0.031
	(0.097)	(0.094)	(0.018)	(0.116)	(0.038)	(0.076)	(0.019)	(0.026)	(0.033)
$\ln(FiDe_{it})$	0.351*	0.325*	-0.045	0.390***	0.229***	0.135***	0.191***	0.132	0.019
	(0.136)	(0.138)	(0.044)	(0.054)	(0.059)	(0.037)	(0.016)	(0.122)	(0.056)
$\ln(FiDe_{it})*VOL_j$		-0.021	0.022***		-0.020	0.032**		0.041	-0.006
		(0.032)	(0.006)		(0.016)	(0.011)		(0.076)	(0.016)
$\ln(AGDP_{it})$			-0.208**			-0.261**			-0.286***
			(0.057)			(0.083)			(0.021)
_cons	8.549***	8.518***	8.274***	9.653***	4.464***	6.170***	9.864***	10.206***	8.927***
	(0.587)	(0.562)	(0.469)	(1.577)	(0.509)	(0.491)	(0.516)	(0.815)	(0.572)
N	195	195	180	276	276	261	239	239	232
AR(1):p-val	0.004	0.002	0.003	0.005	0.006	0.000	0.000	0.001	0.000
AR(2):p-val	0.249	0.534	0.669	0.301	0.318	0.689	0.943	0.675	0.665
Sargan test: p-val	0.374	0.443	0.104	0.694	0.124	0.077	0.162	0.080	0.101
F test: p.val	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: standard errors in parentheses; asterisks *,**,*** indicate 10%, 5%, 1% significance levels. We report the p-values of the AR(1) and AR(2) Arellano-Bond tests, the p-values of the Sargan test for the null hypothesis of instruments validity, and the F-test of the joint validity of the model.

Volatility of domestic prices with respect to yield is found to be statistically significant for wheat and maize (when controlling for the agricultural share of GDP) and rice but only in the basic specification. The negative sign and its magnitude indicates that farmers are on average risk averse agents who react to price instability by reducing investments in technology and diversifying the production (Von Braun and Tadesse, 2012). Concerning the responsiveness of the planted area to price volatility, the estimated coefficients are all statistically insignificant with the exception of wheat area, which responds negatively to

[14]http://www.fapri.iastate.edu/tools/elasticity.aspx.

price instability. The magnitude of the coefficient is -0.65. We did not find any significant relationship between volatility and production for both wheat and maize. A negative and statistically significant coefficient is registered for rice.

Evidence from the past literature suggested that the use of fertilizers during the early part of the growing season can represent an important mechanism by which realized yields may be influenced by price variation. Good proxies of fertilizers usage can be both consumption of nitrogen micro-nutrient, which is the most representative active principle in their composition, and the urea real price of fertilizer. The price of fertilizers is a production cost to farmers, and its variation may lead farmers to reduce either the amount of fertilizer used - which eventually impacts yields - or the area under cultivation. In the latter case farmers apply fertilisers to less area under cultivation, maintaining however constant the total amount of fertilizer per hectare. Positive and significant relationships between fertilizers consumption and yield are registered for all the crops, while negative coefficients of prices of fertilizers indicate that an increase in the fertilizers prices will have a negative impact on yields. This finding is consistent among all the cases analyzed. In each table, columns W3, M3 and R3 show the results of including agricultural share of GDP as an additional control variable. The influence of the relative importance of agriculture in the country's economy, returns opposite results with respect to yield and production. The yield response to larger agricultural share of GDP is negative and statistically significant, suggesting that countries with higher agricultural added values are characterized by less improved production technologies or limited input usage, which may for instance result in lower protection against pest diseases and weather disruptions with subsequent impacts on yields. Regarding production, which is expressed in tonnes of crop per year, we find for rice a positive correlation with $AGDP_t$: the higher the agricultural share over GDP, the higher the production in absolute value. We fail to find any significant relationship with acreage.

Table 3.3: GMM-sys estimates of world acreage response for wheat, rice and maize

	Wheat (W1)	Wheat (W2)	Wheat (W3)	Maize (M1)	Maize (M2)	Maize (M3)	Rice (R1)	Rice (R2)	Rice (R3)
$\ln Y_{j,t-1}$	0.992***	0.992***	1.000***	1.040***	0.956***	0.946***	0.689***	0.694***	0.670***
	(0.014)	(0.011)	(0.012)	(0.052)	(0.018)	(0.022)	(0.087)	(0.083)	(0.083)
VOL_j	-0.143	-0.610*	-0.654*	-1.157	-0.469	-0.362	1.682	2.554	-0.316
	(0.392)	(0.289)	(0.259)	(1.440)	(1.825)	(1.753)	(1.064)	(2.440)	(2.088)
$\ln E(P_{t-p})$	-0.018	-0.026	0.013	0.566*	0.463*	0.397*	0.088	0.086	0.176*
	(0.079)	(0.058)	(0.052)	(0.247)	(0.218)	(0.199)	(0.108)	(0.109)	(0.084)
$\omega_{j,t-1}$	0.035*	0.032*	0.033*	-0.015	0.027	-0.016	0.123*	0.125*	0.044
	(0.014)	(0.012)	(0.012)	(0.085)	(0.076)	(0.079)	(0.059)	(0.059)	(0.041)
$\ln(FTC_{it})$	0.001	0.002	-0.000	-0.011	0.074*	0.088**	0.137***	0.137***	0.152***
	(0.011)	(0.009)	(0.010)	(0.063)	(0.034)	(0.032)	(0.038)	(0.038)	(0.041)
$\ln(FTP_t)$	0.009	0.024	-0.012	-0.675*	-0.334	-0.270	-0.141*	-0.149*	-0.172**
	(0.077)	(0.058)	(0.038)	(0.284)	(0.185)	(0.172)	(0.065)	(0.066)	(0.054)
$\ln(FiDe_{it})$	0.008	-0.021	0.003	0.507	-0.235	-0.189	0.235**	0.265*	0.179
	(0.027)	(0.024)	(0.019)	(0.351)	(0.161)	(0.165)	(0.071)	(0.122)	(0.112)
$\ln(FiDe_{it})*VOL_j$		0.011*	0.014*		0.050	0.048		-0.019	0.056
		(0.004)	(0.006)		(0.052)	(0.051)		(0.058)	(0.055)
$\ln(AGDP_{it})$			0.010			0.065			0.013
			(0.019)			(0.052)			(0.159)
_cons	-0.003	-0.006	0.051	2.596	2.891*	2.108	2.319***	2.185**	2.787*
	(0.401)	(0.297)	(0.263)	(1.336)	(1.251)	(1.211)	(0.627)	(0.697)	(1.203)
N	195	195	180	276	276	261	204	204	232
AR(1):p-val	0.005	0.005	0.007	0.000	0.000	0.000	0.000	0.000	0.000
AR(2):p-val	0.049	0.038	0.047	0.329	0.930	0.867	0.035	0.047	0.077
Sargan test: p-val	0.159	0.123	0.088	0.104	0.041	0.036	0.213	0.259	0.044
F test: p-val	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: standard errors in parentheses; asterisks *,**,*** indicate 10%, 5%, 1% significance levels. We report the p-values of the AR(1) and AR(2) Arellano-Bond tests, the p-values of the Sargan test for the null hypothesis of instruments validity, and the F-test of the joint validity of the model.

Financial deepening has also a strong influence on yield response for wheat and maize crops. The results reveal that credit to private sector by banks may assist farmers to cope with price instability. In particular, including the interaction term which simulates the effect of having access to credit in a context with price instability, we obtain positive figures and statistically significant coefficients. This finding is relevant, particularly in the case of wheat producers (in terms of yield, acreage and production), suggesting that financial deepening can assist in buffering the supply effects of instability. However, these results must be interpreted carefully. Positive values do not necessarily mean that there is a direct causal relationship between expanding financial institutions and food insecurity alleviation. Rural financial institutions expansion in areas with inadequate markets and susceptible to weather risks, may have a non-positive effect, unless it is developed a good strategy of asset diversification coupled with adequate loan loss provisions (Diagne and Zeller, 2001). Therefore at policy level it has to be considered that although financial deepening improves the farmers productivity it is not a panacea for poverty alleviation. The full potential of credit access in increasing the welfare of the poor can only be realized together with adequate investments in hard and soft infrastructure as well as investments in human capital. Access to credit is also dependent on a range of agro-ecological factors like extreme weather events such as floods, droughts and so on. We hypothesize that the yield deviations from a trend are likely to be attributed to random weather fluctuations. The resulting coefficients are slightly higher than the ones employed by Haile and Kalkuhl (2013) for wheat acreage, whereas regarding production response, our results show a positive and statistically significant relationship for all the three crops under analysis.

Table 3.4: GMM-sys estimates of world production response for wheat, rice and maize

	Wheat (W1)	Wheat (W2)	Wheat (W3)	Maize (M1)	Maize (M2)	Maize (M3)	Rice (R1)	Rice (R2)	Rice (R3)
ln$Y_{j,t-1}$	1.031***	1.006***	1.035***	0.690**	0.129	0.562***	0.283***	0.546***	0.676***
	(0.027)	(0.017)	(0.035)	(0.234)	(0.172)	(0.080)	(0.048)	(0.147)	(0.090)
VOL_j	0.283	0.215	0.628	-0.114	-1.005	-0.006	-0.902*	1.121	-0.350
	(0.529)	(0.789)	(0.969)	(1.485)	(2.426)	(1.222)	(0.413)	(0.680)	(2.658)
ln$E(P_{j-p})$	0.363*	0.261**	0.379*	0.542*	0.477*	0.396*	0.303***	-0.050	-0.075
	(0.161)	(0.091)	(0.192)	(0.255)	(0.223)	(0.176)	(0.085)	(0.090)	(0.055)
$\omega_{j,t-1}$	0.157***	0.174***	0.180***	-0.130	0.095***	0.102***	0.175***	0.143***	0.104***
	(0.013)	(0.014)	(0.018)	(0.118)	(0.018)	(0.024)	(0.012)	(0.017)	(0.015)
ln(FTC_{it})	0.000	0.019	0.002	0.261*	0.540***	0.365***	0.106**	0.220**	0.197***
	(0.015)	(0.012)	(0.020)	(0.121)	(0.102)	(0.058)	(0.032)	(0.071)	(0.053)
ln(FTP_t)	-0.183	-0.367**	-0.570*	-0.060	0.046	-0.208	-0.164**	-0.092	-0.110**
	(0.127)	(0.134)	(0.263)	(0.197)	(0.177)	(0.225)	(0.050)	(0.063)	(0.037)
ln$(FiDe_{it})$	0.112*	0.031	0.030	-0.211	-0.480	-0.011	0.420*	0.378**	0.116
	(0.045)	(0.042)	(0.047)	(0.152)	(0.330)	(0.212)	(0.182)	(0.119)	(0.227)
ln$(FiDe_{it})$*VOL_j		0.029*	0.029		-0.027	0.044		0.000	0.127
		(0.014)	(0.016)		(0.111)	(0.038)		(0.020)	(0.109)
ln$(AGDP_{it})$			-0.054			0.478			0.305**
			(0.056)			(0.244)			(0.087)
_cons	0.628	1.896**	3.064*	3.181	8.175***	2.423	8.362***	2.948**	1.438*
	(0.560)	(0.691)	(1.487)	(2.177)	(2.253)	(1.493)	(0.623)	(1.047)	(0.675)
N	195	195	180	276	276	261	239	239	232
AR(1):p-val	0.000	0.000	0.003	0.007	0.002	0.000	0.001	0.000	0.013
AR(2):p-val	0.505	0.283	0.015	0.090	0.772	0.750	0.087	0.330	0.762
Sargan test: p-val	0.128	0.432	0.223	0.411	0.033	0.155	0.312	0.216	0.645
F test: p-val	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: standard errors in parentheses; asterisks *,**,*** indicate 10%, 5%, 1% significance levels. We report the p-values of the AR(1) and AR(2) Arellano-Bond tests, the p-values of the Sargan test for the null hypothesis of instruments validity, and the F-test of the joint validity of the model.

3.5. Conclusions

In the last decade domestic staple food prices experienced several boom and bust cycles. The upward spikes registered in 2008, late 2010/early 2011 and mid 2012 posed serious threats to farmers, particularly in developing countries. This paper investigates the influence of domestic price volatility and expected prices on the area cultivated, yield and production at global scale by using Generalized Methods of Moments dynamic estimation that, compared to other estimators, is found to deal better with "weak instruments" issues and endogenous regressors. Following this approach a supply response model is derived for wheat, rice and maize for the period 2005-2012.

Several conclusions can be drawn from our findings. First of all, world farmers respond strongly to high domestic prices and to domestic price volatility. High prices result in an increase of the quantity produced, and often to an increase in acreage allocation (for maize) and yields (for rice). Price instability leaves the farmers uncertain about whether they are going to be paid a high price or not: this has implications in particular on investment decisions about production with relevant impacts on yields. This risk averse behaviour is evident among wheat, maize and rice producers. Lack of access to risk managements opportunities as well as lack of access to credit tend to exacerbate the effect of price movements on welfare of producers. This frequently leads to poverty traps. The results support our hypothesis about the positive relationship of financial deepening with supply responses, suggesting policy makers to improve local financial systems with well targeted policy reforms of the financial sector in order to facilitate lending and borrowing between financial institutions and poor households. Furthermore, besides prices and financial deepening, other factors must be considered for supply response to be realised: fertilizers consumption and fertilizers prices have respectively a positive and negative relationship in particular with crop yields in almost all models, while yield shocks are positively related with both production and acreage.

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Appendix

Appendix 3A

Table 3A.1: List of variables employed in our study

Variable name	label	Unit	Range	Source	Level
$lnArea_{ij}$	Area Harvested	Ha/Year	1961-2012	FAO-STAT	CC
$lnYld_{ij}$	Yield	Hg/Ha/Year	1961-2012	FAO-STAT	CC
$lnProd_{ij}$	Production	Tonnes/Year	1961-2012	FAO-STAT	CC
$VOL_{ij,t}$	SDLOG Annual Volatility	Unit Free Measure	2005-2013	FAO-GIEWS WFP-VAM FEWS.NET	CC
$E(P_{ij,t})$	Expected Price	USD/Kg	2005-2012	FAO-GIEWS WFP-VAM FEWS.NET	CC
$\omega_{ij,t-1}$	Yield Risk	Jackknifed residuals of deviation from trend	1961-2012	FAO-STAT	CC
$FTC_{i,t}$	Fertilizers consumption	Ion Metric Tonnes of N nutrients per year	2000-2012	FAO-STAT	C
FTP_t	Intl. Prices of Fertilizers	USD/Kg	2000-2012	World Bank Pinksheet	C
$FiDe_{i,t}$	Domestic credit to private sector by banks (% of GDP)	Unit Free Measure	1961-2012	WDI	C
$AGDP_{i,t}$	Agriculture, value added (% of GDP)	Unit Free Measure	2000-2012	WDI	C

C = Country
CC = Country-Commodity

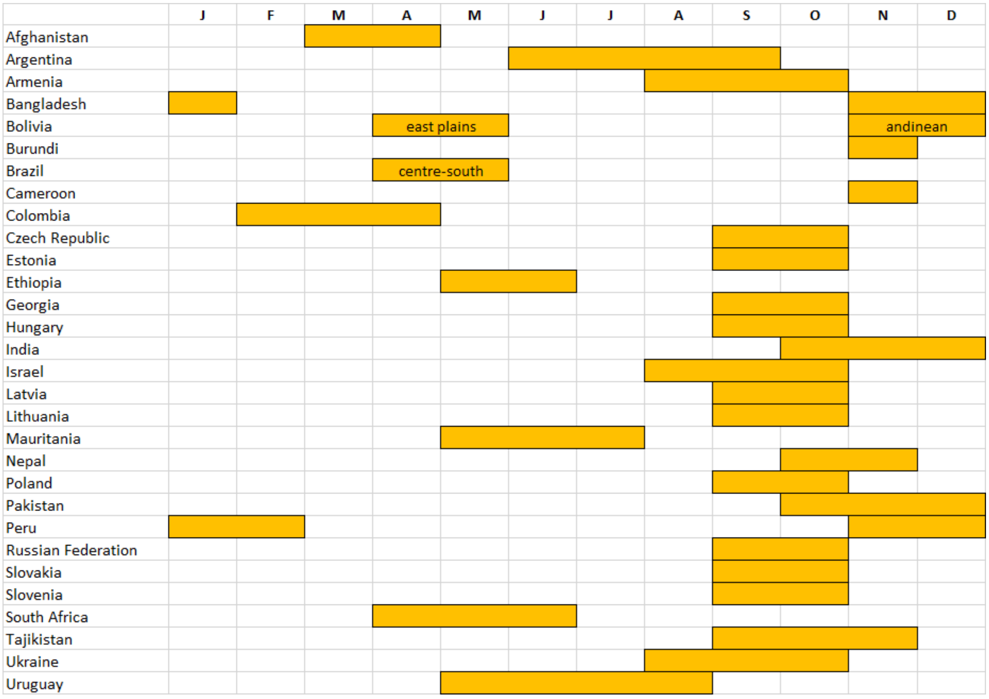

Figure 3A.1: Wheat crop calendar, planting seasons

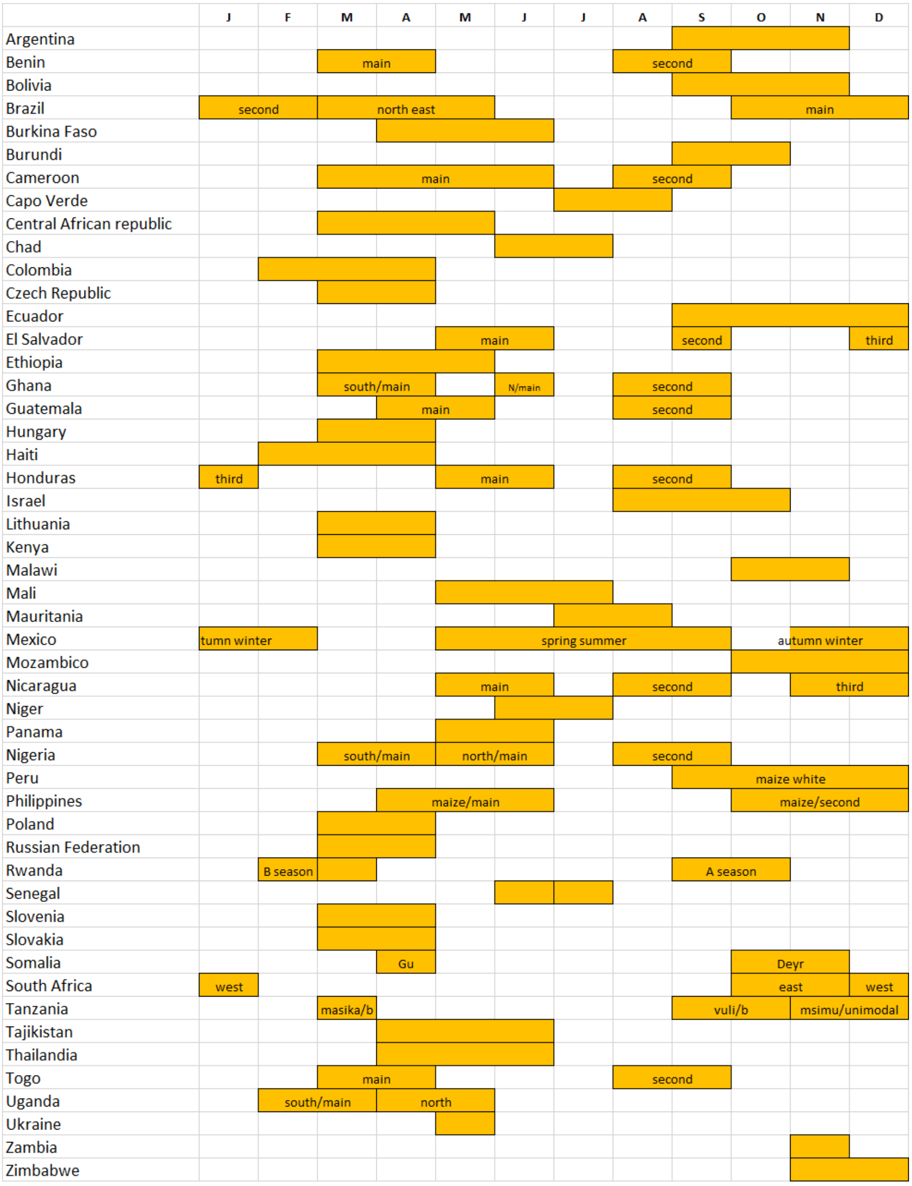

Figure 3A.2: Maize crop calendar, planting seasons

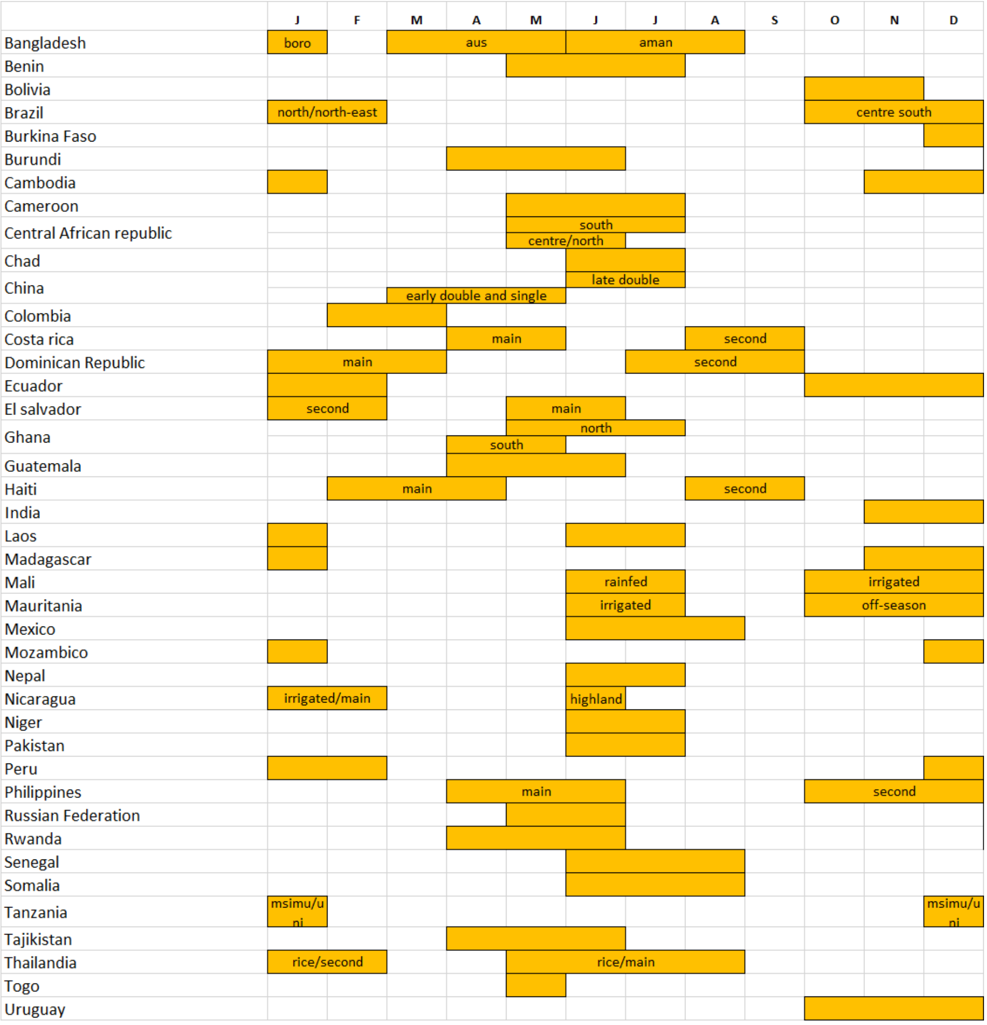

Figure 3A.3: Rice crop calendar, planting seasons

Appendix 3B

Price volatility is defined as a stochastic process with a high overtime variability (Gilbert and Morgan, 2010). Variation is usually measured in terms of price dispersion around the mean and can be computed in different ways. Brummer *et al.* (2013) in a recent survey, divide the literature on price volatility in three strands: descriptive models that do not directly estimate the causal relationship between price volatility and its drivers, theoretical based assessments and novel empirical models which make use of GARCH, cointegration analysis, Granger Causality, heterogeneous agents models (Reitz and Westerhoff, 2007). In the last years the vast majority of the studies conducted on price volatility make use of international food prices and only few contributions assessing the domestic staple food price volatility determinants can be found in the literature. Using both a cross sectional and a panel estimation model (Kohrner and Kalkuhl, 2013) aim to study which are the most influencing determinants of local food price fluctuations. Food price instability is found to be affected on average by trade restrictiveness measures, demand shocks and policy measures. Also Pierre *et al.* (2014) aims to shed more light on the determinants of local price volatility of rice, maize and wheat in 36 developing countries at wholesale and retail level. The conclude that international price volatility, oil price instability as well as yields are three crucial factors influencing domestic price volatility. We report in Tab. 3B.1 a short list of the most recent contributions.

Table 3B.1: Empirical papers on price volatility

Authors	Volatility	Level	Range	Frequency	Model
Roache (2010)	spline-GARCH	Int.	1957-2009	Monthly	Panel Fixed Effects
Gilbert and Morgan (2010)	SDLOG, GARCH	Int.	1970-2009	Monthly	Discussion
Balcombe (2011)	SDLOG	Int.	1962-2007	Monthly	Random Parameters
Huchet-Bourdon (2011)	CV, SD of 1st Diff	Int.	1957-2010	Monthly - Annual	Correlation Coefficients
Apergis and Rezitis (2011)	GARCH	Greece	1985-2007	Monthly	GARCH-GARCH-X
von Braun and Tadesse (2012)	CV	Int.	1986-2009	Monthly - Daily	OLS, FGLS
Lee and Park (2013)	CV	Int.	2000-2011	Quarterly	Panel FE, RE and GMM
Kornher and Kalkuhl (2013)	CV	Domestic	2000-2012	Monthly	Dynamic Panel Fixed Effects
Tadesse *et al.* (2014)	CV	Int.	1986-2009	Monthly - Daily	SUR, OLS, FGLS
Domnez and Magrini (2013)	Midas-GARCH	Int.	1986-2012	Monthly	Midas-GARCH
Pierre *et al.* (2014)	SDLOG	Domestic	2005-2012	Monthly	Linear Mixed Model

Source: adapted from *Pierre et al. (2014)*.

In the last decades a wide range of models have been applied in extensive empirical studies to forecast volatility (Bollerslev, 2008). This is due to their particular ability in capturing the typical stylized facts (i.e. volatility clustering, persistence, time-varying volatility and so on) present in prices time series.

Volatility can be classified either in historical volatility, which is a measurement based on past observations, or implied volatility, which is a measure derived from the market price of a traded option. This last is particularly used in finance. In this paper we will be measuring only the realised volatility based on observed domestic market prices.

The historical volatility can be computed in three different ways:

1)Historical Variance (Coefficient of Variation, SDLOG);
2)Exponentially Weighted Moving Average (EWMA);
3)Generalized Autoregressive Conditional Heteroskedasticity (GARCH).

In these three models the forecast variance is a linear combination of the squared deviation of recent returns from their expected value. The main difference between the three models is that the historical variance measures put a weight equal to zero to squared deviations registered before a cut off date and assigns an equal weight after that date, whilst in the other two methods a higher weight is placed on the most recent observations and a lower weight on the oldest.

The simplest way to measure volatility is to employ the coefficient of variation (CV), which expresses the standard deviation as a percentage of the sample mean. It is defined as in (3.9):

$$CV = s/\mu \tag{3.9}$$

with s representing the standard deviation of prices over a particular time interval, and μ representing the mean price over the same interval. One advantage of this measure is that it is independent of the unit in which the measurement has been taken, so it is a dimensionless number, and for this reason it allows an easy comparison of domestic price volatilities for different countries and different crops. However, the coefficient of variation can generate misleading impressions if a trend is present in the data as its movements can affect the calculus of volatility. As highlighted by Minot (2014) food prices are usually non-stationary: random walk behaviour and presence of unit roots lead to an increase in the error variance for T approaching infinity.

In order to capture both monthly and yearly variability, authors like Peterson and Tomek (2005), Karali and Power (2009), Tadesse *et al.* (2013) compute the Realized Total Volatility (RTV), which is a slightly modification of the CV that allows to measure variability relative to a common price level.

An alternative approach to the CV is the standard deviation of changes in the logarithm of prices (SDLOG). This approach is widely used in agricultural economics as this is a unit free measure. The log standard deviation is approximately equal to the coefficient of variation for low levels of volatility (Gilbert and Morgan, 2010). Extensive applications of this method are reported in the literature by authors such as Gilbert and Morgan (2010), Balcombe (2011), Huchet-Bourdon (2011) and Minot (2014). It is worth noting that with respect to the CV this measure is less affected by strong trends overtime.

Another measure (commonly used in finance) is represented by The $RiskMetrics^{TM}$-EWMA model, which was made famous by J.P. Morgan and Reuters in the early 1990s. It is a measure of variability often used in value at risk analysis. It belongs to the family of Random Walk models and recursively estimates the volatility for a given sequence of r_t returns (3.10), defined as the relative price change (or percentage return):

$$r_t = \frac{P_{t-1} - P_t}{P_t} \tag{3.10}$$

Where P_t is the price of a security at time t, and t is usually taken as one business day but can be a week or a month. As describer earlier, in this method it is given more importance to recent information by putting a lower weight to the oldest prices and placing a greater weight on more recent returns. The volatility forecast is given by:

$$\sigma_{1,t+1|t} = \sqrt{\lambda\sigma^2_{1,t|t-1} + (1-\lambda)r^2_{1,t}} \tag{3.11}$$

where $\sigma_{1,t+1|t}$ is the volatility forecast at time $t+1$ given information up to time t and λ is a decay coefficient which ranges between 0 and 1.

The main tool to measure volatility is certainly the GARCH (p,q) model. The GARCH model is the natural extension of autoregressive conditional heteroscedasticity (ARCH) model and it is often used for modelling volatility in financial markets. It is represented by the following expression (Engle, 1982):

$$r_t = \mu + \varepsilon_t \tag{3.12}$$

$$var(\varepsilon_t) = \sigma^2_t = \gamma + \sum_{i=1}^{q} \alpha^2_{ie_{t-i}} + \sum_{j=1}^{p} \beta^2_j \sigma^2_{t-j} \tag{3.13}$$

The idea behind this model is to estimate the conditional variance of future price from the autoregressive (AR) process followed by a time series. Technically, the advantage of GARCH models is that they allow the variance of returns to change overtime as a function of lagged squared residuals and lagged variance. However, the parameters underlying this kind of model are not always well determined and agricultural economists are quite sceptical towards the ability of random walk models in capturing the transitory nature of the shocks generated by fundamental determinants (Balcombe, 2011; Kohrner and Kalkuhl, 2013). In their seminal paper Deaton and Laroque (1992) stated that random walk models do not fit perfectly for commodity prices, at least for commodities where the weather plays a major role in price movements. A random walk model requires that all shocks in price are permanent, not transitory.

Now, it is fundamental to choose the appropriate way to measure of volatility as results can differ depending on the choice. In order to select the most appropriate method we have to consider the data frequency. Since the data available for commodity prices has monthly frequency and for the majority of the variables involved in our experiment the data has an annual frequency, we need to generate a measure of annual price volatility. Following

Balcombe (2011) and Kohrner and Kalkuhl (2013) approaches, the annualized volatility will be expressed as the standard deviation of the monthly log returns (SDLOG).

$$\sigma_{it} = \sqrt{\frac{\sum_{j=1}^{12}(ln(p_{i,j,t-1}) - ln(p_{i,j,t}))^2}{12}} \tag{3.14}$$

This method can summarize intra year volatility into an annual measure. The logged measure of volatility is approximately normally distributed for the annual series that will be employed in this paper. Herein we focus primarily on the instability in the domestic price of maize, wheat, rice and other staple foods for a defined set of countries.

CHAPTER 4

Price Shocks, Vulnerability and Food and Nutrition Security among Rural and Urban Households in Tanzania

4.1. Introduction

Poor households in developing countries face a wide array of risks arising from many sources, both natural and economic. In particular, food price fluctuations have increased substantially over the last decade and there are concerns that excessive food price movements represent a problem that will persist for a while with severe consequences for the poor (Fan, 2011). Tanzania is not an exception: after the 2007/2008 food price spike, food prices increased between 2010 and 2011 and again at the beginning of 2013, making Tanzania one of the most affected countries in SSA, in particular for cereals like maize, wheat and rice (Minot, 2014). These products account for a large part of the total dietary consumption of Tanzanian households: as a result, the sharp increase and high volatility of their prices raised serious concerns about the ability of Tanzanian poor to meet basic needs and achieve adequate level of food security.

Existing contributions tell us that the effects of higher food prices on poverty are likely to be very differentiated. They depend on which commodity prices change, on the structure of the economy (Ravallion and Lokshin, 2004; Hertel and Winters, 2006) and on the households status as food buyers or sellers (Aksoy and Izik-Dikmelik, 2008)[1].

Many authors tried to analyze the effect of price shocks on poverty. Ivanic and Martin (2008) analyzed nine low-income countries finding that the impact of soaring food prices on poverty is commodity and country specific and that poverty growth is much more frequent, and larger, than poverty reduction. Polaski (2008) explored the links between labour and agricultural prices in India highlighting that food price upswings benefited mostly poor households, whilst Wodon *et al.* (2008) found a negative effect of price rise for West and Central Africa poor. More recent contributions on this literature come from Sarris and Rapsomanikis (2009), Wodon and Zaman (2010), Ivanic *et al.* (2012). A smaller body of

[1] These analyses employ a number of methodologies which are applied to household survey data from different developing countries.

the literature attempted to measure how food price movements affected households food consumption. Using data from two provinces in China, Jensen and Miller (2008) found a small impact of price increase on consumption and nutrition of poor households. Brinkman *et al.* (2010) examined the impact of the crises on food consumption, nutrition and health outcomes for several specific developing countries, emphasizing that, as a result of the crises, a large number of vulnerable households has reduced the quantity and quality of their food consumption. Similarly, Harttgen and Klasen (2012) showed a very large impact of changes in prices of maize and staple food on individual caloric consumption in Malawi and Uganda. Drawing from the very recent micro-economic development literature, Alem and Sodebrom (2012) measured the effect of the recent price spikes on household vulnerability by including in their analysis a direct measure of self-reported food price shocks. By employing an AIDS model, Zaki *et al.* (2014) evaluated the impact of rising food prices on micronutrients intake among households in Lebanon, showing that soaring prices negatively affected the intake of some macro and micronutrients. In contrast with the recent literature, D'Souza and Jolliffe (2014) found that Afghan most vulnerable households experienced no decline in caloric intake as a response of wheat price surge, arguing that food caloric intake is indeed an ineffectual indicator to measure the onset of food insecurity. Concerning Tanzania, only few authors have systematically analysed the effect of food price movements on households vulnerability and food consumption. Christiansen *et al.* (2006) examined the effects of coffee and cashew price decline in 2000s on household welfare, pointing out that they resulted in an important average welfare loss. A study by Sarris and Karfakis (2007) focusing on Kilimanjaro (north) and Ruvuma (south-west) regions, showed that vulnerability in the rural regions of Tanzania is quite high and considerably higher in poorer (Ruvuma) as compared to more well off regions (Kilimanjaro). However, vulnerability sistematically differ among different areas within both region, in particular in Kilimanjaro. Both studies were conducted before the food price spikes, thus leaving the question about the effect of the recent food price crisis on vulnerability among Tanzanian urban and rural households still unanswered.

The overall objective of this paper is to contribute to the existing literature on shocks and household vulnerability by documenting the effects of the very recent food price shocks on food consumption across households in urban and rural Tanzania. We will examine the impact both quantitatively (e.g. food caloric intake) and qualitatively (e.g. dietary diversity), assuming that the greater the correlation, the less effective the risk management strategy implemented by the household to insulate consumption from idiosyncratic and covariate shocks[2]. Moreover we will try to shed light on whether certain types of households are relatively more 'vulnerable' than others to food price surges. In doing this, we will control for the intensity of the event, measuring the consumption response in case the event is classified by the household as severe or not. Since Tanzania is affected by several shocks we

[2]We define food consumption smoothing as a form of consumption insurance in the way intended by Skoufias and Quisumbing (2004).

think that it is important to take into account also the incidence of other idiosyncratic and covariate shocks. We will employ as shock variables the household's self-reported perception of the shocks they experienced over the five years before the survey. This measure is used as an indicator of whether households perceived (positive or negative) food price changes had a detrimental impact on the household welfare or not. In order to pursue our objectives we rely on the Vulnerability as Uninsured Exposure to Risk (VER) framework of analysis[3]. Following Dercon and Khrisnan (2000) we adopt food consumption instead of income as a well-being measure (because the latter is more volatile, while households are assumed to seek stable levels of welfare over time) and we assess our measurement of vulnerability to shocks by using the coefficients of shock variables instead of the income variation[4]. The database employed for the analysis is the Tanzanian Living Standard Measurements Study - Integrated Surveys on Agriculture (LSMS - ISA). From the technical view point, the fact that in Tanzania are available three waves of the LSMS (2008/09, 2010/11 and 2012/13) offers a unique opportunity to take advantage of a panel data structure with good quality data.

The paper is set out as follows. Section 4.2 provides background information on Tanzanian economic growth, food prices and inflation. Section 4.3 reviews the empirics of shocks. Section 4.4 presents the methodology. Section 4.5 introduces the data, variables description and the econometric specification of the model. Section 4.6 reports the results of the analysis and, finally, section 4.7 concludes.

4.2. Economic growth, inflation and food volatility in Tanzania

Official statistics indicate that Tanzania has grown at a constant pace over the last ten years (cf. table 4A.6 in the Appendix 4A). Real GDP grew on average at an annualized rate of approximately 7%. However, Tanzania is still among the world's poorest countries. In November 2013, the Government of Tanzania announced the new official poverty figures indicating that approximately 28.2% of the population lives below the national poverty line[5]. The decline in poverty incidence over the last years has been modest, though about 6 millions of people have been lifted out of poverty since 2007 (IMF, 2014). Although in the last decade agricultural value added (as a share of GDP) sharply declined, agriculture still remains the backbone of Tanzanian economy. According to the figures reported in table 4A.6, in 2013 it accounted for nearly 27% percent of Tanzanian GDP. Cereals represent more than half of Tanzania's total harvested land area. Maize is the country's dominant staple food crop, while the country is a net importer of wheat and rice. Maize yields are low (about 0.75 tons per hectare) and smallholder farmers rely on traditional agronomic practices and

[3]VER is a backward looking measurement, which can be defined as an ex-post assessment of the extent to which a negative shock (e.g. price surge, drought) generates a welfare loss.

[4]See Hoddinott and Quisumbing (2003) for a comprehensive review of all the possible VER framework specifications.

[5]World Bank, available at http://www.worldbank.org/en/country/tanzania/overview

technologies. Cassava and potatoes are also important food sources and account for 15% of harvested land (WFP, 2012).

The recent successful economic growth occurred despite many local and global challenges. At local level, Tanzania was hit by a severe drought in 2009, which adversely affected crop production, livestock and power generation (WFP, 2012). At the global level the country was negatively impacted by high oil and food prices in 2007-2008 and in the subsequent years. From 2007 onwards, consumer price inflation registered the highest peaks in Tanzanian recent history[6](see figure 4.1). After the 2007/08 unprecedented food prices peak, the Government of Tanzania imposed an export ban and removed the import duties for maize and rice. The government lifted up the export ban in October 2012 and implemented again an import duty in 2013. As a result, food prices continued to increase thus affecting the majority of net buyers in urban areas. In particular, prices of cereals experienced the highest fluctuations, as shown by maize prices movements in the main Tanzanian local markets[7] (see figure 4.2). In February 2008 maize prices almost doubled with respect to 12 months before. Then, maize prices began to fall prior to reach other two peaks in March 2009 and in January 2010, respectively. An unprecedented peak was touched in February 2013 when in Der Es Salaam the cost of 1 kg of maize was about 900 Tsh. Prices of agricultural inputs have also increased, especially fertilizers, thereby shrinking agricultural incomes; as expected, this resulted in an increase in food insecurity of the more vulnerable households.

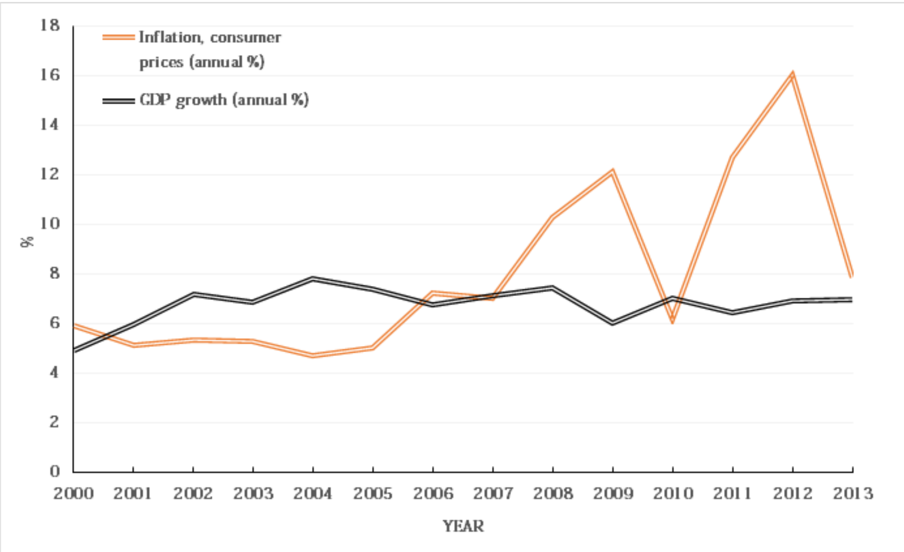

Figure 4.1: Inflation and GDP growth between 2000 and 2013 in Tanzania. *Source*: Author's elaboration of World Development Indicators data, World Bank (2014).

[6]The driving factors of price inflation in Tanzania have been deeply assessed by Adam *et al.* (2012). These include monetary or demand-side effects, pass through from world food prices and asymmetric effects of trade policies.

[7]We adopt maize as a benchmark for cereals prices for two reasons. First, as pointed out by Minot (2010) maize is the main staple food in Tanzania and is consumed by the majority of the households in both rural and urban areas. Second, data on maize are the most complete available time series.

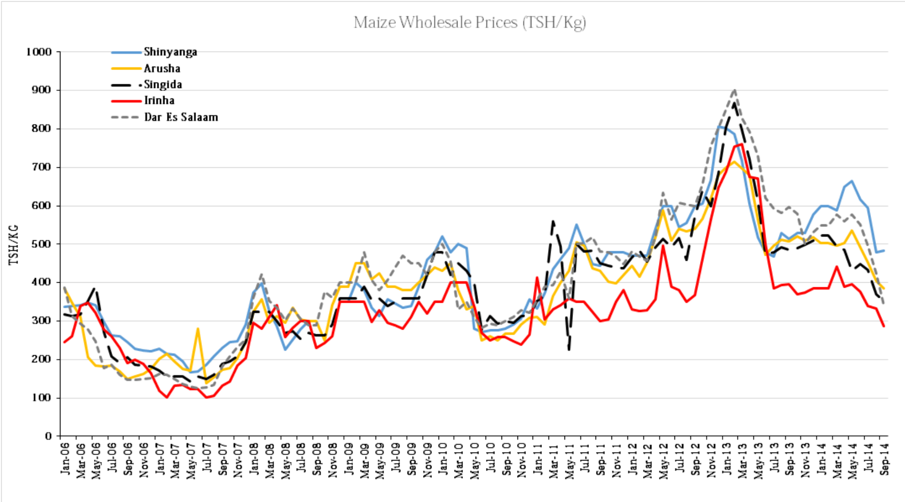

Figure 4.2: Wholesale Prices of Maize (TSH/Kg) in Shinhanga, Arusha, Singida, Irinha, Dar Es Salaam (Tanzania). *Source*: Author's elaboration of WFP-VAM (2014) data.

4.3. Shocks and vulnerability

The vulnerability literature has identified different sources of shocks, characterizing them according to the nature of the event and the magnitude at which they occur. Using Dercon *et al.* (p. 5, 2005) definition, in this paper shocks are defined as "adverse events that lead to a loss of household income, a reduction in consumption and/or a loss in productive assets".

4.3.1. Empirics of shocks

Since information on idiosyncratic and covariate shocks is often lacking in most household surveys[8], our understanding of risk is at the moment relatively incomplete (Toye, 2007). A common conclusion of the recent studies[9] on the effect of idiosyncratic and covariate shocks on vulnerability is that people affected by shocks commonly respond to a welfare reduction[10] by smoothing consumption, increasing the working hours, looking for credit and assistance, adjusting the level of assets or relying on savings and sales. Yet, the outcomes are context specific and depend strongly on the relative incidence of covariate and idiosyncratic shocks (World Bank, 2005).

Since the aim of this paper is to understand how different households change their consumption patterns as a response to price shocks (large fall of crop selling prices, large

[8]By comparing sixteen different households survey, Heltberg *et al.* (2012) provide a general overview on what are the most frequent sources of risk and coping strategies.

[9]Some authors contributed to this literature on vulnerability by analysing only the impact of selected shocks on households' consumption (e.g., Paxson, 1992; Rosenzweig and Binswanger, 1993; Kochar, 1995; Glewwe and Hall, 1998; Gertler and Gruber, 2002; Ligon and Schechter, 2003; Christiaensen and Subbarao, 2004; Skoufias and Quisumbing, 2004; Woolard and Klasen, 2005; Alderman, Hoddinott, and Kinsey, 2006; Gertler *et al.* 2006; Grimm, 2008).

[10]Skoufias and Quisumbing (2004) discussed the impact of shocks on household welfare.

rise of food prices, large rise of agricultural input prices), but these shocks are not exhaustive of all shocks hitting a household (e.g. drought and health shocks), we will provide a broad picture of some of the contributions related to the three most important sources of risks, namely natural disasters, health and price shocks.

As reported by Wagstaff and Lindelow (2014) studies on weather-related shocks normally analyze asset losses determined by shocks, whilst health shocks studies focus more on consumption and labor-market consequences. Concerning natural shocks, Dercon (2004) highlights that rainfall shocks in Ethiopia slowed down the growth of households consumption while Hoddinott and Kinsey (2001), Alderman *et al.* (2006) and Yamano *et al.* (2005) underlined the existence of a causal relationship between rainfall shocks and human capital formation. Hoddinott and Kinsey (2001), by relying on natural experiments, identified the long and short-term impacts of shocks on children born during periods of severe natural or systemic shocks, while Kurosaki (2014) tried to assess which are the types of households most affected by drought and floods shocks. Households may respond to agricultural shocks especially through off-farm labor supply and income to mitigate crop income loss (Kijima, 2006).

In some countries, health shocks have a larger effect on consumption than natural disasters shocks (Heltberg and Lund, 2009). Other recent contributions confirming this finding include Wagstaff (2007), which looks at the effect of health shocks in Vietnam, and Islam and Maitra (2012) that examined the effect of health shocks in Bangladesh.

Regarding the effect of price shocks on consumption Alem and Sodebrom (2012) and Kumar and Quisumbing (2013) investigated how Ethiopian urban households and rural female headed households coped with the 2008 food price shocks. The former concluded that households with lower assets levels as well as households with members engaged in casual works were more affected by high food price shocks. The latter found that female headed households are more vulnerable to food price shocks than male headed households and more likely to experience a food price shock. Furthermore, food price shocks may have a great incidence on the quality of food intake. Brinkman *et al.* (2010), for example, modeled the effect of high food prices on food consumption by employing the Food Consumption Score Index finding that, large numbers of vulnerable individuals reduced the quality and quantity of consumed food as a result of the food price crisis. Not always the most vulnerable households experience the largest consumption fall. For example, D'Souza and Jolliffe (2014), in a study conducted on Afghanistan households, found that the most vulnerable households exhibit no decline in caloric intake when food prices increase, while a stronger variation in the quantity of calories absorbed is registered by households at the top of the caloric intake distribution. A coping strategy usually adopted to buffer against a decline in energy intake is often changing the dietary mix (D'Souza and Jolliffe, 2012).

4.3.2. Shocks in rural and urban Tanzania

To understand the incidence of different risky events we report descriptive statistics on shocks among Tanzanian rural and urban households in 2008/09, 2010/11 and 2012/13. We seek to quantify the incidence of shocks, how severe they were and their degree of dispersion. For each shock we have several information. The enumerators inquired about the incidence of the shocks over the five years prior to the survey, the timing of the shocks, their severity and the costs in terms of income/asset losses and their degree of dispersion, that is, whether the adverse event was experienced by other people in the community (i. e. covariate shocks, such as drought, epidemic illnesses and economic shocks), or if it was faced only at individual household level (i.e. idiosyncratic shocks, like for example chronic illness of an household member, death of other household members). As reported by Sango *et al.* (2007) this distinction is important because households are much more able to insure consumption from the adverse effects of idiosyncratic shocks by making use of informal insurance mechanisms, such as social safety nets, while such networks are inadequate in shielding households' consumption from systemic (covariate) risks (Kochar, 1995; Morduch, 1995; Dercon, 2004, Gunther and Harttgen, 2009; Hoogeveen *et al.*, 2011).

The figures reported in table 4A.1 and tables 4A.2, 4A.3, 4A.4, provide an overview of shocks experienced by Tanzanian households in 2008/09, 2010/11 and 2012/13 expressed as the shares of rural (urban) households hit by a given shock over total rural (urban) households. We split the shocks into seven broader categories: (i) price shocks, (ii) natural disasters, (iii) asset shocks, (iv) employment shocks, (v) health shocks, (vi) crime and safety shocks, (vii) household break-up. Since the majority of households are at least partly engaged in agricultural activities, agricultural shocks account for most of the shocks reported. Price shocks include large fall of crop selling prices, large rise of food prices, large rise of agricultural input prices. Natural disasters comprise drought/flood, water shortage, fire and crop disease. Asset shocks include loss of land, livestock death, dwelling damage. Employment shocks include loss of salaried employment and household business failure. Health shocks comprise death, chronic/severe illness or accident of household members, while crime and safety comprise common theft and violence of all kinds. Separations but also incidents (e.g. jail) are included in household break-up. To facilitate the comparison between shocks, table 4A.1 shows the percentage of urban and rural surveyed households, reporting the incidence of a single/multiple shock in 2008/09, 2010/11 and 2012/13.

Looking across our sample we notice that food price shocks, natural disasters and health shocks clearly stand out as the most frequent shocks. In particular, food price rise affects more than two-third households. This is the most common shock registered in all years. This evidence is not surprising because the surveys were conducted during or in the aftermaths of the 2008 and 2010 peaks of the food price crisis[11]. It is also evident from table 4A.1 that

[11] These figures confirm the findings of Heltberg *et al.* (2012) about the incidence of the food price crisis on both rural and urban households.

rural households are more sensitive than urban households to large fall in crop prices as well as to large rise in agricultural input prices. Conditional to the occurrence of a shock, rural households are more likely than urban respondents to experience natural disasters and asset shocks (i.e. livestock dead 13-28 percent). Droughts/floods and crop disease rank high among shocks. They are reported as shock by approximately one-third of the rural households against 7% and 14% of urban households, respectively, in the case of crop disease shock and drought/flood shock. Some shocks are relatively common among both urban and rural households. For example the proportion of rural and urban households being affected by severe water shortage or death of other family member is similar (with higher values registered for urban households). On the other hand, some other shocks like dwelling damages (0-1%), loss of land (1-4%), employment shocks (1-9%), household break-up shocks (0-8%) are far less frequent.

Respondents were also asked to rank shocks by severity (table 4A.2). Both rural and urban respondents reported perceived shocks mostly as high impact shocks. The finding may indicate that respondents recall shocks more often when the shocks are severe or the respondents perceive them as severely affecting household welfare. Among the events ranked by households as most serious, there are primarily health-related shocks. More than two-thirds of the households that suffered the death of a household member reported this as the "most severe". Also, the death of a member of another family is found to be among the most severe shocks. Fire destroying dwelling or assets, it is also a serious concern for households. Although it affects a small number of individuals, it is considered a very critical shock by half of the respondents who have experienced it. The same goes for household break-up shocks. Except for the price shock of agricultural inputs, which is described as the most severe shock by one third of rural households, it can be concluded that households tend to perceive idiosyncratic shocks as the most serious shocks (see table 4A.4). This is true for both rural and urban households. However, rural households tend to suffer less the employment shocks. The relationships between idiosyncratic shocks and the severity ranking emerge even more when comparing this shock with more covariant shocks. For example, the incidence of price rise is rated as the most critical shock only by the 15% of rural households and by the 11% of urban households, as well as the fall in sales prices of crops is assessed as most severe by 12-16% of households.

Many shocks have significant adverse effects. Table 4A.3 reports the extent to which shocks have different costs among households. We identify three different consequences: income loss, asset loss and a combination of income and asset losses. On average, shocks cause more adverse consequences in terms of income than in terms of assets. Assets are usually depleted when they are stolen (e.g. livestock stolen), in case of fire or when the dwelling is damaged or destroyed. In the other cases, the households mainly report income reduction as a consequence of a shock. A more pronounced effect is observed for those households who bear the brunt of the impact of price volatility and natural disasters even if the differences between the shocks are similar, and it is quite difficult to single out which are the most relevant in terms of income reduction.

Table 4A.4 shows the degree of dispersion of each shock, i.e. covariate vs. idiosyncratic shocks. In doing this, the respondents were asked to estimate whether the impact of each shock occurred for: their household, some other households, most households, all households. We categorize shocks as idiosyncratic if they belong to the first two groups and as covariate if they belong to the last two groups. As expected, in both rural and urban subsamples, responses reveal that price shocks and natural disasters can be defined as covariate shocks. The remaining shocks are idiosyncratic.

4.4. Methodology

4.4.1. Theoretical Framework

Hoddinott and Quisumbing (2003) identified three different approaches to assess vulnerability. The first one links vulnerability with high expected poverty (VEP), considering it as the probability of consumption falling below an ex-ante defined poverty line (Christiaensen and Boisvert, 2000; Chauduri, 2000; Chauduri *et al.* 2002, Pritchett *et al.*, 2000, and Kamanou and Morduch, 2004).

To this end, it adapts to a stochastic environment the standard FGT index (Foster *et al.*, 1984) and derives its expected value as follows:

$$V_{\alpha,ht} = F(z) \int_0^z (max \left(\left\{ 0, \frac{z - c_{h,t+1}}{z} \right\} \right)^\alpha \frac{f(c_{h,t+1})}{F(z)} dc_{h,t+1} \tag{4.1}$$

where c_h is household's consumption; z is the standard poverty line, while $F(.)$ and $f(.)$ are the cumulative distribution and the density function of consumption at time $t+1$[12], respectively eq. (4.1) measures the probability of falling below the poverty line, i.e. $F(z)$, multiplied by a conditional probability-weighted function of the shortfall below this poverty line (Christiaensen and Boisvert, 2000). Depending on whether we rely on the headcount measurement of poverty ($\alpha = 0$) or not[13], the VEP measure reduces to the probability that the household will experience poverty, i.e. $V = F(z)$.

The second approach associates vulnerability with low expected utility (VEU) (Ligon and Schechter, 2003). It assesses vulnerability as the difference between the utility derived from some level of certainty-equivalent consumption analogous to the choice of a poverty line in the literature of poverty measurement, z (above which the household would not be considered vulnerable), and the expected value of the actual utility of the household from

[12] Eq. (4.1) is obtained by multiplying the expected value of the poverty index by $\frac{F(z)}{F(z)}$. For more information on the derivation procedure of Eq. (4.1), see Christiaensen and Boisvert (2000).

[13] For instance, some studies employ depth of poverty ($\alpha = 1$) (see, for example, Ravallion, 1988).

its (risky) stream of consumption, as follows:

$$v_i = U_h(z_{ce}) - EU_i(c_i) \tag{4.2}$$

where U_h is a weakly concave, strictly increasing function. This can be rewritten as:

$$V_i = [U_i(z_{ce}) - U_i(Ec_i)] + [U_i(Ec_i) - EU_i(c_i)]. \tag{4.3}$$

The first bracketed term $[U_i(z_{ce})-U_i(Ec_i)]$ measures poverty, it is basically the difference between a concave function evaluated at the 'poverty line' and at household i's expected consumption expenditure. The second term is a measure of the risk that the household faces. As Ligon and Schechter (2003) show, this term can be split up into a measure of aggregate risk and a measure of idiosyncratic risk. Thus we can write:

$$\begin{aligned} V_i = {} & [U_i(z_{ce}) - U_i(Ec_i)] + \\ & + \{U_i(Ec_i) - EU_i[E(c_i|x)])\} + \\ & + \{EU_i[E(c_i|x)] - EU_i(c_i)\}\,. \end{aligned} \tag{4.4}$$

with $E(c_i|x)$ is the expected value of consumption, conditional on a vector of covariant variables x. The second term $\{U_i(Ec_i) - EU_i[E(c_i|x)])\}$ represents the aggregate risk faced by the household i, and finally $\{EU_i[E(c_i|x)] - EU_i(c_i)\}$ is a term expressing the idiosyncratic risk the household faces. When risks are not managed in an effective way, shocks may result in a fall in consumption and hence welfare losses. For this reason we need to use an ex-post measurement of vulnerability, which corresponds to the so called Uninsured Exposure to Risk (VER). This is the third measure of vulnerability, and it is based on an ex-post assessment of the extent to which a negative shock causes welfare loss (Hoddinott and Quisumbing, 2003; Skoufias, 2003). This approach, which is mainly based on regressions of panel datasets containing the consumption levels of specific households before and after a specific shock, analyzes how households manage to smooth their consumptions over time, and categorizes households as vulnerable (Deressa *et al.*, 2009).

To get an estimate of such vulnerability, let h denote the *h-th* household living in village v at time t. Let's define the dependent variable, $\Delta lnFC_{htv}$, as the difference between log food consumption between $t-1$ and t, i.e. the rate of food consumption over the period under consideration. Then the impact of the shocks occurred between $t-1$ and t on the food consumption of the *h-th* household can be estimated according to the following relationship:

$$\Delta lnFC_{htv} = \Sigma_i \alpha_i CS(i)_{tv} + \Sigma_i \beta_i IS(i)_{htv} + \sigma_{tv}\delta_{tv}D_{tv} + \gamma X_{hvt} + \phi Z_{hv} + \Delta\epsilon_{hvt} \tag{4.5}$$

where, $CS(i)_{tv}$ is a vector of covariant shocks occurred between $t-1$ and t, $IS(i)_{htv}$ is a vector of idiosyncratic shocks over the same period, D_{tv} is a set of dichotomous variables identifying each community, X_{hvt} and Z_{hv} are respectively time varying and time invariant household characteristics, and $\Delta\epsilon_{hvt}$ is a household-specific stochastic error term[14].

The estimated values for α and β identify the magnitude of the impacts of covariate and idiosyncratic shocks, respectively, net of the mitigating role played by private coping strategies and public responses: by quantifying the impact of these shocks this approach identifies which risks would be an appropriate focus of policy. Moreover, considering the well-known asymmetric impact of positive and negative shocks, it may be useful to disaggregate the shock variables into positive and negative shock components (Dercon and Krishnan, 2003).

4.5. Data and Variables

4.5.1. Data and sample household

We use household data from the 2008/09, 2010/11 and 2012/13 Tanzania National Panel Survey (TZNPS Y1, Y2 and Y3). The surveys are part of the World Bank's Living Standards Measurement Study - Integrated Surveys on Agriculture (LSMS - ISA) and are the subsequent rounds of a series of three household panel surveys. The TZNPS Y1 was administered between October 2008 and October 2009 and covered 3,265 households and about 16,709 individuals. The TZNPS Y2 started in October 2010 and ended in September 2011, interviewing the same households of TZNPS Y1 plus some more households totaling 3,924 households and 20,559 individuals. Household members leaving their original households in order to start new households of their own or move with other households explains the increase. Marriage and migration are the most common reasons for households splitting over time. The last wave, TZNPS Y3, consists of 5,010 households (and 25,412 individuals) including all households already surveyed in the previous two rounds. Similarly, the duration and timing of the field work for the third round ranged from October 2012 to November 2013. These survey are based on a multi-stage, stratified, random sampling of Tanzanian households which is representative at the national, urban/rural, and agro-ecological level. Therefore the final sample consists of 59,475 units, that, after tracking the individuals over time reduces to 58,022 units.

4.5.2. Estimation model

In this section, we introduce the estimation model and describe the variables employed to address the hypothesis introduced previously. In order to measure the impacts of price

[14]The literature on vulnerability as uninsured exposure to risk uses four variants of the equation (4.5). All four specifications include controls for fixed household characteristics (sex, ehtnicity, education level of household head) or by estimating the model using household level fixed effects but they model the shocks differently (see Hoddinott and Quisumbing (2003) for a complete review).

shocks and other idiosyncratic and covariate shocks on the food caloric intake, we specify the food consumption at the individual level as a function of the shocks, as well as household and individual characteristics. The model specification of the food caloric intake of individual i, in household j, at year t, denoted by y_{ijt}, is reported in levels[15] as follows:

$$y_{ijt} = \beta_0 + \beta_1 P_{jt} + \beta_2 S_{jt} + \beta_3 X_{it} + \beta_4 Z_{jt} + \gamma_{ij} + \eta_t + \epsilon_{ijt} \tag{4.6}$$

where P is a vector of price shock variables, S represents a vector of non-price shock variables, X is a vector of variables of individual characteristics, Z is a vector of household characteristics. γ are the individual time-invariant fixed effects (such as for example eating habits or food preferences), η represents the year effects, and ϵ is an error term which is IID $\sim N(0, \sigma^2)$. We assume that individual fixed effects can be captured by a separate constant for each individual. The use of time-invariant individual fixed effects is necessary to remove unobserved time-invariant factors at the individual level. The failure to control for these individual-specific attributes will produce omitted variable bias if the omitted factors are correlated with observed covariates. Regarding the dependent variable we use the per capita daily caloric food intake, which is also a measure of household food security. It basically relates to the access to food and is a widely used measure of health and undernutrition. We employ the Tanzania Food Composition Tables (Lukmanji, 2008) to convert the total reported household food consumption[16] over the seven days prior to the interview into kilo-calories. We then obtain per capita daily caloric intake by dividing the total kilo-calories by the household size expressed in adult equivalents[17]. Following WFP (2012) we incorporate in the effective number of household members eating at home, also the number of "guests eating meals within home".

As for variables representing price shocks, we build three dummies aimed at identifying whether over the past five years the household was severely negatively affected by (i) "large fall in sale prices for crops"[18], (ii) "large rise in prices of food", (iii) "large rise in agricultural input prices". We control also for covariant shocks by setting up a dummy which is equal to 1 if a natural disaster (i.e. drought/floods) hit the household in the past five years, and idiosyncratic shocks controlling for the households experiencing chronic/severe illness of a household member. By using this model we assess whether food caloric intake increases/decreases after food price shocks and if the responses are different when considering idiosyncratic and covariate shocks.

As regressors for the household characteristics (vector Z_{jt} in equation (4.6)) we include

[15] We represent our model in levels by taking advantage from having a three years-panel dataset. This specification differs slightly from the cross-section specification reported in (4.5)

[16] Total food consumption was based on a list of regularly consumed local foods from the different food groups (cereals, roots and tubers, vegetables and fruits, meat and fish, fats).

[17] We adopt the nutrition (calories) based equivalence scales used by Dercon and Krishnan (1998).

[18] The household respondent was asked "Did you experience in the past five years a "large fall in sale prices for crops"?"

demographic composition (number of household members, number of children, sex ratio and dependency ratio), the characteristics of the household head (sex, education[19] and whether he/she is employed in agriculture/livestock), the average land acreage owned by the household, a set of productive assets indices[20], wealth indices[21] and the household net position in the market. Finally we include an index of source of income diversity, since households with more diversified income sources can better mitigate the effect of shocks. As controls for individual characteristics that determine food consumption variation (vector X_{jt} in equation (4.6)) we include roster information (i.e. age of the individual), education (three different dummies (=1) if the individual has completed respectively primary school, secondary school or university) and income source from agricultural activity (a dummy (=1) if the household member works in agriculture). Summary statistics are reported in table 4A.7.

4.6. Results and Discussion

4.6.1. Model Specification: Rural vs Urban

Table 4.1 reports model (4.6) fixed effects estimates for the overall, rural and urban samples at individual level. The signs of the coefficients are generally in line with theory, and several coefficients are large relative to their standard errors. In all regressions, standard errors are robust to heteroskedasticity.

Table 4.1 focuses on the overall sample, presenting a fixed effects estimator of the log of food caloric intake on levels of individual and household characteristics, and a set of covariate and idiosyncratic shock variables.

In the overall sample specification the findings are broadly consistent, with several variables among the controls having statistically significant coefficients. First of all, female-headed households consumption is positive and statistically significant: this result, which seems counterintuitive, confirms the findings of Christiansen and Sarris (2007). Two explanations can be offered. First, female heads may be much more concerned about children's health and decide to allocate a larger share of their expenditure to children nutrition. A second explanation could be that since female headed households are often the chief earners as well as being responsible for the whole household, they are more likely to report accurate information about household food consumption. This emphasizes the existence of a bias in the estimation, inflating the consumption level for female headed and understating that of male headed households (Louat *et al.*, 1993). Age is negative for rural households

[19] The education of the household head variable ranges between 0 and 3. It equals 0 if the household head has not completed primary school, and is equal to 1, 2, 3 if the household head has completed primary, secondary, and post-secondary education respectively.

[20] Three indexes including the ownership of base agricultural assets, sophisticated agricultural assets and animals (cf. table 4B.2 for details on the composition of these assets).

[21] Which serve as proxy for household economic status. They include a set of asset indicators, household quality and access to services. For more information see table 4B.1.

and positive for urban households, both significant at 10%. Head of households' education clearly matters. Our results for the overall sample show that this has a positive impact on food caloric intake. This effect is also statistically significant among rural individuals. Looking at the individual effect of the education level we notice that the only significant results are registered at urban level for those individuals holding a primary education and a post-secondary education. This might be plausible because of the larger remunerative employment opportunities for the better educated in urban areas. Regarding the effect of the household size on daily food caloric intake, we find a negative and statistically significant correlation at 1 percent level. The larger the household, the lower tends to be the per-capita consumption. As expected, consumption falls as the number of children within the household increases. We note that households with more children (urban in particular), consume, on average, less, suggesting that they are (*ceteris paribus*) more vulnerable. Households with higher dependency ratios, particularly rural, tend to be more vulnerable. Two out of three wealth indices, namely the Housing Quality Index and the Consumer Durables Index have positive and statistically significant effects on per capita consumption. The Quality/Access to services index is negative and statistically significant for both the overall and rural specifications. Regarding labour variables (i.e. employment in agriculture/livestock), we do not find any significant effect, neither for individuals, nor for households heads. Conversely, we do find a statistically significant effect of income diversification in the total and rural samples.

Table 4.1: Econometric results: basis specification

	Overall log(Caloric Intake)		Rural log(Caloric Intake)		Urban log(Caloric Intake)	
Head is female	0.045**	(2.69)	0.021	(1.01)	0.074*	(2.39)
Age of head	-0.013	(-0.63)	-0.054*	(-2.15)	0.119*	(2.49)
Educ of Head	0.038**	(3.12)	0.068***	(4.71)	0.040	(1.75)
HH size	-0.250***	(-8.72)	-0.264***	(-6.78)	-0.211***	(-4.94)
Number of Children	-0.021	(-0.76)	0.020	(0.53)	-0.115**	(-2.89)
Sex Ratio	0.002	(0.20)	0.007	(0.61)	-0.002	(-0.08)
Dependency Ratio	-0.064***	(-4.60)	-0.080***	(-4.72)	0.009	(0.37)
Primary education	0.015	(1.41)	0.003	(0.24)	0.044*	(1.97)
Secondary education	-0.014	(-1.04)	-0.025	(-1.77)	0.027	(0.91)
University education	0.010	(0.98)	-0.003	(-0.24)	0.042*	(2.18)
Head works in Agri/Livestock	0.003	(0.32)	0.012	(1.12)	0.010	(0.50)
Ind works in Agri/Livestock	-0.009	(-0.83)	-0.012	(-0.91)	0.011	(0.58)
Income Diversity	0.027**	(3.11)	0.039***	(3.63)	0.027	(1.67)
Acres of land	0.035***	(4.39)	0.042**	(2.95)	0.024*	(2.44)
Asset Sofisticated Index	0.030***	(3.80)	0.030**	(2.86)		
Animal index	0.126***	(13.90)	0.125***	(11.72)		
Asset base index	-0.007	(-1.03)	-0.004	(-0.38)		
Housing quality index	0.067***	(6.70)	0.063***	(5.33)	0.077***	(5.58)
Quality/access to services index	-0.036***	(-4.82)	-0.053***	(-6.73)	0.007	(0.47)
Consumer durable index	0.104***	(9.88)	0.105***	(8.82)	0.138***	(6.99)
Cash crop seller	-0.003	(-0.39)	0.013	(1.41)	-0.060***	(-4.44)
Staple Food Buyer	0.134***	(17.56)	0.119***	(15.05)	0.209***	(9.03)
Shock illness	-0.007	(-1.09)	0.015	(1.91)	-0.040***	(-3.64)
Shock drought/flood	0.030***	(4.91)	0.022**	(3.01)	0.036**	(2.83)
Shock P fall	-0.000	(-0.07)	-0.005	(-0.81)	0.019*	(2.45)
Shock P rise	-0.007	(-1.20)	0.010	(1.48)	-0.021	(-1.74)
Shock P input rise	-0.022*	(2.40)	0.010	(1.67)	-0.026**	(-2.58)
Observations	58022		40015		18007	
R^2	0.053		0.055		0.085	
F	44.92		31.70		20.16	

Standardized beta coefficients; t statistics in parentheses

Note: The dependent variable is food consumption, as measured by logarithm of per capita daily calories intake. We control for individual fixed effects and we include year dummies (not reported) in all the regressions. Standard errors (corrected for heteroskedasticity) are reported in parenthesis. The symbols ***, **, * indicate that coefficients are statistically significant respectively at the 1, 5, and 10 percent level.

Households with larger landholdings experience an increase in consumption, reinforcing the finding that economic growth experienced by Tanzania between 2008 and 2012 was mainly based on agriculture (see the figures reported in Table 4A.6). The signs of these partial correlations appear reasonable.

Looking at the impact of the shock variables on consumption, which is the main focus of this paper, we notice that in the overall, rural and urban specifications all the statistically significant coefficients are of the expected sign (negative) with the exception of the natural shocks (drought/flood), which are surprisingly positive. One possible explanation could be that this variable embraces both drought and flood shocks, since respondents were asked about the perception of both types of shock and their response was recorded under the same variable. Furthermore, severe/chronic illness shocks have a negative and statistically significant impact on consumption only for urban households. As expected, a food price fall results in an increase in purchasing power and higher consumption. This effect is particularly robust in urban areas where we record a higher share of food buyer households[22]. Food

[22]The share of food buyers in urban vis-a-vis rural areas is 95% vs 77%, see table 4A.8 in the Appendix).

price rise shocks are not statistically significant, while shocks regarding price of input rise are statistically significant and play a negative role on food consumption for both the overall and urban sample.

4.6.2. Market participation and shock severity

The estimates reported in the previous section provide a broad understanding of the effects of shocks on food caloric intake. However the causal effect of price shocks on food caloric intake, which are surprisingly not significant, may be due to the fact that we did not take explicity in consideration the households' market position. For instance, crop price fall may generate significant benefits for food buyers, but at the same time can worsen the conditions for cash crop sellers while the inverse happens for food price surges, which worsen the welfare of net consuming households and favour the income of producers. Therefore, to better investigate the extent by which the effect of price shocks may differ among staple food buyers (rice, maize, sorghum, wheat and cassava) and cash crops sellers, we run additional fixed effects regressions including an interaction term between the price shock variable and the dummies for staple food buyers and cash crop sellers. At the same time we control also for the effect of natural shocks on staple food buyers and cash crop sellers. Results for rural and urban households are provided in Table 4.2, in columns (2) and (5) respectively.

Concerning the price of input rise, we control for the interaction with crop sellers, since we are aware that the effect of the relative impact of the recent dramatic increases in input costs (i.e. pesticides, fertilizers, fuel) may have had a direct effect in particular on producers. We find price of inputs rise being the only statistically significant interaction. It clearly matters when interacted with cash crop sellers: about 3.5% decline in food caloric intake is registered for rural households. This impact is lower in magnitude and significant at 5% level for urban residents, which experience a decline in food caloric intake of about 1.7%. The occurrence of natural shocks is negative and statistically significant for urban staple food buyers, whereas we register no impact in the rural sub-sample.

In columns (3) and (6) of Table 4.2, we report the estimates of the model including the interaction of the severity of price shocks with staple food buyers and cash crop sellers. We rely on respondents' self-reported classification of the severity of shocks they had experienced. The occurrence of both severe food price increases and input price upsurges has indeed a consistently negative impact on food caloric intake. The estimates are significant for rural staple food buyer (the former) and urban cash crop sellers (the latter). At the same time the effect of the interaction between price rise and staple food buyers becomes significant at 1 percent level in the rural subsample.

Table 4.2: Econometric results: impact of price, idiosyncratic and covariate shocks on food caloric intake in rural and urban areas

	(1) log(Caloric Intake)		(2) log(Caloric Intake)		(3) log(Caloric Intake)		(4) log(Caloric Intake)		(5) log(Caloric Intake)		(6) log(Caloric Intake)	
	Rural		Rural		Rural		Urban		Urban		Urban	
Head is female	0.021	(1.01)	0.023	(1.10)	0.042*	(1.98)	0.074*	(2.39)	0.075*	(2.47)	0.081**	(2.64)
Age of head	-0.054*	(-2.15)	-0.053*	(-2.11)	0.006	(0.23)	0.119*	(2.49)	0.122**	(2.60)	0.146**	(3.00)
Educ of Head	0.068***	(4.71)	0.065***	(4.52)	0.066***	(4.62)	0.040	(1.75)	0.042	(1.86)	0.047*	(2.05)
HH size	-0.264***	(-6.78)	-0.262***	(-6.76)	-0.247***	(-6.48)	-0.211***	(-4.94)	-0.226***	(-5.33)	-0.234***	(-5.54)
Number of Children	0.020	(0.53)	0.016	(0.43)	-0.000	(-0.00)	-0.115**	(-2.89)	-0.095*	(-2.40)	-0.093*	(-2.35)
Sex Ratio	0.007	(0.61)	0.009	(0.72)	0.006	(0.52)	-0.002	(-0.08)	-0.004	(-0.15)	-0.003	(-0.13)
Dependency Ratio	-0.080***	(-4.72)	-0.080***	(-4.74)	-0.081***	(-4.84)	0.009	(0.37)	-0.007	(-0.29)	-0.007	(-0.31)
Primary education	0.003	(0.24)	0.004	(0.33)	0.036**	(2.75)	0.044*	(1.97)	0.044*	(1.99)	0.052*	(2.33)
Secondary education	-0.025	(-1.77)	-0.024	(-1.64)	0.015	(1.06)	0.027	(0.91)	0.031	(1.05)	0.044	(1.46)
University education	-0.003	(-0.24)	-0.002	(-0.18)	0.010	(0.80)	0.042*	(2.18)	0.043*	(2.25)	0.049*	(2.57)
Head works in Agri/Livestock	0.012	(1.12)	0.013	(1.18)	0.000	(0.02)	0.010	(0.50)	0.011	(0.57)	0.008	(0.42)
Ind works in Agri/Livestock	-0.012	(-0.91)	-0.011	(-0.85)	-0.004	(-0.31)	0.011	(0.58)	0.014	(0.74)	0.016	(0.84)
Income Diversity	0.039***	(3.63)	0.038***	(3.52)	0.020	(1.92)	0.027	(1.67)	0.029	(1.77)	0.020	(1.19)
Acres of land	0.042**	(2.95)	0.042**	(2.98)	0.040**	(2.82)	0.024*	(2.44)	0.022*	(2.22)	0.023*	(2.30)
Asset Sofisticated Index	0.030**	(2.86)	0.030**	(2.89)	0.031**	(3.06)						
Animal index	0.125***	(11.72)	0.123***	(11.61)	0.099***	(9.14)						
Asset base index	-0.004	(-0.38)	-0.003	(-0.36)	-0.010	(-1.01)						
Housing quality index	0.063***	(5.33)	0.065***	(5.33)	0.089***	(7.29)	0.077***	(5.58)	0.080***	(5.83)	0.082***	(5.83)
Quality/access to services index	-0.053***	(-6.73)	-0.049***	(-5.53)	-0.027**	(-3.02)	0.007	(0.47)	0.002	(0.14)	-0.004	(-0.30)
Consumer durable index	0.105***	(8.82)	0.105***	(8.79)	0.114***	(9.59)	0.138***	(6.99)	0.134***	(6.90)	0.131***	(6.68)
Cash crop seller	0.013	(1.41)	0.024*	(2.31)	0.026**	(2.58)	-0.060***	(-4.44)	-0.050***	(-3.89)	-0.050***	(-3.83)
Staple Food Buyer	0.119***	(15.05)	0.128***	(13.28)	0.093***	(9.33)	0.209***	(9.03)	0.274***	(9.86)	0.273***	(9.75)
Shock illness	0.015	(1.91)	0.014	(1.84)	0.005	(0.61)	-0.040***	(-3.64)	-0.041***	(-3.74)	-0.041***	(-3.72)
Shock drought/flood	0.022**	(3.01)	0.042**	(2.91)	0.041**	(2.88)	0.036**	(2.83)	0.401***	(6.75)	0.408***	(6.82)
Shock P fall	-0.005	(-0.81)	0.001	(0.13)	0.003	(0.28)	0.019*	(2.45)	0.019	(1.04)	0.018	(0.97)
Shock P rise	0.010	(1.48)	0.012	(1.72)	-0.003	(-0.45)	-0.021	(-1.74)	-0.027*	(-2.13)	-0.029*	(-2.11)
Shock P input rise	0.010	(1.67)	-0.014	(-1.64)	-0.013	(-1.53)	-0.026**	(-2.58)	-0.025*	(-2.31)	-0.025*	(-2.26)
Drought/flood * Staple Food Buyer			-0.021	(-1.59)	-0.015	(-1.14)			-0.388***	(-6.67)	-0.395***	(-6.75)
Drought/flood * Cash Crop Seller			-0.010	(-0.98)	-0.008	(-0.83)			-0.001	(-0.07)	-0.005	(-0.43)
P fall * Staple Food Buyer			-0.008	(-0.81)	-0.014	(-1.44)			-0.011	(-0.57)	-0.006	(-0.34)
P rise * Staple Food Buyer			0.010	(1.44)	-0.043***	(-5.88)			-0.005	(-0.48)	-0.007	(-0.73)
P input rise * Cash Crop Seller			-0.035***	(-4.85)	-0.034***	(-4.49)			-0.017**	(-2.60)	-0.015*	(-2.35)
Severity P fall * Staple Food Buyer					0.004	(0.68)					-0.005	(-0.69)
Severity P rise * Staple Food Buyer					-0.021**	(-3.22)					-0.001	(-0.09)
Severity P input rise * Cash Crop Seller					-0.003	(-0.46)					-0.027*	(-2.55)
Observations	40015		40015		40013		18007		18007		18005	
R^2	0.055		0.056		0.070		0.085		0.098		0.100	
F	31.70		28.06		32.73		20.16		17.18		15.65	

Standardized beta coefficients; t statistics in parentheses

Note: The dependent variable is food consumption, as measured by logarithm of per capita daily calories intake. We control for individual fixed effects and we include year dummies (not reported) in all the regressions. Standard errors (corrected for heteroskedasticity) are reported in parenthesis. The symbols ***, **, * indicate that coefficients are statistically significant respectively at the 1, 5, and 10 percent level.

4.6.3. Differentiated impacts of shocks among households

In the previous section we basically addressed whether different types of shocks had an impact on food caloric intake among rural and urban households, estimating their magnitude and disentangling their impact among staple food buyers and cash crop sellers.

In this section we will examine the heterogeneity of the impact of price shocks, natural shocks (drought/flood), and idiosyncratic shocks on food caloric intake by interacting them with the households characteristics. We perform separate regressions for rural (Tab. 4.3) and urban (Tab. 4.4) residents. We selected some of the households characteristics that resulted to have statistically significant coefficients in the analysis reported in table 4.2 and we interacted them with the shock terms. The right hand variables are the following: dependency ratio, household head education, primary school education, sex of the household head, acres of land owned, number of children, household size and age of the household head. We find the following:

Dependency ratio. First of all, households with more dependent members (elderly and children) are less able to insulate their consumption from a natural shock. This is particularly evident for rural households. The same applies for the idiosyncratic shocks, whose interaction with the dependency ratio variable results in a negative and statistically significant coefficient for both rural and urban households, with a greater incidence for the latter group. As the number of households members in working age declines, the ability of the household to bear the exogenous risk decreases.

The relative importance of price of input shocks is confirmed to be much higher for rural than for urban households. More precisely, whereas among urban households the interaction between price of input rise and dependency ratio coefficient is not significant, among rural households the latter is positive and significant at 1% level.

Education. Education is an important tool to acquire competences and skills that could directly or indirectly impact individual's capacity to cope with a shock. Individuals with a higher level of education may have enhanced access to and higher ability to understand and evaluate information, including those related to markets, climate risks or self-protection (Jerit *et al.* 2006). Having at least a primary school degree helps to bear the risk of food price rise shocks (positive and statistically significant coefficient for urban households) but it is evidently not sufficient to mitigate the impact of price of input rise, since a higher level of education may be required, for example to adopt much more sustainable farming practices which limit the use of inputs. However, when price of input rise, rural households with better educated heads consume 3.7% more than households with less educated heads.

Female headed. All the interaction terms using female headed households do not show significant coefficients, showing that there are not relevant differences between male/female headed households in terms of shocks perception.

Land holding. Owning land mitigates the effects of climate shocks, in both rural and urban contexts, since landholdings may have the effect of reducing households' vulnerability by improving their ability in resource allocation. Same effect is registered for food price rise in rural context, and food price fall and illness in urban areas. The coefficient is negative for price rise in urban areas. Similar results were found by Kurosaki (2014).

Household Size. The interaction term of household size with non-price shocks is significant and negative only among urban households: larger households are less able to mitigate the effect of natural and idiosyncratic shocks on food intake than the smaller ones. Regarding the ability to mitigate the effects of price movements, we find statistically significant coefficients only among rural households: individuals belonging to larger ones experience an (i) increase of their total caloric intake as a consequence of a price fall and (ii) a decrease when price of inputs rise.

Children. Households with many children living in urban areas are particularly affected by natural risks (the coefficient is negative and significant at 5%). In rural areas, households with a large number of children are also pretty sensitive to food price shocks: we estimate a decrease in total daily caloric intake of about 7% as a response to a crop sale prices fall and of about 10% as a response to a price of inputs increase.

Age. In seven out of ten specifications, age of head has a statistically significant effect on the daily calories intake. Households headed by older individuals experience a larger consumption decline when hit by natural and idiosyncratic shocks, particularly in urban areas. The age of household head is always statistically significant and negative when the household characteristics are interacted with price of input shocks, idiosyncratic and natural shocks and positive and statistically significant in case of food price surges.

Table 4.3: Heterogeneity in the marginal impact of shocks on individual and household characteristics in rural areas

	(1)		(2)		(3)		(4)		(5)	
	log(Caloric Intake)		log(Caloric Intake)		log(Caloric Intake)		log(Caloric Intake)		log(Caloric Intake)	
Head is female	-0.008	(-0.37)	-0.005	(-0.22)	-0.007	(-0.30)	-0.008	(-0.37)	-0.006	(-0.29)
Age of Head	-0.085***	(-3.49)	-0.080***	(-3.34)	-0.088***	(-3.65)	-0.099***	(-4.05)	-0.089***	(-3.71)
Educ of Head	0.083***	(5.61)	0.083***	(5.62)	-0.044	(-1.30)	0.076***	(5.03)	0.072***	(4.88)
HH size	-0.244***	(-10.61)	-0.224***	(-9.63)	-0.237***	(-10.19)	-0.243***	(-10.17)	0.133	(1.18)
Dependency Ratio	-0.044***	(-3.75)	-0.045***	(-4.02)	-0.050***	(-4.55)	-0.050***	(-4.19)	-0.058***	(-5.18)
Primary education	0.004	(0.35)	0.000	(0.04)	0.002	(0.21)	0.005	(0.39)	0.003	(0.30)
Acres of Land	0.008	(0.77)	0.008	(0.72)	0.010	(0.95)	0.008	(0.71)	0.010	(0.92)
Children	-0.010	(0.55)	-0.010	(0.53)	-0.009	(0.50)	-0.013	(0.70)	-0.012	(0.67)
Shock drought/flood	0.070	(1.93)								
Drought * Dep_ratio	-0.046*	(-2.43)								
Drought * Head Educ	-0.018	(-1.32)								
Drought * Female head	0.004	(0.50)								
Drought * Landholding	0.031***	(3.47)								
Drought * Primary	-0.005	(-0.46)								
Drought * HH Size	-0.062	(-1.12)								
Drought * Children	0.068	(1.45)								
Drought * Age	-0.007	(-0.23)								
Shock illness			0.009	(6.31)						
Illness * Dep_ratio			-0.046*	(-2.40)						
Illness * Head Educ			-0.025	(-1.59)						
Illness * Female head			-0.011	(-1.14)						
Illness * Landholding			-0.012	(-1.15)						
Illness * Primary			0.004	(0.35)						
Illness * HH Size			-0.066	(-1.51)						
Illness * Children			-0.009	(-0.26)						
Illness * Age			-0.095**	(-2.88)						
Shock P fall					0.044	(1.53)				
P Fall * Dep_ratio					-0.017	(-1.36)				
P Fall * Head Educ					0.132***	(3.97)				
P Fall * Female head					-0.001	(-0.10)				
P Fall * Landholding					-0.004	(-0.37)				
P Fall * Primary					-0.003	(-0.40)				
P Fall * HH Size					0.115**	(2.94)				
P Fall * Children					-0.071*	(-2.31)				
P Fall * Age					-0.035	(-1.36)				
Shock P rise							-0.077	(-1.90)		
P Rise * Dep_ratio							-0.008	(-0.43)		
P Rise * Head Educ							-0.000	(-0.03)		
P Rise * Female head							0.004	(0.40)		
P Rise * Landholding							0.054***	(3.39)		
P Rise * Primary							-0.006	(-0.64)		
P Rise * HH Size							0.047	(1.07)		
P Rise * Children							-0.028	(-0.74)		
P Rise * Age							0.075*	(2.26)		
Shock P input rise									-0.095***	(-4.09)
P Input Rise * Dep_ratio									0.055***	(3.75)
P Input Rise * Head Educ									0.037**	(3.00)
P Input Rise * Female head									-0.007	(-1.33)
P Input Rise * Landholding									0.001	(0.09)
P Input Rise * Primary									-0.006	(-0.72)
P Input Rise * HH Size									-0.379***	(-3.31)
P Input Rise * Children									-0.100***	(-3.33)
P Input Rise * Age									-0.002*	(-0.13)
Observations	40059		40059		40059		40059		40059	
R^2	0.020		0.022		0.020		0.021		0.020	
F	17.02		18.25		15.80		15.65		17.06	

Standardized beta coefficients; t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: The dependent variable is food consumption, as measured by logarithm of per capita daily calories intake. We control for individual fixed effects and we include year dummies (not reported) in all the regressions. Standard errors (corrected for heteroskedasticity) are reported in parenthesis. The symbols ***, **, * indicate that coefficients are statistically significant respectively at the 1, 5, and 10 percent level.

Table 4.4: Heterogeneity in the marginal impact of shocks on individual and household characteristics in urban areas

	(1)		(2)		(3)		(4)		(5)	
	log(Caloric Intake)		log(Caloric Intake)		log(Caloric Intake)		log(Caloric Intake)		log(Caloric Intake)	
Head is female	0.058	(1.79)	0.052	(1.64)	0.049	(1.53)	0.051	(1.44)	0.047	(1.47)
Age of Head	0.153**	(3.09)	0.133**	(2.80)	0.128**	(2.64)	0.098	(1.82)	0.135**	(2.78)
Educ of Head	0.060**	(2.69)	-0.129*	(-2.49)	0.062**	(2.79)	0.057*	(2.22)	0.062**	(2.82)
HH size	-0.078	(-0.77)	-0.092	(-1.23)	-0.299***	(-11.60)	-0.272***	(-9.53)	-0.299***	(-11.58)
Dependency Ratio	-0.019	(-1.09)	-0.015	(-0.84)	-0.025	(-1.41)	-0.015	(-0.77)	-0.027	(-1.55)
Primary education	0.024	(1.45)	0.023	(1.38)	0.030	(1.86)	0.002	(0.10)	0.033*	(1.99)
Acres of Land	-0.014	(-0.75)	-0.012	(-0.60)	-0.008	(-0.41)	-0.012	(-0.62)	-0.011	(-0.58)
Children	0.010	(0.55)	0.010	(0.53)	0.009	(0.50)	0.013	(0.70)	0.012	(0.67)
Shock drought/flood	0.136*	(2.42)								
Drought * Dep_ratio	0.046	(1.52)								
Drought * Head Educ	-0.014	(-0.64)								
Drought * Female head	-0.011	(-0.87)								
Drought * Landholding	0.030***	(4.20)								
Drought * Primary	0.021	(1.19)								
Drought * HH Size	-0.271*	(-2.36)								
Drought * Children	-0.169**	(-2.81)								
Drought * Age	-0.192***	(-3.55)								
Shock illness			0.040	(0.64)						
Illness * Dep_ratio			-0.047*	(-1.98)						
Illness * Head Educ			0.216***	(4.10)						
Illness * Female head			-0.004	(-0.43)						
Illness * Landholding			0.036***	(4.29)						
Illness * Primary			0.024	(1.30)						
Illness * HH Size			-0.251**	(-3.19)						
Illness * Children			-0.033	(-0.91)						
Illness * Age			-0.106*	(-2.26)						
Shock P fall					0.023	(0.32)				
P Fall * Dep_ratio					0.013	(0.73)				
P Fall * Head Educ					-0.006	(-0.21)				
P Fall * Female head					0.008	(0.99)				
P Fall * Landholding					0.024**	(3.24)				
P Fall * Primary					0.007	(0.67)				
P Fall * HH Size					-0.077	(-1.23)				
P Fall * Children					0.001	(0.03)				
P Fall * Age					0.028	(0.53)				
Shock P rise							-0.096	(-1.47)		
P Rise * Dep_ratio							-0.004	(-0.15)		
P Rise * Head Educ							0.016	(0.54)		
P Rise * Female head							-0.001	(-0.04)		
P Rise * Landholding							-0.035***	(-3.88)		
P Rise * Primary							0.051*	(2.53)		
P Rise * HH Size							-0.018	(-0.28)		
P Rise * Children							-0.055	(-1.15)		
P Rise * Age							0.108*	(1.99)		
Shock P input rise									0.064	(1.24)
P Input Rise * Dep_ratio									-0.059	(-1.45)
P Input Rise * Head Educ									-0.021	(-0.88)
P Input Rise * Female head									-0.008	(-0.70)
P Input Rise * Landholding									0.030	(1.21)
P Input Rise * Primary									-0.030*	(-2.11)
P Input Rise * HH Size									-0.120	(-1.59)
P Input Rise * Children									0.103	(1.47)
P Input Rise * Age									-0.006*	(-2.16)
Observations	18010		18010		18010		18010		18010	
R^2	0.028		0.034		0.023		0.026		0.024	
F	16.96		16.08		11.32		13.50		12.50	

Standardized beta coefficients; t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: The dependent variable is food consumption, as measured by logarithm of per capita daily calories intake. We control for individual fixed effects and we include year dummies (not reported) in all the regressions. Standard errors (corrected for heteroskedasticity) are reported in parenthesis. The symbols ***, **, * indicate that coefficients are statistically significant respectively at the 1, 5, and 10 percent level.

4.6.4. Impact on Dietary Diversity

In the previous section we provided evidence on the negative effect that soaring food prices have on daily food caloric intake among rural and urban households in Tanzania. However, price spikes not only can compromise the energy absorption, they may also have relevant effects on households and individuals' diet quality which we define as the number of different foods or food groups consumed over a given reference period (Hoddinott, 2002). Authors agree about the fact that dietary diversity is a useful indicator for the quality of the diet, because a more varied diet is associated with an improved birth-weight (Rao *et al.* 2001), with reduction of cancer incidence (Kant *et al.* 1995) and reduced risk of mortality. A series of proxy indicators aimed at providing qualitative measures of dietary diversity (e.g. Food Consumption Scores (FCS), Household Dietary Diversity Score (HDDS)) have been proposed over the last years by many organizations involved in food security valuations. Over the last decade a lot of studies have been carried out with the aim of both supporting the use of dietary diversity measures (Savy *et al.*, 2005) as well as linking household dietary diversity indicators to improved nutrient intake in developed and developing countries (Arimond, 2004; Stein, 2005; Kennedy *et al.*, 2007). Ferguson *et al.* (1993) and Hatloy *et al.* (2000) showed the existence of a strong correlation between the improvement of socio-economic conditions and dietary diversity scores. Savy *et al.* (2005) compared dietary diversity scores measured over a 1-day or 3-day period and assessed their relationship to the nutritional status of women in a rural area of Burkina Faso, while Ogle (2001) found that dietary diversity has a positive relationship with the vegetable intake in the Asian diet. The World Food Programme (WFP) conducted several assessments of household level food security to assess the impacts of high food prices on dietary changes (see Brinkman *et al.* (2010) for a comprehensive review).

To assess the impact of high food prices, WFP relied on a set of proxies. Among all, WFP (2007 and 2009) adopted the so-called Food Consumption Score (FCS), which is a frequency-weighted diet diversity score that uses information on both dietary diversity and food frequency (defined as the number of days per week in which the food is consumed) and applies a different system of weights (from 0.5 to 4) for each food group based on its 'nutrient density'. In this way the weights are supposed to make the FCS more capable of capturing two dimensions of food security: diet quality and diet quantity. The index is constructed by grouping all the food items into specific food groups (which include grains, pulses, vegetables, fruit, meat/fish, milk/dairy, sugar, and oil/fat). By summing up the consumption frequencies of food items within the same household it is possible to generate a food group score for each food group. Any score greater than seven is recorded as seven. Each value is then multiplied by its weight creating different weighted food group scores, that, once summed up again, finally give the FCS. Higher scores denote a more varied diet and are suggestive of a higher quality diet with a potential for higher micronutrient intake.

In this section we examine the correlation between our set of shocks (price, covariate and idiosyncratic) and the logarithm of Food Consumption Score. Since information about the frequency of consumption was not available for the 2008/09 survey, with just two waves of data we decided to perform two cross-section regressions for the 2010/11 and 2012/13 survey separately.

The results from our estimates, shown in table 4.5[23], display the expected results. As a result of the soaring food prices, Tanzanian households had to make large concessions in terms of dietary quality: we find in fact a statistically significant effect of food price rise shocks for the overall sample (first column) in both years. Households self-reporting a food price rise shock experienced a huge reduction in their diet's quality with respect to households not hit by the shock. This effect was significant for urban households in 2010 and rural households in 2012 respectively. When interacting food price rise with staple food buyers we again find a negative and statistically significant coefficient: price upsurges not only lead to a dramatic reduction in the food caloric intake, but also severely threaten the quality of diet. Our overall findings are consistent with the literature. By employing OLS estimates, both Brinkman *et al.* (2010) for Haiti and D'Souza and Jolliffe (2014) for Afghanistan find similar drops in the dietary diversity as a response to a price decline.

The same conclusions can be drawn when considering the idiosyncratic shock variable: in households hit by severe/chronic illnesses dietary diversity is extremely low. Table 4.5 indicates also that amongst the households interviewed in 2010, rural staple food buyers had a statistically significant gain from price falls also in terms of dietary diversity, while this was not statistically significant in 2012. The remaining variables display negative coefficients (when significant) with the exception of the dummy for natural shocks, which is negative only for rural households (2010) and the dummy for the rise of input prices which is positive and statistically significant for the overall sample specification in 2010.

To sum up, these findings suggest that as a response of price movements households modified their consumption patterns. This happened perhaps by either substituting more expensive and nutrient-rich food with cheaper ones, or reducing the size and frequency of meals. A shift towards a lower quality diet which typically equates to a lack of fundamental sources of micro and macro nutrients, can have potentially severe implications for a well-functioning of the immune system for the most vulnerable individuals like infants, pregnant mothers or elderly people, whose nutrients requirements are higher.

[23]Full estimates including all the control variables are available in the Appendix 4B

Table 4.5: Econometric Results: Impact of shocks on Dietary Diversity in 2010 and 2012

	2010					
	Overall Log(FCS)		Rural Log(FCS)		Urban Log(FCS)	
Individual Controls	(Yes)		(Yes)		(Yes)	
Household Controls	(Yes)		(Yes)		(Yes)	
Shock illness	-0.033***	(-5.45)	-0.036***	(-5.07)	-0.027**	(-2.60)
Shock drought/flood	0.029*	(2.50)	-0.030*	(-2.41)	0.336***	(7.56)
Drought/flood * Staple Food Buyer	-0.064***	(-5.66)	-0.034**	(-2.70)	-0.300***	(-6.90)
Drought/flood * Cash Crop Seller	0.035***	(4.04)	0.065***	(6.19)	-0.008	(-0.65)
Shock P fall	-0.011	(-1.30)	-0.014	(-1.47)	-0.034	(-1.38)
Shock P rise	-0.080***	(-4.26)	0.021	(1.36)	-0.447***	(-7.01)
Shock P input rise	0.063***	(7.99)	-0.055***	(-6.73)	-0.027	(-1.68)
P fall * Staple Food Buyer	0.009	(1.12)	0.032***	(3.47)	-0.020	(-0.92)
P rise * Staple Food Buyer	-0.108***	(-5.55)	-0.012	(-0.73)	-0.466***	(-7.26)
P input rise * Cash Crop Seller	-0.022***	(-4.20)	-0.072***	(-9.37)	-0.029	(-1.73)
Observations	19562		13864		5698	
R^2	0.262		0.278		0.278	
F	225.9		173.4		65.58	
	2012					
	Overall Log(FCS)		Rural Log(FCS)		Urban Log(FCS)	
Individual Controls	(Yes)		(Yes)		(Yes)	
Household Controls	(Yes)		(Yes)		(Yes)	
Shock illness	-0.041***	(-7.57)	-0.024***	(-3.91)	-0.072***	(-7.09)
Shock drought/flood	0.013	(1.19)	0.014	(1.13)	0.124**	(3.17)
Drought/flood * Staple Food Buyer	-0.052***	(-4.95)	-0.059***	(-5.02)	-0.173***	(-4.43)
Drought/flood * Cash Crop Seller	0.027**	(3.28)	0.029**	(2.87)	0.030**	(2.67)
Shock P fall	0.006	(0.70)	0.006	(0.63)	0.040	(1.59)
Shock P rise	-0.059***	(-7.82)	-0.069***	(-8.44)	0.008	(0.40)
Shock P input rise	-0.034***	(-5.03)	-0.039***	(-4.87)	-0.030*	(-2.48)
P fall * Staple Food Buyer	-0.000	(-0.04)	0.006	(0.68)	-0.059*	(-2.32)
P rise * Staple Food Buyer	-0.100***	(-11.82)	-0.120***	(-12.76)	-0.040*	(-2.00)
P input rise * Cash Crop Seller	-0.010	(-1.60)	-0.015*	(-2.14)	0.006	(0.47)
Observations	23269		15986		7283	
R^2	0.180		0.203		0.135	
F	148.5		114.1		36.46	

Standardized beta coefficients; t statistics in parentheses

Note: The dependent variable is the logarithm of Food Consumption Score (FCS). Standard errors are corrected for heteroskedasticity. The symbols ***, **, * indicate that coefficients are statistically significant respectively at the 1, 5, and 10 percent level. The full estimation is provided in the Appendix A4.

4.6.5. Regional nutrition mapping

It is well known that as households diversify from staple carbohydrates-based diets to a diet rich in eggs, milk, meat, fish, fruits and vegetables, they increase their intake of essential macronutrients such as proteins and fibres, and micronutrients such as calcium, iron, zinc, folate, vitamin A, B and C. However, when faced with a sharp increase in food prices households usually adopt a number of food-based coping strategies such as changing their dietary pattern towards cheaper food, skipping meals, decreasing intake of non staple foods, increasing consumption of street foods or modifying intra-household allocation of resources (i.e. mothers acting as a buffer for their children) (Rouel *et al.*, 2010). These coping strategies, although fundamental for the households to mitigate the shocks, are all likely to result in significant deterioration of macro and micronutrient intakes.

Micronutrient deficiencies exacerbate the risk of wasting (i.e. underweight-for-attained-height), stunting (i.e. insufficient attained height-for-age) and dramatically impoverish health conditions. In addition to that, they also slow down cognitive development and growth, contributing to poorer school performance and reduced work productivity (Meerman and Aphane, 2012). Given the estimated dramatic effects of price shocks on food caloric intake and dietary diversity, it is thus necessary to provide much more detailed assessments about Tanzanian nutritional deficiencies. For this reason, we conclude our analysis by including among our indicators of households' nutritional status also the changes in consumption of essential macro and micro-nutrients. In particular, in this section we will provide a picture of the evolution of macro and micronutrients distribution across geographic groupings (regions) over the three periods of analysis, so that we can provide important information to policy makers and program planners to be used in designing effective intervention to decrease the population prevalence of undernourished.

To give an idea of the temporal geographical variation of the dietary structure (from 2008/09 to 2012/13), three macronutrients (carbohydrates, proteins and fats), two minerals (calcium and zinc) and two vitamins (vitamin A and vitamin C) were chosen among the macro and micronutrients available and plotted in thematic maps[24]. We made use of the Tanzania Food Consumption tables to convert the quantities consumed of each food item to its macro and micro-nutrients content. All the values obtained were expressed in g/person/day, with the exception of vitamin A, reported in mg/person/day. Then we provide for each region an updated estimate of the average intake of each of the nutrients over the three periods[25].

The assessment of the nutritional status is then reported geographically through *choro-*

[24]The choice of these seven elements is justified by the fact that they are recognized by WHO and FAO (2006) for their indispensability for physical and cognitive activity and growth and for maintaining a healthy and well-functioning immune system and metabolic process.

[25]Unfortunately, since data on consumption was provided at household level, we were unable to further disaggregate the estimates for children, adults and elderlies

pleth maps[26] in which areas are patterned in proportion to the measurement of the nutrient intake variable being displayed on the map. For each nutrient we report a panel with three different maps representing the three different waves (TZNPS Y1, Y2, Y3). We superimposed a code on the region's centroid, to easily identify the regions. Region names and codes are reported in table 4.6.

Table 4.6: Region codes

Region Name	Code	Region Name	Code
Arusha	1	Mbeya	14
Dar Es Salaam	2	Morogoro	15
Dodoma	3	Mtwara	16
Iringa	4	Mwanza	17
Kagera	5	Pwani	18
Kaskazini Pemba	6	Rukwa	19
Kaskazini Unguja	7	Ruvuma	20
Kigoma	8	Shinyanga	21
Kilimanjaro	9	Singida	22
Kusini Pemba	10	Tabora	23
Lindi	11	Tanga	24
Manyara	12	Kusini Unguja	25
Mara	13	Mjini/Magharibi Unguja	26

Figures 4.1 to 4.3 report the macronutrient intake in acquired food. Carbohydrates dominate the nutrient composition of the food eaten by Tanzanian households, with maize being indeed the most important source of carbohydrates (it contributes to the 33% of the total daily caloric intake) followed by cassava and rice (Minot, 2010). The estimated carbohydrates intake are on average in line with the recommended values of 300 g/day (FAO and WHO, 1998) but with a considerable variance across regions and time. Peaks of consumption are registered for the eastern regions (particularly the Eastern Arc Mountains area) of the mainland - with Kilimanjaro region having the highest daily intake rate over the whole period - while the lowest consumption rates are distributed among the central and western areas. Carbohydrates consumption decreases across time, in particular between the first two waves. With respect to 2008/09, Arusha, Kagera, Lindi, Mara and Tanga regions experienced a drop in carbohydrates consumption (in 2010/11) most probably as a result of the food price changes registered between the two waves.

According to FAO (2010) the recommended fat intake for most individuals should range between 15-20% and 30-35% of total energy intake. In our analysis it is close to the minimum recommended threshold in most southern and western regions. Regarding proteins, our findings are in line with the ones reported by Mazengo *et al.* (1998). The values are on average slightly above the 45-55 g/person/day recommended values (WHO and FAO, 2007). They experience a decline between 2008 and 2010 followed by an upswing in 2012.

[26] Maps were plotted using the shape file for Tanzania, which was downloaded from http://data.biogeo.ucdavis.edu/data/gadm2/shp/TZA_adm.zip. Then two new files with (i) the country names and other information, and (ii) with the coordinates of the country boundaries were extracted with *shp2dta* command in STATA 13 to draw the map.

The most striking declines were registered between 2008 and 2010 for the regions of Mara, Pwani, Shinyanga and Tanga.

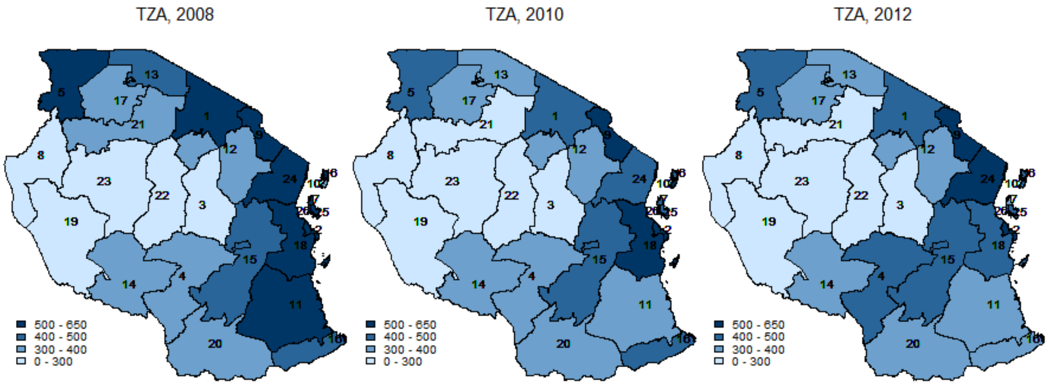

Figure 4.1: Macronutrient intake: carbohydrates (g/person/day)

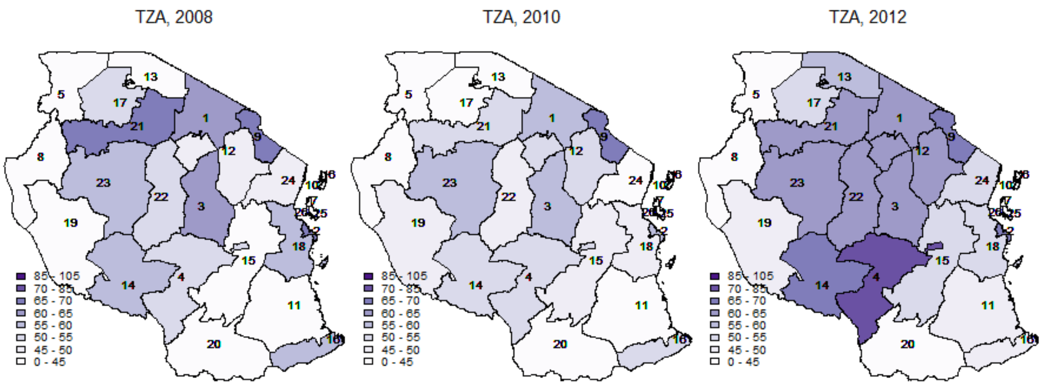

Figure 4.2: Macronutrient intake: fats (g/person/day)

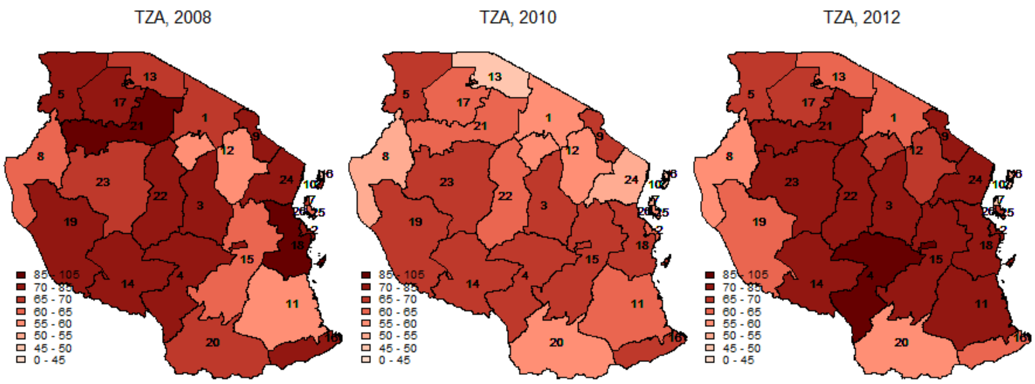

Figure 4.3: Macronutrient intake: proteins (g/person/day)

Figures 4.4 and 4.5 show the maps related to calcium and zinc intake. The low absorption of calcium evidenced by our analysis further exacerbates an already dramatic situation. The average daily intake per region is lower than the recommended nutritional intake (750 mg/person/day, WHO and FAO, 2004) with very deep deficiencies concentrated specifically in the western side of the country. In particular, in Kigoma and Rukwa calcium deficiency worsen over the years. The low intake of calcium depends on poor consumption of milk, dairy products, but also fish, which is one of the most relevant sources in these regions.

The levels of zinc intake stay within the range established by WHO and FAO (2004) (ranging from 4 to 14 mg/person/day depending on diets, sex and age). However, we notice that the amount absorbed decreased over time, in particular in central Tanzania. Similarly to calcium, this is an effect of changing dietary patterns, which in turn is a consequence of the economic and other covariate shocks. Finally, the regions situated along the borders of the country have on average lower rates of zinc absorption.

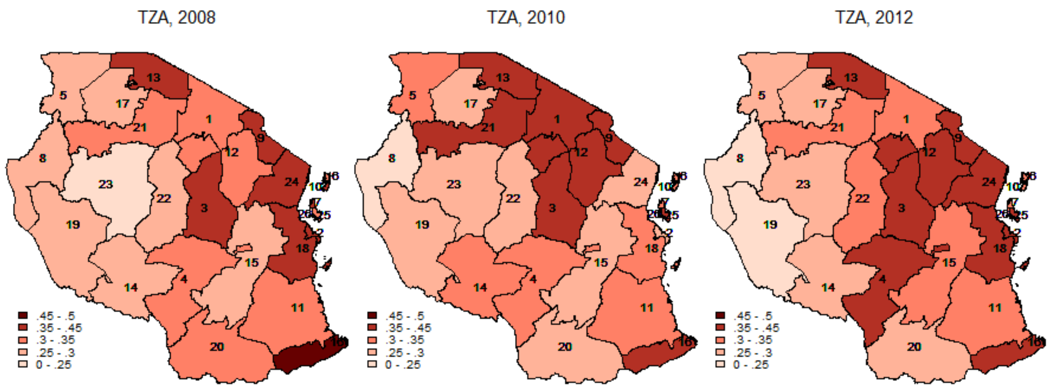

Figure 4.4: Mineral intake: calcium (g/person/day)

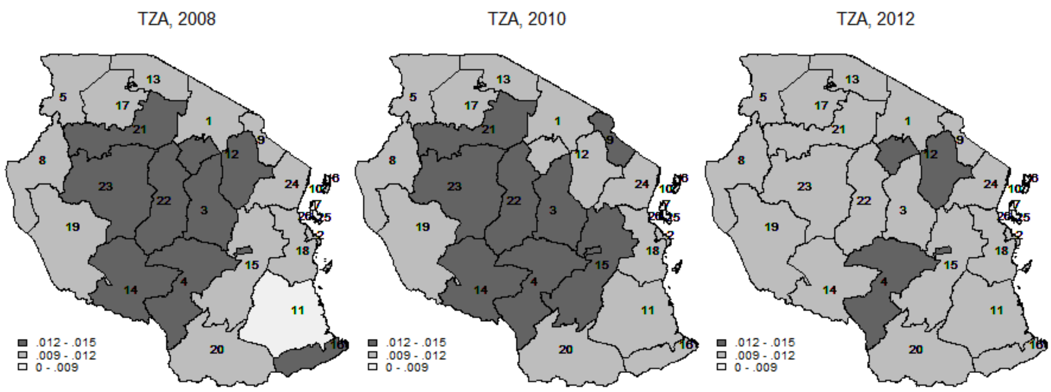

Figure 4.5: Mineral intake: zinc (g/person/day)

In terms of vitamin A intake (fig. 4.6), the regions located in the north-west (Kigoma, Ruvwa, Tabora) and south east (Lindi, Morogoro, Mtwara, Pwani) display the lowest levels of consumption for 2008, while in north Tanzania (Kagera, Shingyanga, Mara and Mwanza) the average absorption is higher. This is probably because there is a large production and consumption of sweet potatoes, which are particularly rich of this micronutrient. In this area the values registered do not change much over time. By contrast, in southern Tanzania (Lindi and Ruvuma) we register a decline in 2010 followed by a tight increase in 2012. Despite this positive variation, the vitamin A level keeps being dramatically low vis-a-vis the recommended level of 0.5-0.6 mg RE[27]/day with important implications for the children and adolescents' associated nutritional status.

As regards to vitamin C, the national average daily availability of ascorbic acid per person was 108 mg in 2008/09, 123 mg in 2010/11 and 109 mg in 2011/12. All the levels registered were well above the recommended nutrition intakes (RNI) estimates of 40 mg/person/day. Central-eastern regions - Dodoma and Manyara - registered the lowest rates of absorption (around 42 mg/person/day) for all the three years.

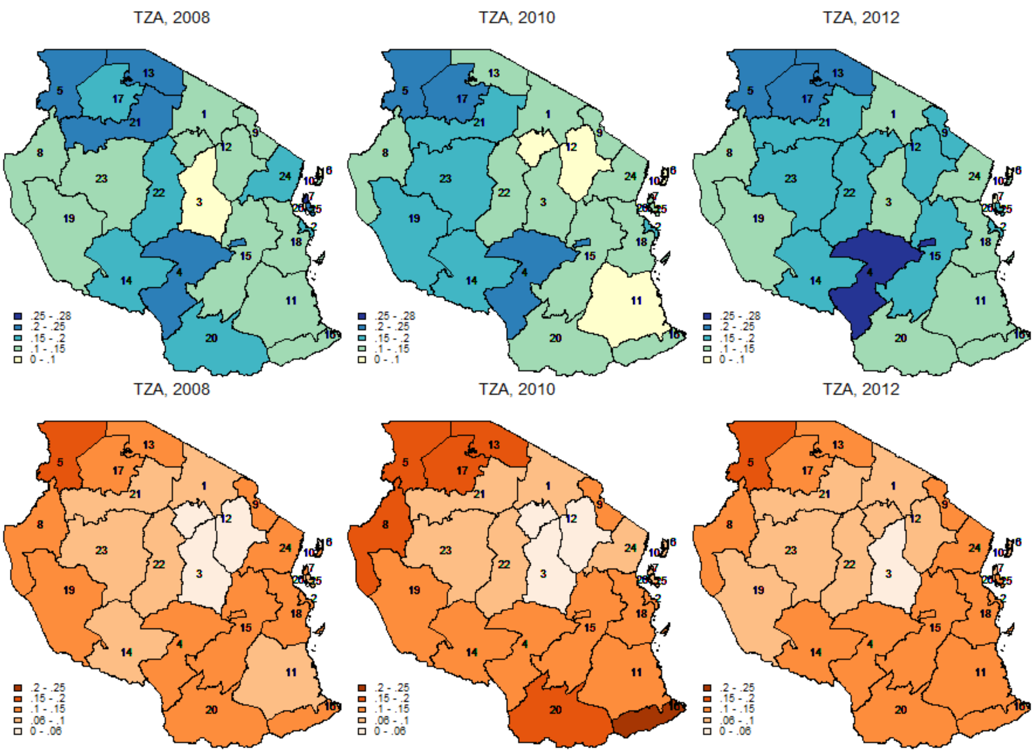

Figure 4.6: Vitamins intake: vitamin A (blue) (mg/person/day) and vitamin C (orange) (g/person/day)

[27]Retinol equivalent (RE)

4.7. Conclusions

Since the first price spike, the prices of basic staple foods swung again up and down, fueling new concerns about the food security of poor people, in particular in developing countries (Fan *et al.*, 2011). Tanzania was not spared from the food price inflation, with Tanzanian people reporting the incidence of price movements as one of the most harmful shocks they experienced in the last years: assessing the effect of price and other idiosyncratic and co-variate shocks on rural and urban households vulnerability was the main objective of this paper.

The value added of our study is threefold. First of all, we included in our panel the newly released 2012/13 Tanzania National Panel Survey dataset which provided new information on households demographic and economic characteristics. This allowed us to offer a new contribution to the existing literature on vulnerability to shocks by giving new insights on the impact of price, idiosyncratic and covariate shocks on the quantity and quality of food consumed. Secondly, in a context of global food crisis we updated the existing studies on Tanzania by assessing also the impact of each shock on a set of households characteristics, highlighting the typologies of households to be defined as most vulnerable. Third, we reveal important patterns of malnutrition in the country by making an assessment of the evolution of macro and micro-nutrients consumption across regions over the three years.

The most important findings of our analysis can be summarized as follows. The sensitivity of food intake variation to price shocks is different among rural and urban subgroups. In the basic specification we find statistically significant results only among urban households. In particular, price of input rise and price fall had respectively a negative and positive correlation with food caloric intake. Regarding rural households the impact of price shocks turns significant when controlling for the household market position: rural food buyers respond negatively to price surges. However, with the proposed method it is hard to state if the impact of a given shock is a result of an effect on households' income or rather is related to households' bad coping mechanisms against shocks. We also highlight the importance of idiosyncratic shocks among urban households. Concerning the sensitivity of households' characteristics to shocks, our findings revealed that in rural areas, more landed households are better protected against both natural shocks and price surges, while households with higher dependency ratios are particularly susceptible to idiosyncratic, natural and input price shocks.

Households also changed their consumption patterns as a response of price movements. Price surges led to a negative variation of the food consumption score in both the years under examination. Finally, according to our analysis, fats, calcium and vitamin A were the most cut-back macro and micro-nutrients, which may led to negative outcomes in particular for children as well as lactating and pregnant women.

The debate on the relative importance of the different sources of risk on poor and vulnerable households in developing countries has important implications for social protection and other policies. Understanding which are the more frequent and severe sources of risk can help designing the most appropriate policy responses. In the case of Tanzania, policies should address first of all idiosyncratic risks via health insurance or other ad-hoc policies for the poorest and secondly insure households against price volatility and natural disasters introducing for example social safety nets that are more responsive to systemic crises. Potential policy interventions such as appropriate social cash transfer programs, food fortification or micro-nutrient supplementation programmes, can be used to protect the diet diversity and micro-nutrient intake of poor households during food price crises.

Table 4.1: Summary statistics

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**
Caloric Intake	2275.259	1253.426	16.072	4653
Head is female	0.26	dummy	0	1
Age of head	47.431	14.74	0	108
Educ of Head	0.958	0.669	0	3
HH size	6.767	3.699	1	55
Sex Ratio	1.172	0.96	0	8
Dependency Ratio	1.106	0.879	0	8
Head works in Agri/Livestock	0.588	dummy	0	1
Asset Sofisticated Index	0.117	0.354	0	5
Animal index	0.862	0.875	0	3
Asset base index	0.131	0.416	0	5
Housing quality index	0.489	0.307	0	3.25
Quality/access to services index	0.268	0.284	0	1
Consumer durable index	0.194	0.194	0	1
Income Diversity	0.471	0.447	0	1
Cash crop seller	0.243	dummy	0	1
Staple Food Buyer	0.783	dummy	0	1

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Appendix

Appendix 4A

Table 4A.1: Percentage of urban and rural households surveyed reporting the incidence of a single/multiple shock in 2008/09, 2010/11 and 2012/13

	Rural			Urban		
Year	2008	2010	2012	2008	2010	2012
(i) Price Shocks						
Large fall in sale prices for crops	32%	25%	20%	7%	8%	6%
Large rise in agricultural input prices	32%	22%	20%	11%	10%	8%
Large rise in price of food	65%	48%	43%	70%	59%	51%
(ii) Natural Disasters						
Crop disease	31%	25%	18%	6%	7%	5%
Droughts or floods	30%	26%	27%	13%	12%	14%
Fire	2%	3%	1%	1%	1%	1%
Severe water shortage	32%	27%	21%	41%	35%	21%
(iii) Asset Shocks						
Dwelling damaged, destroyed	1%	0%	0%	1%	0%	1%
Livestock died or were stolen	28%	19%	13%	8%	10%	8%
Loss of Land	4%	4%	3%	1%	3%	2%
(iv) Employment Shocks						
Household business failure	3%	4%	3%	9%	8%	8%
Loss of salaried employment	1%	2%	1%	6%	4%	3%
(v) Health Shocks						
Chronic illness/accident of HH member	11%	6%	5%	7%	8%	5%
Death of a member of the HH	16%	9%	9%	11%	9%	7%
Death of other family member	37%	31%	23%	46%	45%	37%
(vi) Crime and Safety Shocks						
Hijacking/Robbery/burglary/assault	9%	6%	5%	13%	16%	7%
(vii) Household break-up						
Break-up of the HH	5%	6%	7%	6%	8%	8%
Jailed	1%	1%	1%	0%	0%	0%

Values expressed as percentage of rural (urban) households over total rural (urban) households
Note: the numbers in the columns do not add up to 100% since households indicated multiple shocks.

Table 4A.2: Percentage of households ranking a shock "Most Severe" "2nd Most Severe" "3rd Most Severe", Rural and Urban Tanzania, 2008, 2010 and 2012

	Rural									Urban								
Year	2008	2010	2012	2008	2010	2012	2008	2010	2012	2008	2010	2012	2008	2010	2012	2008	2010	2012
Severity	Most	Most	Most	2nd most	2nd most	2nd most	3rd most	3rd most	3rd most	Most	Most	Most	2nd most	2nd most	2nd most	3rd most	3rd most	3rd most
(i) Price Shocks																		
Large fall in sale prices for crops	12%	16%	17%	24%	22%	23%	23%	18%	24%	13%	13%	24%	16%	16%	19%	24%	16%	19%
Large rise in price of food	29%	26%	30%	28%	31%	32%	22%	21%	19%	40%	29%	39%	36%	38%	35%	17%	21%	19%
large rise in agricultural input price	15%	14%	14%	21%	20%	23%	17%	17%	17%	11%	12%	14%	18%	21%	23%	28%	14%	23%
(ii) Natural Disasters																		
Crop disease	19%	22%	23%	20%	22%	25%	25%	18%	19%	13%	6%	21%	20%	32%	24%	19%	24%	16%
Droughts or floods	29%	38%	39%	24%	25%	30%	19%	17%	17%	30%	32%	13%	19%	22%	26%	17%	10%	20%
Fire	50%	51%	55%	15%	12%	17%	10%	12%	14%	27%	50%	73%	64%	33%	13%	0%	8%	0%
Severe water shortage	17%	21%	23%	23%	25%	25%	22%	19%	16%	13%	13%	13%	32%	23%	28%	33%	35%	26%
(iii) Asset Shocks																		
Dwelling damaged, destroyed	9%	38%	54%	23%	13%	31%	27%	25%	8%	14%	0%	69%	29%	40%	15%	36%	20%	8%
Livestock died or were stolen	23%	21%	18%	23%	22%	27%	19%	19%	15%	15%	21%	14%	19%	22%	19%	23%	18%	18%
Loss of Land	29%	36%	27%	19%	24%	30%	21%	12%	15%	24%	36%	42%	47%	33%	33%	24%	11%	9%
(iv) Employment Shocks																		
Household business failure	10%	15%	24%	15%	10%	14%	19%	17%	12%	19%	18%	15%	19%	21%	26%	28%	31%	32%
Loss of salaried employment	22%	19%	24%	19%	23%	20%	7%	19%	17%	30%	38%	33%	36%	21%	21%	9%	17%	19%
(v) Health Shocks																		
Chronic illness/accident of HH member	40%	48%	57%	24%	27%	22%	12%	10%	8%	43%	47%	59%	26%	31%	25%	15%	10%	3%
Death of a member of the HH	73%	81%	88%	12%	8%	6%	5%	4%	2%	74%	84%	78%	7%	6%	13%	9%	4%	2%
Death of other family member	42%	58%	67%	19%	15%	17%	10%	9%	6%	53%	57%	46%	15%	19%	22%	14%	8%	10%
(vi) Crime and Safety Shocks																		
Hijacking/Robbery/burglary/assault	19%	29%	33%	27%	33%	25%	23%	14%	13%	25%	22%	27%	29%	35%	24%	22%	26%	20%
(vii) Household break-up																		
Break-up of the HH	34%	37%	45%	19%	27%	31%	22%	15%	12%	21%	37%	55%	37%	30%	21%	29%	16%	11%
Jailed	33%	35%	52%	13%	29%	38%	20%	6%	0%	20%	50%	86%	0%	25%	0%	40%	25%	0%

Values expressed as percentage of rural (urban) households over total rural (urban) households
Note: the numbers in the columns do not add up to 100% since household could indicate multiple shocks.

Table 4A.3: Percentage of households reporting income reduction, asset reduction or reduction of both by rural/urban residence in Tanzania, 2008, 2010 and 2012

	Rural									Urban								
Year	2008 Income	2010 Income	2012 Income	2008 Asset	2010 Asset	2012 Asset	2008 Both	2010 Both	2012 Both	2008 Income	2010 Income	2012 Income	2008 Asset	2010 Asset	2012 Asset	2008 Both	2010 Both	2012 Both
(i) Price Shocks																		
Large fall in sale prices for crops	39%	46%	45%	6%	2%	5%	13%	7%	15%	41%	32%	44%	3%	5%	2%	8%	8%	15%
Large rise in agricultural input prices	46%	61%	61%	7%	5%	5%	22%	11%	13%	56%	63%	64%	3%	5%	3%	32%	18%	23%
Large rise in price of food	24%	40%	40%	3%	2%	1%	23%	8%	13%	31%	42%	50%	4%	1%	1%	20%	4%	9%
(ii) Natural Disasters																		
Crop disease	39%	49%	50%	2%	5%	4%	21%	7%	12%	29%	52%	46%	3%	3%	5%	20%	7%	10%
Droughts or floods	36%	53%	53%	4%	5%	10%	30%	21%	23%	21%	31%	42%	9%	7%	12%	27%	22%	22%
Fire	21%	25%	36%	13%	18%	21%	33%	27%	26%	0%	25%	33%	9%	25%	7%	55%	33%	40%
Severe water shortage	25%	37%	34%	2%	3%	1%	20%	10%	11%	37%	41%	38%	1%	3%	1%	26%	13%	15%
(iii) Asset Shocks																		
Dwelling damaged, destroyed	18%	25%	23%	23%	0%	31%	14%	38%	31%	21%	40%	31%	14%	20%	31%	36%	0%	23%
Livestock died or were stolen	22%	33%	29%	18%	15%	16%	23%	12%	13%	25%	37%	24%	7%	14%	17%	22%	8%	8%
Loss of Land	31%	38%	26%	8%	11%	20%	28%	21%	24%	53%	14%	18%	6%	33%	21%	35%	31%	33%
(iv) Employment Shocks																		
Household business failure	29%	25%	34%	2%	3%	2%	11%	14%	14%	39%	24%	19%	0%	1%	1%	26%	45%	52%
Loss of salaried employment	37%	51%	52%	0%	6%	0%	11%	4%	9%	47%	63%	56%	0%	0%	0%	26%	12%	18%
(v) Health Shocks																		
Chronic/severe illness or accident of HH member	28%	46%	52%	3%	8%	2%	34%	23%	29%	44%	48%	43%	2%	0%	3%	29%	31%	35%
Death of a member of the HH	25%	34%	35%	6%	4%	5%	21%	27%	27%	38%	37%	38%	4%	4%	0%	29%	24%	31%
Death of other family member	22%	27%	29%	3%	3%	5%	13%	7%	13%	27%	35%	34%	3%	1%	2%	19%	10%	11%
(vi) Crime and Safety Shocks																		
Hijacking/Robbery/burglary/assault	27%	38%	33%	16%	17%	18%	24%	18%	17%	42%	44%	29%	8%	19%	22%	24%	18%	14%
(vii) Household break-up																		
(vii) Household break-up																		
Break-up of the HH	18%	25%	28%	3%	11%	8%	28%	17%	26%	32%	21%	27%	6%	9%	11%	21%	21%	22%
Jailed	27%	24%	62%	7%	6%	5%	20%	35%	24%	60%	75%	43%	0%	0%	0%	0%	25%	29%

Values expressed as percentage of rural (urban) households over total rural (urban) households.
Note: the numbers in the columns do not add up to 100% since household could indicate multiple shocks.

Table 4A.4: Percentage of hh perceiving a certain degree of dispersion of both by rural/urban residence in Tanzania, 2008, 2010 and 2012

	Rural												Urban											
Year	2008	2010	2012	2008	2010	2012	2008	2010	2012	2008	2010	2012	2008	2010	2012	2008	2010	2012	2008	2010	2012	2008	2010	2012
	This HH	This HH	This HH	Some other	Some other	Some other	Most HHs	Most HHs	Most HHs	All HHs	All HHs	All HHs	This HH	This HH	This HH	Some other	Some other	Some other	Most HHs	Most HHs	Most HHs	All HHs	All HHs	All HHs
(i) Price Shocks																								
Large fall in sale prices for crops	3%	1%	2%	6%	9%	7%	42%	34%	42%	8%	11%	14%	1%	3%	3%	4%	13%	10%	40%	26%	41%	8%	4%	9%
Large rise in agricultural input prices	2%	3%	2%	8%	7%	6%	32%	34%	38%	11%	7%	9%	5%	4%	5%	9%	9%	5%	34%	29%	39%	9%	5%	11%
Large rise in price of food	3%	2%	3%	15%	15%	11%	52%	44%	49%	9%	17%	18%	3%	4%	4%	9%	13%	8%	59%	50%	58%	21%	21%	2%
(ii) Natural Disasters																								
Crop disease	4%	4%	2%	8%	11%	8%	47%	39%	46%	5%	9%	12%	5%	4%	6%	11%	16%	10%	33%	39%	37%	3%	3%	8%
Droughts or floods	2%	2%	2%	8%	19%	15%	56%	47%	55%	6%	13%	15%	5%	4%	5%	7%	16%	17%	40%	38%	46%	16%	7%	15%
Fire	1%	0%	1%	8%	10%	8%	41%	34%	36%	12%	22%	19%	0%	1%	1%	4%	9%	4%	51%	47%	48%	23%	14%	14%
Severe water shortage	1%	0%	1%	8%	10%	8%	41%	34%	36%	12%	22%	19%	0%	1%	1%	4%	9%	4%	51%	47%	48%	23%	14%	14%
(iii) Asset Shocks																								
Dwelling damaged, destroyed	36%	63%	85%	0%	0%	0%	23%	13%	8%	0%	0%	0%	36%	20%	62%	0%	20%	8%	43%	20%	23%	0%	0%	0%
Livestock died or were stolen	50%	42%	38%	4%	6%	6%	11%	11%	14%	0%	2%	3%	51%	47%	28%	2%	2%	7%	5%	9%	14%	0%	2%	1%
Loss of Land	60%	59%	61%	3%	3%	3%	5%	9%	5%	1%	0%	2%	76%	67%	67%	6%	0%	6%	6%	14%	12%	6%	0%	0%
(iv) Employment Shocks																								
Household business failure	34%	33%	36%	2%	3%	10%	8%	5%	5%	0%	0%	0%	50%	33%	25%	2%	3%	3%	13%	33%	44%	0%	0%	1%
Loss of salaried employment	30%	55%	57%	0%	0%	2%	19%	6%	2%	0%	0%	0%	70%	77%	58%	4%	0%	2%	0%	0%	12%	0%	0%	2%
(v) Health Shocks																								
Chr./sev. illness/accident of HH member	73%	80%	85%	2%	3%	1%	0%	2%	0%	0%	0%	0%	79%	84%	83%	1%	2%	0%	3%	2%	4%	0%	0%	0%
Death of a member of the HH	85%	85%	88%	4%	4%	5%	1%	4%	3%	0%	0%	0%	86%	76%	88%	2%	12%	2%	1%	6%	2%	1%	0%	0%
Death of other family member	60%	55%	48%	7%	16%	32%	4%	10%	9%	0%	1%	0%	65%	58%	51%	10%	21%	22%	5%	5%	6%	1%	0%	0%
(vi) Crime and Safety Shocks																								
Hijacking/Robbery/burglary/assault	67%	74%	69%	1%	1%	1%	2%	1%	1%	0%	1%	1%	75%	79%	65%	0%	1%	1%	0%	3%	4%	1%	0%	1%
(vii) Household break-up																								
Break-up of the HH	76%	76%	86%	0%	2%	1%	0%	1%	1%	0%	0%	0%	84%	81%	83%	1%	1%	1%	1%	1%	4%	0%	0%	0%
Jailed	67%	65%	90%	0%	6%	0%	0%	0%	0%	0%	0%	0%	60%	100%	86%	20%	0%	0%	0%	0%	0%	0%	0%	0%

Table 4A.5: Poverty measures

	Survey Year			
	1992	**2000**	**2007**	**2012**
Mean ($)	33.42	25.68	36.79	55.91
Pov. Line ($/month)	38	38	38	38
Headcount (%)	71.98	84.23	67.87	43.48
Pov. Gap (%)	29.24	41.23	28.10	12.98
Squared Pov. gap	15.20	24.06	14.78	5.12
Watts Index	0.44	0.66	0.42	0.17
Gini Index	33.83	34.62	37.58	37.82
MLD Index	0.19	0.20	0.24	0.24

Source: PovcalNet. Authors' elaboration.

Table 4A.6: Selected Macroeconomic Indicators for Tanzania (2000-2013)

Indicator Name	**Scale**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Agriculture, value added (% of GDP)		33.48	32.87	32.46	32.53	33.33	31.76	30.41	29.97	29.71	28.79	28.13	27.68	27.58	27.00
Agriculture, value added (annual % growth)		4.46	4.93	5.04	3.22	5.91	4.42	3.88	4.05	4.58	3.21	4.06	3.43	4.22	4.22
Agricultural land (% of land area)		38.38	38.50	38.61	38.69	39.69	39.92	39.92	40.25	41.74	42.00	42.11	42.11	na	na
Current account balance (% of GDP)		na	na	na	na	na	-7.73	-7.69	-10.19	-12.44	-8.47	-8.55	-16.72	-12.88	na
Current account balance (BoP, current US$)	Billions	na	na	na	na	na	-1.09	-1.10	-1.71	-2.58	-1.81	-1.96	-3.99	-3.64	na
GDP (constant LCU)	Billions	8585.34	9100.27	9752.18	10423.73	11239.74	12068.09	12881.16	13801.92	14828.34	15721.30	16828.56	17913.80	19155.77	20489.15
GDP (current LCU)	Billions	8152.79	9100.27	10444.51	12107.06	13971.59	15965.29	17941.27	20948.40	24781.68	28212.65	32293.48	37532.96	44717.66	53174.68
GDP (current US$)	Billions	10.19	10.38	10.81	11.66	12.83	14.14	14.33	16.83	20.72	21.37	22.92	23.87	28.25	33.23
GDP deflator (base year varies by country)		94.96	100.00	107.10	116.15	124.31	132.29	139.28	151.78	167.12	179.45	191.90	209.52	233.44	259.53
GDP growth (annual %)		4.93	6.00	7.16	6.89	7.83	7.37	6.74	7.15	7.44	6.02	7.04	6.45	6.93	6.96
GDP per capita (constant LCU)	Units	259727	268420	280349	291890	306386	320008	332025	345591	360492	370958	385330	397978	412869	428450
GDP per capita (current LCU)	Units	246641	268420	300251	339027	380854	423349	462455	524534	602468	665702	739436	833842	963811	1111940
GDP per capita (current US$)	Units	308.14	306.27	310.63	326.48	349.62	375.00	369.40	421.30	503.60	504.20	524.69	530.39	608.85	694.77
GDP per capita growth (annual %)		2.36	3.35	4.44	4.12	4.97	4.45	3.76	4.09	4.31	2.90	3.87	3.28	3.74	3.77
GDP, PPP (current international $)		27.32	29.62	32.23	35.14	38.93	43.14	47.46	52.20	57.18	61.09	66.18	71.84	78.16	84.87
Inflation, consumer prices (annual %)		5.92	5.15	5.32	5.30	4.74	5.03	7.25	7.03	10.28	12.14	6.20	12.69	16.00	7.87
Inflation, GDP deflator (annual %)		7.57	5.31	7.10	8.45	7.02	6.43	5.28	8.97	10.11	7.38	6.93	9.18	11.42	11.17
Population (Total)	Millions	34.02	34.90	35.81	36.76	37.77	38.82	39.94	41.12	42.35	43.64	44.97	46.35	47.78	49.25

Source: World Development Indicators.

Table 4A.7: Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.
Log(Caloric Intake)	7.51	0.49	2.22	9.38
Head is female	0.26	dummy	0	1
Age of head	47.431	14.74	0	108
Educ of Head	0.958	0.669	0	3
HH size	6.767	3.699	1	55
# Children	3.034	2.309	0	30
Sex Ratio	1.172	0.96	0	8
Dependency Ratio	1.106	0.879	0	8
Primary education	0.515	dummy	0	1
Secondary education	0.148	dummy	0	1
University education	0.009	dummy	0	1
Head works in Agri/Livestock	0.588	dummy	0	1
Ind works in Agri/Livestock	0.287	dummy	0	1
Asset Sofisticated Index	0.117	0.354	0	5
Animal index	0.862	0.875	0	3
Asset base index	0.131	0.416	0	5
Housing quality index	0.489	0.307	0	3.25
Quality/access to services index	0.268	dummy	0	1
Consumer durable index	0.259	dummy	0	1
Income Diversity	0.471	dummy	0	1
Cash crop seller	0.243	dummy	0	1
Staple Food Buyer	0.783	dummy	0	1

Table 4A.8: Percentage of households buying staple food (rice, maize, sorghum, wheat and cassava).

	Rural	Urban
# HH non staple food buyer	23%	5%
# HH staple food buyer	77%	95%

Appendix 4B

Measuring economic status using wealth indices facilitates the identification of poor households and individuals. Drawing from the approach of Kumra (2008)[28], we computed three individual indexes (Consumer Durables Index (CDI), Housing Quality Index (HQI), and Services Index (SVI) (see Tab. 4B.1) that range between 0 (low wealth) and 1 (high wealth). In particular they are derived respectively from ten assets, four indicators of housing quality, and three indicators of quality/access to services. As regarding the Productive Assets, we calculate three indices: (i) basic assets, (ii) sophisticated assets, (iii) animals (see table 4B.2). The (i)-(iii) indices are computed by summing up the number of the respective assets included in each of them.

1) **Consumer Durables Index (CDI)**

- This index is obtained by computing a simple arithmetical mean of the number of assets owned by the households. The list of assets is reported in the first column of table 4B.1. The index ranges between 0 and 1, the higher the index, the higher is the number of assets owned by the household.

2) **Housing Quality Index (HQI)**

- HQ1: Rooms per Person. Number of rooms divided by the number of household members. The HQ1 variable is set to take a maximum value of unity. Ratios higher than 1 are recoded accordingly.
- HQ2: Wall Quality. Has the value of 1 if the wall is made of baked/burnt bricks, cement/stone. 0 otherwise.
- HQ3: Roof Quality. Has the value of 1 if the roof is made of cement, metal sheets, asbestos sheets, or tiles; 0 otherwise.
- HQ4: Floor Quality. Has the value of 1 if the floor is made of a finished material (cement, tile or timber); 0 otherwise.

3) **Services Index (SI)**

- S1: Electricity. Has the value of 1 if the household has access to electricity; 0 otherwise.
- S2: Water. Has the value of 1 if the household's source of drinking water is piped inside dwelling; 0 otherwise.
- S3: Toilet. It takes the value of 1 if the household has access to its own pit latrine or flush toilet, in 2010/11 and 2012/13 surveys we consider also the access to pour toilet; 0 otherwise.

[28] which draws on a work undertaken by the World Bank and Macro International that developed a wealth index cited in the UNICEF Multiple Indicator Cluster Surveys

4) **Productive Asset Indices** These indices are constructed with the same procedure used for the Consumer Durables Index.

Table 4B.1: Wealth Indices

Wealth Indices		
Consumer Durable Index (CDI)	**Housing Quality Index (HQI)**	**Quality/access to services (SVI)**
Radio and Radio Cassette	Number of rooms/hh size	Toilet quality
Telephone (land line)	Wall quality	Electricity
Telephone (mobile)	Roof quality	Drinking Water Quality
Refrigerator or freezer	Floor quality	
Fan/Air Conditioner		
Television		
Watches		
Computer		
Motor vehicles		
Bicycle		

Table 4B.2: Productive Assets Indices

Productive Assets Index Indices		
Basic Assets	**Sophisticated Assets**	**Animals**
Carts	Outboard Engine	Livestock
Animal-drawn Cart	Spraying machine	Poultry
Wheel Barrow	Water pumping set	Donkey
Hoes	Trailer for tractors	
Plough	Hand Milling Machine	
	Coffee pulping Machine	
	Fertilizer distributor	
	Reapers	
	Tractor	
	Harrow	
	Milking Machine	
	Harvesting and Trashing Machine	

Table 4B.3: Econometric Results: Impact of shocks on Dietary Diversity - 2010

	Overall		Rural		Urban	
	Log(FCS)		Log(FCS)		Log(FCS)	
Head is female	-0.019**	(-2.84)	-0.014	(-1.84)	-0.014	(-1.16)
Age of head	0.002	(0.24)	0.007	(0.80)	-0.033*	(-2.31)
Educ of Head	0.049***	(6.06)	0.026**	(2.91)	0.100***	(6.65)
HH size	0.193***	(10.94)	0.146***	(6.33)	0.220***	(8.92)
Number of Children	-0.074***	(-4.12)	-0.034	(-1.41)	-0.071**	(-2.90)
Sex Ratio	0.007	(1.09)	-0.011	(-1.54)	0.042***	(3.53)
Dependency Ratio	0.091***	(9.17)	0.069***	(5.94)	0.095***	(4.84)
Primary education	-0.005	(-0.72)	-0.001	(-0.15)	-0.012	(-0.85)
Secondary education	0.017*	(2.15)	0.014	(1.56)	0.016	(1.06)
University education	-0.002	(-0.26)	0.010	(1.22)	-0.003	(-0.21)
Head works in Agri/Livestock	-0.021*	(-2.27)	-0.048***	(-4.97)	0.091***	(5.93)
Ind works in Agri/Livestock	0.010	(1.50)	0.005	(0.57)	0.012	(0.94)
Income Diversity	-0.005	(-0.59)	-0.017	(-1.64)	0.022	(1.44)
Acres of land	0.017***	(3.55)	0.017**	(3.00)	0.012	(1.21)
Asset Sofisticated Index	0.070***	(7.48)	0.088***	(9.50)		
Animal index	0.101***	(12.86)	0.096***	(11.05)		
Asset base index	-0.014	(-1.58)	-0.004	(-0.35)		
Housing quality index	0.113***	(12.92)	0.112***	(11.52)	0.061***	(4.33)
Quality/access to services index	0.119***	(12.63)	0.135***	(13.07)	0.078***	(5.43)
Consumer durable index	0.231***	(23.91)	0.229***	(22.25)	0.222***	(12.57)
Cash crop seller	0.019*	(2.46)	0.011	(1.21)	0.017	(1.20)
Staple Food Buyer	0.185***	(19.30)	0.153***	(14.62)	0.207***	(9.34)
Shock illness	-0.033***	(-5.45)	-0.036***	(-5.07)	-0.027**	(-2.60)
Shock drought/flood	0.029*	(2.50)	-0.030*	(-2.41)	0.336***	(7.56)
Drought/flood * Staple Food Buyer	-0.064***	(-5.66)	-0.034**	(-2.70)	-0.300***	(-6.90)
Drought/flood * Cash Crop Seller	0.035***	(4.04)	0.065***	(6.19)	-0.008	(-0.65)
Shock P fall	-0.011	(-1.30)	-0.014	(-1.47)	-0.034	(-1.38)
Shock P rise	-0.080***	(-4.26)	0.021	(1.36)	-0.447***	(-7.01)
Shock P input rise	0.063***	(7.99)	-0.055***	(-6.73)	-0.027	(-1.68)
P fall * Staple Food Buyer	0.009	(1.12)	0.032***	(3.47)	-0.020	(-0.92)
P rise * Staple Food Buyer	-0.108***	(-5.55)	-0.012	(-0.73)	-0.466***	(-7.26)
P input rise * Cash Crop Seller	-0.022***	(-4.20)	-0.072***	(-9.37)	-0.029	(-1.73)
Observations	19562		13864		5698	
R^2	0.262		0.278		0.278	
F	225.9		173.4		65.58	

Standardized beta coefficients; t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: The dependent variable is the logarithm of Food Consumption Score (FCS). Standard errors are corrected for heteroskedasticity.

Table 4B.4: Econometric Results: Impact of shocks on Dietary Diversity - 2012

	Overall		Rural		Urban	
	Log(FCS)		Log(FCS)		Log(FCS)	
Head is female	0.002	(0.31)	0.007	(0.93)	0.002	(0.14)
Age of head	0.052***	(7.13)	0.040***	(4.59)	0.052***	(3.84)
Educ of Head	0.060***	(7.00)	0.047***	(4.89)	0.078***	(4.98)
HH size	-0.036*	(-1.96)	-0.036	(-1.52)	-0.012	(-0.45)
Number of Children	0.112***	(5.64)	0.091***	(3.68)	0.132***	(4.26)
Sex Ratio	0.009	(1.43)	0.014	(1.88)	-0.007	(-0.59)
Dependency Ratio	0.017	(1.60)	0.034**	(2.68)	-0.004	(-0.18)
Primary education	-0.004	(-0.54)	0.004	(0.44)	-0.016	(-1.14)
Secondary education	0.031***	(3.81)	0.051***	(5.50)	-0.012	(-0.78)
University education	0.002	(0.25)	-0.013	(-1.10)	0.009	(0.67)
Head works in Agri/Livestock	0.002	(0.21)	-0.040***	(-4.40)	0.054***	(3.83)
Ind works in Agri/Livestock	-0.032***	(-4.88)	-0.039***	(-5.17)	-0.024	(-1.91)
Income Diversity	-0.003	(-0.39)	-0.045***	(-4.31)	0.037**	(2.71)
Acres of land	-0.015**	(-2.66)	-0.015*	(-2.20)	-0.001	(-0.06)
Asset Sofisticated Index	0.025***	(3.29)	0.023*	(2.37)		
Animal index	0.072***	(9.86)	0.071***	(8.31)		
Asset base index	0.024***	(3.32)	0.024**	(2.62)		
Housing quality index	0.113***	(13.91)	0.134***	(14.75)	0.065***	(5.05)
Quality/access to services index	-0.015*	(-2.25)	-0.042***	(-5.24)	0.022	(1.71)
Consumer durable index	0.217***	(23.51)	0.198***	(18.75)	0.257***	(15.32)
Cash crop seller	0.002	(0.22)	0.002	(0.17)	-0.011	(-0.94)
Staple Food Buyer	0.148***	(17.40)	0.167***	(17.04)	0.060***	(3.51)
Shock illness	-0.041***	(-7.57)	-0.024***	(-3.91)	-0.072***	(-7.09)
Shock drought/flood	0.013	(1.19)	0.014	(1.13)	0.124**	(3.17)
Drought/flood * Staple Food Buyer	-0.052***	(-4.95)	-0.059***	(-5.02)	-0.173***	(-4.43)
Drought/flood * Cash Crop Seller	0.027**	(3.28)	0.029**	(2.87)	0.030**	(2.67)
Shock P fall	0.006	(0.70)	0.006	(0.63)	0.040	(1.59)
Shock: price rise in last 5 years	-0.059***	(-7.82)	-0.069***	(-8.44)	0.008	(0.40)
Shock P input rise	-0.034***	(-5.03)	-0.039***	(-4.87)	-0.030*	(-2.48)
P fall * Staple Food Buyer	-0.000	(-0.04)	0.006	(0.68)	-0.059*	(-2.32)
P rise * Staple Food Buyer	-0.100***	(-11.82)	-0.120***	(-12.76)	-0.040*	(-2.00)
P input rise * Cash Crop Seller	-0.010	(-1.60)	-0.015*	(-2.14)	0.006	(0.47)
Observations	23269		15986		7283	
R^2	0.180		0.203		0.135	
F	148.5		114.1		36.46	

Standardized beta coefficients; t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: The dependent variable is the logarithm of Food Consumption Score (FCS). Standard errors are corrected for heteroskedasticity.