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ABSTRACT

TIME SERIES MODELING OF FAMINE EARLY WARNING SYSTEMS IN MALI

By

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Since the mid-eighties, famine early warning systems have been implemented throughout Africa. This research focuses on expanding the analytical methods used to evaluate the information collected by these systems. Time series techniques are employed to explore the vulnerability to food insecurity for eight regions in Mali. The first part of the study develops an econometric model of the dynamic relationship between socioeconomic and agroclimatic measures, and the state of food security vulnerability. For each region, a single-index leading indicator model is constructed to identify significant relationships that enhance early warning of supply-side susceptibility to food insecurity. The indexes distinguish between periods of high and low vulnerability to food insecurity and are compared to reference cycles derived from qualitative assessments of vulnerability. The vulnerability indexes produced turning points that tended to provide early warning of one to three months lead times to the onset of periods of moderate or high vulnerability to food insecurity.

The second part of the research concerns spatial and temporal market integration and the econometric tests used to measure such relationships. The vulnerability index developed in the first part is used in the tests of market integration to examine the functioning of goat markets in Mopti. A model that explores the relationship between

regime shifts, expressing different levels of vulnerability to food insecurity, and price information is developed. Empirical results suggest that there exist highly significant regime shifts in the level of market integration in Mopti goat markets which are triggered by the state of vulnerability to food insecurity.

Whether markets are integrated and, if so, the degree to which markets are integrated is important to policy makers. Markets that may have appeared integrated in less vulnerable times may cease to function well under stress. Rather than moving to a deficit region, a surplus in one market may remain in that market during a period of food insecurity. Thus, policy makers should find this information useful in their efforts to mitigate food shortages as they decide whether food aid is necessary, how to distribute food aid shipments, and whether to purchase imported grain. With this in mind, early warning also encompasses understanding the manner in which markets respond in times of crisis.

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Introduction

1.1 Problem Statement

This research centers on the econometric analysis of the system used by USAID to assess vulnerability of a subset of African nations to acute food insecurity. The Famine Early Warning System (FEWS) Project of USAID was developed in 1987 as a response to the severe famines of the mid-eighties. The FEWS mandate includes a) providing early warning capacity for decision-makers within USAID, b) providing support for host governments in the development of national early warning systems; and c) collaboration with the international community on the development of improved early warning technologies (Riley, 1993). FEWS analyzes market, socioeconomic, and climatic data from various early warning systems and market information systems in numerous African countries. The project also uses information from satellite imagery on crop vegetation and rainfall levels. FEWS monitors conditions in Mauritania, Mali, Burkina Faso, Niger, and Chad in the Sahel as well as in Sudan, Ethiopia and Kenya in East Africa. Since May 1992, FEWS expanded to include Malawi, Mozambique, Zambia and Zimbabwe in Southern Africa. These expansions are part of the FEWS mandate to influence and enhance food security in Africa (FEWS, 1992).

This study will undertake time-series modeling of agroclimatic and socioeconomic data for Mali. The biophysical data includes rainfall indices and the normalized difference vegetative index (NDVI) while the socioeconomic data include cereal prices and infrastructure information. The first part of the study develops an econometric model of the dynamic relationship between socioeconomic and agroclimatic measures, and the state of food security vulnerability. A single index leading indicator model is constructed to identify significant relationships that might enhance early warning of supply-side susceptibility to food insecurity. The index distinguishes between periods of high and low vulnerability to food insecurity. The second part of the research concerns spatial and temporal market integration and the econometric tests used to measure such relationships. The single index developed in the first part of this study will be used in the tests of market integration.

Whether markets are integrated and, if so, the degree to which markets are integrated is important to policy makers. Markets that may have appeared integrated in less vulnerable times may cease to function well under stress. Rather than moving to a deficit region, a surplus in one market may remain in that market during a period of food insecurity. Thus, policy makers should find this information useful in their efforts to mitigate food shortages as they decide whether food aid is necessary, how to distribute food aid shipments, and whether to purchase imported grain. With this in mind, early warning also encompasses understanding the manner in which markets respond in times of crisis.

1.2 Objectives of the Study

Figures 1 and 2 provide an overview of the two parts of this research. The specific objectives of the research are:

1) Construct a food security vulnerability index and evaluate its effectiveness in depicting the state of vulnerability to food insecurity for regions in Mali using NDVI and price data.

2) Employ robust econometric tests for market integration which are structural in nature.

3) Use the vulnerability indicators in the construction of models of market integration to assess the impact of vulnerability on the degree and stability of market integration between regions.

Figure 1

Creating a Single Index to Depict Vulnerability to Food Insecurity

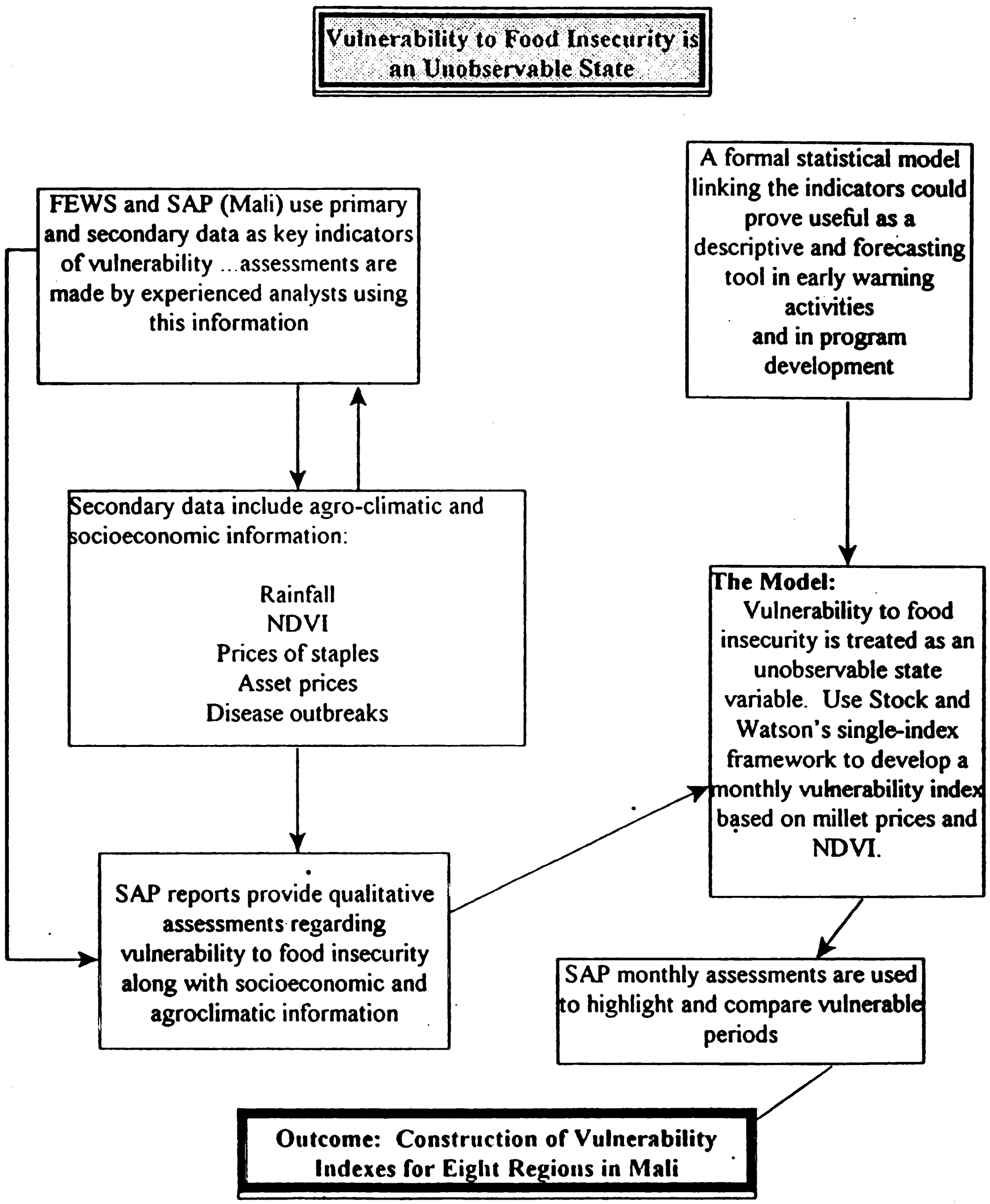
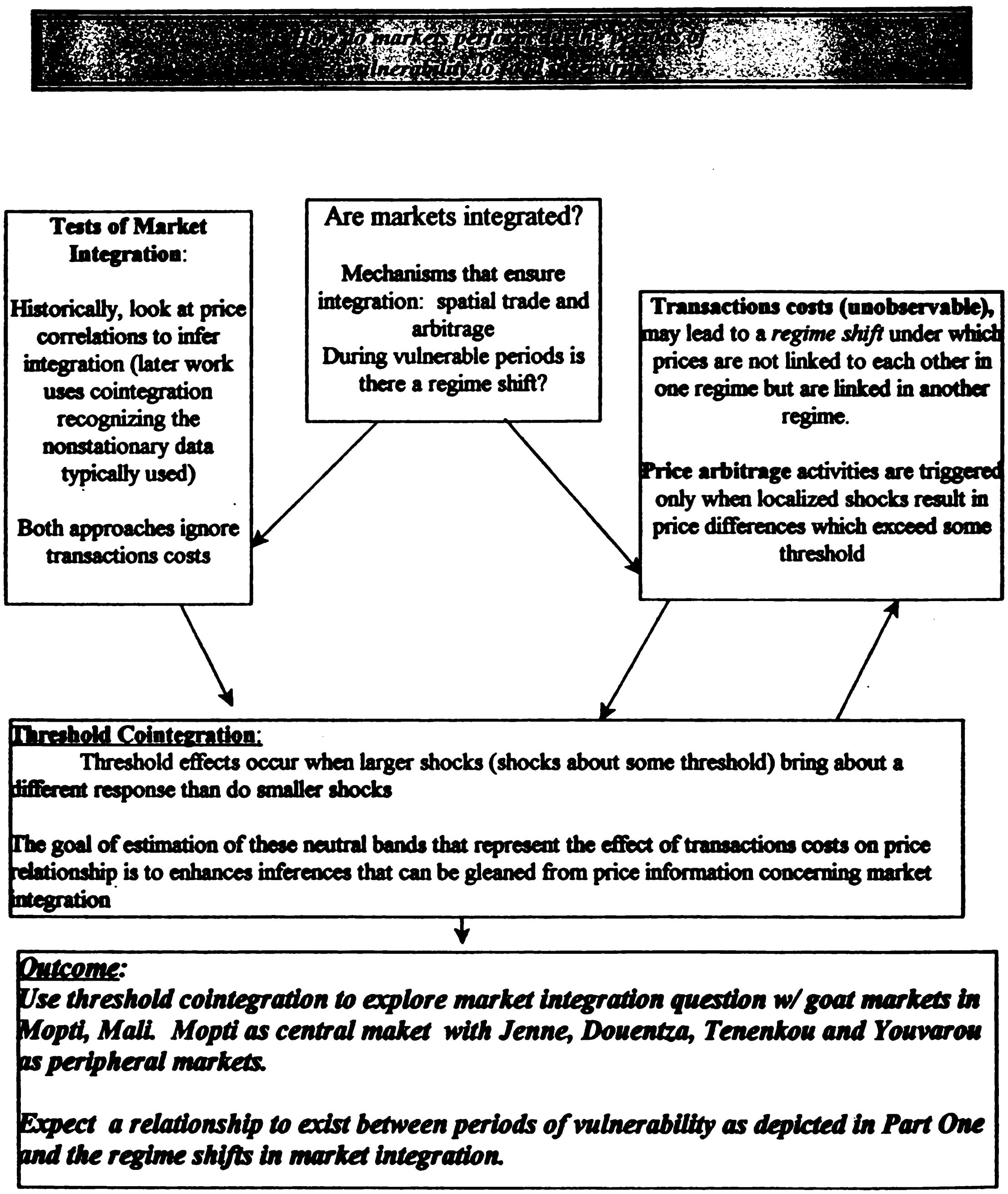


Figure 2

Market Integration and Vulnerability to Food Insecurity



1.2.1 The Construction of Vulnerability Indices

FEWS does not conduct primary data collection. Instead, it develops, manages, analyzes, and presents data from a variety of existing sources. In this sense, FEWS is a consumer of African information systems. In return, the FEWS management and analysis of the data is helpful to national and regional agencies. With this approach, FEWS is able to investigate regional patterns of food security indicators across FEWS countries. (May, 1992).

Geographical Information Systems (GIS) are a method for digitally organizing, storing and analyzing information on the earth's resources in a spatial framework. Information from satellite imagery, population, agricultural and geological characteristics can be analyzed and simulated for policy analysis. FEWS relies on this tool in its assessments.

Currently, FEWS uses the term *vulnerability* to describe the "relative susceptibility of households to various levels of food insecurity" (Riley, 1993). In practice, FEWS does not evaluate individual households but relatively homogenous groups of households. The project focuses on pastorialists, agro-pastorialists, sedentary farming groups, landless laborers, fishermen, craftsmen, urban poor and refugees located in specific areas. The frequently used indicators used in early warning and vulnerability assessment are:

1) Crop production, area and yield estimates for both food and non-food crops;
2) Livestock production data;
3) NDVI satellite data which reflects photosynthetic activity and vigor, or the "greenness" of vegetation;
4) Meteosat estimates of probable rainfall in a given area;
5) Point rainfall estimates from individual weather stations;
6) Market prices and quantities of throughput of food and cash crops,

livestock and other commodities;

7) Data on the outbreak of civil conflict in specific locations;
8) Information on food aid distributions; and
9) Health information such as vaccination programs and disease outbreaks.

The most consistently collected of these indicators are market prices, rainfall estimates and the vegetative index.

At each stage of the assessment process, FEWS analysts use *confirming indicators* such as information on household behavior and nutritional status to evaluate the evidence supplied by the secondary data sources. Using the *convergence of evidence approach* (NRC, 1987 in Riley, 1993), the confirming indicators are used to support formal analysis or to direct further data gathering when contradictions occur (Riley, 1993). Ideally, all indicators would be available in all regions in some consistent time interval, e.g. on a monthly basis. This not being the case, the FEWS Field Representatives (FFRs) do not use a formal model. Rather, they evaluate vulnerability from period to period using the above mentioned indicators and anecdotal information, placing more weight on some information in one period than another.

While the FEWS analysis is informative, a precise model used consistently in assessments has not yet been established even on a country or region specific basis. It is unclear how the *convergence of evidence* approach is operationalized or whether there is any means to verify its efficacy in any formal way. Without a well-defined notion of vulnerability or a formal framework, it is difficult to assess the effectiveness of the early warning capacity of the project. An analysis which has the means for validation of assessments could potentially improve the early warning facility of the analysis.

The first part of the dissertation will provide a formal model of early warning to food security vulnerability in Mali. The dynamic relationship between market indicators and agroclimatic information will be investigated. The indicators used in this study are market prices and NDVI. Thus, the model results will reflect a notion of supply-side susceptibility food insecurity. Here we hope to capture the relationship between leading and lagging components such that if one indicator implies a potential problem, it is detected early enough to be confirmed through further targeted research. The nature of these relationships may assist analysts in early warning activities so that vulnerable areas can be identified well in advance.

The vegetative indices, rainfall estimates and price data are available on a monthly basis and a dekadal basis for many regions in Mali. Evaluation of the univariate characteristics of each series as well as their relationship to each other provides some useful insights into the assessment of vulnerability and early warning capabilities.

The goal of this research is to build a leading indicator model of Mali's famine early warning system. USAID and the government of Mali developed early warning systems in the mid-eighties, FEWS and the Systeme d'Alerte Precoce (SAP), respectively. Both use agroclimactic and socioeconomic variables to detect evidence of famine conditions and allow for maximal response time to crisis on the part of donors and government agencies. The information gathered by FEWS and SAP include the following: normal differenced vegetative index (NDVI, a measure of crop greenness), rainfall levels, and price information. SAP also provides some qualitative and quantitative assessments on health, migration and insect infestation. Monthly data is used to construct the model for the period of October/November 1986 -January 1998. The regions within Mali selected in this study are a subset of those monitored by SAP: Areas in Segou, Mopti, Gao and Timbuktu above the 14^{th} parallel.

The model developed here is similar to those used to describe and predict macroeconomic downturns and turning points of business cycles for developed economies (Stock and Watson (1991), Necfti (1991), Kim and Nelson (1999), Hamilton (1994)). In this approach, we define a variable which represents the general "state of vulnerability" with respect to a region's susceptibility to food insecurity. This notion of vulnerability refers to the regime during which regional food insecurity could emerge. Given the observed information in the model, we create a variable which is descriptive of this unobserved state and serves as an indication of the vulnerability of agents within regions to a Food Availability Decline (FAD). The regions monitored by SAP were selected because they are prone to entitlement failures. While FAD theories of famine are grounded in the lack of available food, entitlement failures emphasize the inability of agents to acquire resources even when they are available in ample supply. It is assumed that the regions are not closed systems and trade can take place between them. This issue is explored in the second part of the research. Essentially, in regions monitored by SAP, a broad generalization would be that in these areas the FAD and entitlement failures are intertwined because real incomes in these areas, even among non-subsistence households, are largely dependent on agriculture and livestock. People, in general, are prone to entitlement failure which is further exacerbated by food availability declines, such as those engendered by poor rainfall conditions and other events which depress crop production.

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We describe the current "state of vulnerability", which is a common element of key variables collected by FEWS and SAP. We build a probability model which creates a definition of the unobserved "state of vulnerability". As in Stock and Watson (1991), we assume linearity in the unobserved variables. We employ a Kalman Filter to construct the Gaussian Likelihood function and glean estimates of the parameters. From this we get the mean squared error (MSE) estimate of the unobserved state of vulnerability variable using the observed information at time t. We are then creating a "single-index" model in which the state of vulnerability, V_t, is an unobserved variable common to multiple time series.

The estimate of V_t can be viewed as an index of coincident indicators using a single index model. This alternative index can be forecasted using leading variables including NDVI, prices of staple crops, asset prices, cumulative rainfall, as well as qualitative variables. The steps which lead to this vulnerability index involve characterizing the system in a state-space representation, estimating parameters using the Kalman filter, and updating parameter estimates with the most current information. From this model, we can also calculate the expected duration of vulnerability states.

1.2.2 Tests for Market Integration

There have been numerous studies using price series to evaluate the existence of market integration between regions (Alderman 1992, Timmer 1987, Ravallion 1986). These studies use various econometric models to assess information flows between markets. Essentially, this body of work investigates the correlations between prices and infers that comovement means that markets are integrated. The basis for this approach rests in the concept of the Law of One Price which posits that in an efficient market, prices for homogenous goods in two different regions should differ at most by the transportation costs.

Crucial information concerning infrastructure (the existence and quality of roads) and transactions costs has been notably absent from these models primarily due to inaccessibility of data. Optimally, transport rates between markets would be available and integration assessments would include these. However, this information, especially in countries with less developed transport sectors, is costly to collect and potentially unreliable. Essentially, this leaves the researcher with price data only. Still, an issue remains the appropriateness of using prices alone to determine the existence and nature of market integration. A strong correlation between two or more prices from various markets is difficult to interpret. Ravallion (1986) constructed a simultaneous system with many restrictions in order to yield an expression of long-run market integration primarily using prices.

Fackler (1994) carefully critiques Ravallion's approach as well as the efforts of other researchers. Fackler develops a spatial equilibrium model and develops testable restrictions on market efficiency and market integration. While Fackler achieves testable restrictions for long-run market integration similar to those of Ravallion, he uses econometric techniques such as cointegration and error-correction models which are better suited to some price data due to non-stationarity. Fackler has developed a model which lends itself better to interpretation and which does not impose ad hoc restrictions in order to achieve identification of a system.

Fackler argues that there has been much confusion over the concepts of market integration and market efficiency. If we define market integration to mean that two regions are actively trading with each other, then markets could have varying levels of integration. For example, a natural disaster may make it difficult to transport between regions as reflected in high transport costs. If traders are deterred by the high costs, then it is hard to say that they are not acting efficiently. These markets are still potentially integrated and, most likely, once transport costs decrease, trade will resume. In using only prices, the shock to transport costs would affect both markets and thus their prices. It would be difficult to distinguish just from an investigation of prices whether markets are integrated.

Recent work by Goodwin and Piggott (2001) uses a model of threshold cointegration to explore the role of transactions costs in inhibiting price adjustments which can affect tests of market integration. They evaluate price linkages among several local North Carolinian corn and soybean markets. Goodwin and Piggott's analysis employs nonlinear modeling techniques to account for regimes shifts within a neutral band to depict the effects of transactions costs on long-run equilibrium relationships. Threshold models characterize a regime switch as triggered by a transition variable (or variables) crossing some threshold value. This threshold parameter delineates alternative regimes. Hitherto, most tests for market integration express the long-run price adjustment as a linear phenomenon while threshold cointegration allows for alternative regimes to exist along with the long-run relationship.

This idea of incorporating regime shifts in tests of market integration leads to another issue which is the functioning of markets during times of food security vulnerability or famine. The fact that market A is a net seller of maize to market B in a non-stress period does not imply that this integration would prevail in times of vulnerability. Such information would be useful to donors and policy makers with respect to food aid distribution design and other policy oriented concerns. Thus, it would be useful to incorporate a dynamic measure of vulnerability into a structural model of market integration. A model that explores the relationship between regime shifts, expressing different levels of vulnerability to food insecurity, and price information would be useful in assessing the stability of market integration. In the second part of this research, we examine the functioning of goat markets in Mopti. We incorporate additional structural information and allow differential integration in times of stress using the vulnerability indicator developed in the first part of this study.

1.3 Outline for the Dissertation

The dissertation is organized into six chapters. Chapter One is the introduction just presented. Chapter Two provides an overview of famine early warning systems and some background on Mali and its famine early warning program. Chapter Three provides an overview of the regions in the study and presents a reference cycle of vulnerability to food insecurity for each region. Chapter Four presents a model of leading indicators and then develops an application for modeling the unobservable state of vulnerability to food insecurity. Chapter Four also provides empirical results for the leading indicator model for famine early warning. Chapter Five presents an investigation of market interrelatedness in Mopti's goat markets and explores nonlinear aspects of these relationships. Chapter Six provides a summary of the research findings and the implications for policy.

Chapter 2

Historical Overview of Famine Early Warning Systems

2.1 Definitions of Famine and Famine Theories

Famines have occurred throughout the history of mankind. The twentieth century saw many incidences of famine internationally (see Table 2.1). As we embark on the twenty-first century, the risk and occurrence of famine persists globally, but most predominantly in Africa (Von Braun et al, 1999). Different disciplines in the social and physical sciences each approach famine with particular views, definitions, and theories. Definitions of famine range from a focus on anthropomorphic measures, such as relative body-weight (Rivers, 1988), to socioeconomic definitions, such as the lack of available food in a region causing migration in search of sustenance. Walker (1989) defines famine as a socioeconomic process which causes the accelerated destitution of the most vulnerable, marginal and least powerful groups in a community, to a point where they can no longer, as a group, maintain a sustainable livelihood. According to D'Souza (1988), famine can be defined as a reduction in normally available food supply such that individuals, families, and eventually whole communities are forced to take up abnormal social and economic activities in order to ensure food. If these activities are unsuccessful, then starvation will follow.

Table 2.1 Selected famines of the twentieth century (Von Braun et al, 1999)

Country/Area	Year	Country/Area	Year
India	1899-1900	**Mozambique**	1982-83
India (Darbhanga)	1906-7	**Sahel Region**	1982-85
Russia	1913-1915	**Sudan**	1984-85
Russia	1921-22	**Horn of Africa Region**	1983-85
China	1929	**Mozambique**	1985-86
Russia/Ukraine	1933-34	**Sudan**	1988
Russia (Leningrad)	1941-43	**Somalia**	1988
India/Bengal	1943	**Ethiopia (Horn of Africa)**	1989-90
Russia/Ukraine	1946-47	**Liberia**	1992-93
China	1958-61	**Somalia**	1992-93
Nigeria (Biafra)	1968-69	**Sudan**	1993
Bangladesh	1971-72	**Angola**	1993-94
Cambodia	1973	**Liberia/Sierra Leone**	1995-98
Sahel Region (West Africa)	1969-74	**Zaire**	1997
Ethiopia	1972-74	**North Korea**	1996-98
Bangladesh	1974-75	**Sudan**	1998
Angola	1974-76		
Zaire (Bas Fleure)	1977-78		
Uganda	1980		

Sen (1981, p40-41) notes that in analyzing starvation in general, it is important to make clear distinctions between three different issues: (1) *lowness of typical level* of food consumption; (2) *declining trend* of food consumption; (3) *sudden collapse* of food consumption. Famine is chiefly a problem of the third kind. As the above suggests, definitions of famine range from a state of crisis or catastrophe, as in Sen, to that of a process, as depicted by Walker and others.

To Western observers, famine is commonly thought of as a widespread death from starvation. De Waal (1989) and Devereux (1993) note that the crisis state definition depicts "outsider" definitions of famine where famines imply starvation (referring to perspectives such as donors and international organizations). The "insider"perspective incorporates concepts such as the coping strategies engaged, the fact that famine mortality relates to disease outbreaks indirectly tied to undernutrition, and the complexities and stratum of famine. To illustrate, the Arabic word for hunger is *maja'a*. In Darfur, Sudan, the word takes on a process oriented, or dynamic meaning, incorporating three aspects: hunger, destitution, and death, with the emphasis on destitution (Devereux, 1993 and Starr, 2000, personal correspondence). Davies (1996) and others use the terms "food vulnerability" and "food insecurity" interchangeably, with the understanding that famine is the last stage in a process of hunger and destitution. *FEWS* (1997) employs the following definitions in defining levels of food security which it then uses in its publications such as *Vulnerability Assessments*:

> **Food Insecurity** is the inverse of food security: a condition in which a population does not have access to sufficient safe and nutritious food over a given period to meet dietary needs and preferences for an active life. Possible causes are insufficient food availability, insufficient food access, and inadequate food utilization.
>
> **Current (or transitory) food insecurity** occurs when a population suffers a temporary decline in consumption. Current food insecurity can result from instability in food production, food prices, household incomes, or health conditions.

Chronic (or long-term) food insecurity occurs when a population has continuously inadequate consumption. Chronic food insecurity arises from conditions of poor food production, limited incomes, and poor health.

In this work, famine will be defined as the endpoint of a process during which households and communities move from a situation of food security through various stages of vulnerability to food insecurity where the end of the process is famine as defined in the 'outsider' sense. Essentially, this notion of mapping the vulnerability to food insecurity captures both "insider' and "outsider" perspectives and terminology.

There have been many attempts to develop comprehensive theories of famine which tend to be divided along disciplinary lines. Dominant theories have approached famine as a *Food Availability Decline (FAD)* resulting from population increases or external shocks, such as drought or war. Alternative explanations include market failure (Alamgir, 1989) and exchange entitlements failure (Sen, 1981). Table 2.2 provides a taxonomy of famine theories. Von Braun et al (1999) note that the debate over famine suffers from the following: (1) untestable hypotheses of broad generality, (2) the synthetic hypotheses of broad generality, (3) a lack of empirical analysis of the actual socioeconomic processes that occur during famine. Single-cause and general theories fail to provide lasting insights into the complex and dynamic famine risks facing African nations as well as the rest of the developing world. Political, institutional, organizational, market, and production failures set the stage for households and communities to be vulnerable to food insecurity. Armed conflict has been widely acknowledged as a major factor in both famine and chronic food insecurity in Africa (Duffield (1990), Von Braun et al (1999), Harrison (1988), Davies (1996)).

Table 2.2 A taxonomy of famine theories, adapted from Devereuex (1993)

1. ***Food Availability Decline*** **(FAD)**

    1.1 Population Increase (Malthus)
    1.2 War
    1.3 Climatic Factors

2. ***Economic Theories***

    2.1 Market Failure
    2.2 Exchange entitlements (Sen)

3. ***Socioeconomic and Political Dislocation***

    3.1 Due to Structural Changes
    3.2 Due to changes associated with development

4. ***Government Mismanagement*** *(Political or Institutional Failure)*

5. ***Anthropological or Sociological Explanations***

6. ***Multi-causal or Eclectic Approaches***

Drought itself does not immediately translate into famine. Seasonality, climate shocks, and production failures are not unknown to households in these vulnerable regions. In response, they have developed coping (short-term) and adaptive (long-term) strategies. The relationship between drought and famine, as well as between production failures and famine becomes strong when poverty is endemic, the resource base is poor, and the public capacity for prevention and mitigation is weak (Von Braun, 1999). When drought takes place in consecutive years and other factors combine, a reoccurring vulnerability prevails that can be defined as 'not lack or want, but defenselessness, insecurity, and exposure to risks, shocks, and stress' (Chambers, 1989). Crow (1986) notes that climatically-induced reductions in output may affect the household's ability to get food by: (1) reducing their own production (and any sales thereof); (2) reducing their ability to get cash or kind wages through work, and (3) reducing purchasing power of what wages they do get (and assets they have accumulated) by raising the price they pay for food. To survive, households respond to these circumstances with a variety of coping strategies or adjustments, such as risk minimization, risk absorption, and risk taking. Persistent challenges that necessitate evoking these strategies exhaust the household's asset base and make them more vulnerable to food insecurity. In Chapter 3, this process is discussed in more detail.

Given the complex process that leads to famine, it may be more constructive to think of the famine early warning as an effort to identify the triggers that compromise food security and map the resulting path of vulnerability to food insecurity.

2.2 Famine Early Warning Systems

In response to the tragic loss of life due to the African famines of the 1970's and

1980's, the international community established a variety of famine early warning systems. The creation of these systems stems from the hypothesis that there had been a lack of available information for donors and in-country policy makers to equip them to respond in a timely manner to food security emergencies. These early warning systems (EWS) gathered information which tended to focus on the food availability issues, such as crop production. All of the EWS have their own approach and objectives for their systems.

There are a variety of early warning systems monitoring conditions in the Sahel, Horn of Africa, and in southern Africa, each which operate on different levels. There is a global-level EWS , the Global Information and Early Warning System (GIEWS) of the United Nations' Food and Agricultural Organization. GIEWS was founded in 1974 and operates on a very broad national basis. It is geared toward information gathering to address food shortages and is designed to be used by policymakers in decisions concerning food aid and emergency measures. The integration of the information concerning food security conditions generated from sources such as country food balance sheets and the use of remote sensing techniques were pioneered by GIEWS. Indicators such as the "normalized differenced vegetative index" (NDVI) and methods for monitoring cloud cover for inference on rainfall conditions were also developed through GIEWS' Africa Real Time Environmental Monitoring Satellites (ARTEMIS) and other NOAA satellite imagery. GIEWS is supply-oriented and is an important source of information for donors and governments in food security decision-making. GIEWS is not formally linked to response mechanisms (Buchanan-Smith et al, 1991). A complementary system to GIEWS is the World Health Organization's Epidemiological Early Warning System (EEWS).

There are also regional early warning systems that include the two early warning projects operated by the Comité Permanent Inter-Etats de Lutte contre la Secheresse dans le Sahel (CLISS) in nine countries in West Africa and the Famine Early Warning System (FEWS) of the United States Agency for International Development (USAID) that operates throughout Africa.

On a national level, there are multiple systems in Mali, Chad, Ethiopia, Sudan, Botswana, Kenya, and Burkina Faso. The Système d'Alerte Précoce (SAP) is Mali's official early warning system. Southern Africa's regional EWS is run by the Southern African Development Coordination Conference (SADCC) in ten countries. There are also several non-governmental organizations that maintain or have operated targeted early warning systems, including Save the Children Fund that operated in the Inner Niger Delta region of Mali (SADS project), and the Red Crescent Society that operates in parts of Sudan.

The Evolution of Famine Early Warning Systems

There has been much criticism to date of the crisis orientation of EWS. Researchers (Davies (1995), Campbell (1991), Devereux (1993), Walker (1981), Brock (1998), Rakodi (1999)) and policymakers point out that, for the system to possess an truly early warning capacity, there should be an emphasis on sustainable livelihoods as an approach to minimize the vulnerability of households heading into a downward spiral to destitution when a drought or some other external shock occurs. Table 2.3 outlines the different approaches to early warning (where conventional refers to systems such as GIEWS and FEWS, historically). There have been efforts to incorporate the alternative approaches; however, regional and international early warning systems tend to focus on the conventional approaches in terms of information gathering and analysis. In recent years, FEWS (1999) has extended its approach to gather and analyze the sorts of access and socioeconomic information called for by critics. FEWS still tends to rely on conventional indicators in its *Vulnerability Assessments* while developing alternative indicators (FEWS 1999).

Table 2.3 Typology of early warning systems

	Conventional Famine Early Warning Systems	***Alternative Food Information Systems***
Scope	Famine-oriented	Food security-oriented
Determinants of food security	Food production	Access to food
Level of operation	Macro-centralized	Micro-decentralized
Unit of analysis	Geographic e.g. nation/districts	Socio-economic e.g. vulnerable groups
Approach	Top-down Data-centered	Bottom-up People-centered
Response	Food-aid oriented	Sustainable improvement in access to food

Source: Davies et al. (1991)

The mission of famine early warning systems is still evolving. The current EWS are viewed as state-of-the-art in their collection and dissemination of information.

However, there exist problems with the link between early-warning and response mechanisms. As recently as 1996/97, the Sahelian countries of Chad, Mauritania, and Niger faced problems of food shortages due to production shortfalls. Assistance to vulnerable communities came late at best. The reasons include the inability to communicate effectively the direness of circumstances in some regions, conflicts between donor and recipient countries, and the lack of news media attention as the problems emerged. As a result, the slow response increased the vulnerability of many communities who faced even further erosion of their assets (FEWS 1998). As these challenges are addressed, and the capacity for broader use of the information systems such as FEWS is recognized, the role for such systems will most likely be expanded in development planning. In a recent article, Pierstrup-Andersen (2000) summarized the emerging issues in agricultural development. He noted that incorporation of technological advances (which include information systems) in economic development planning is an emerging issue. Early warning systems as a leader in high tech information gathering mechanisms will certainly have an important role to play as a tool in development policy and program analysis (for example, in the analysis of programs such as marketing information systems) and will likely continue to evolve with an expanded mandate for information collection and analysis.

2.3 Famine Early Warning Systems in Mali

Mali is a land-locked country situated in West Africa, with Mauritania, Niger, Burkina Faso, Côte d'Ivoire, Guinea (Conkry) and Senegal as its neighbors. Official estimates of population are 10.6 million in 2000 with a low growth rate of approximately 1.8% due to emigration. Twenty-five percent of the population is urban and 75% reside in rural areas of which five percent is nomadic. Mali is one of the world's poorest nations, with a GDP per capita of $270 in 1996. Since independence in 1960, economic growth and structural change have been slow. In 1965, 90% of the labor force drew their subsistence level of income from agriculture, while the figure is estimated between 80 and 90 percent in 1995 (Davies, 1996). Opportunities for wage employment are few. The main agricultural crops for Mali are millet, sorghum, and cotton. Livestock-raising accounts for approximately one half of agriculture's contribution to GDP and is the principle economic activity in the north. Drought, institutional problems, and low prices to producers have affected Malian agricultural production. Cotton, gold and livestock are Mali's main exports. In 1994 there was a devaluation in the CFA franc which has stimulated exports. GDP growth is expected with the expansion of the mining of gold and cotton exports. Cotton accounted for over 50% of export income in 1998.

The Malian transportation system is poorly developed. The road systems are comprised of a mere 18,000 km of classified roads, of which 6,000 km are all-weather and 2,000 km are tarred (See Figure 2.1). The inland waterways, which extend over 1,815 km, are essential to the transportation infrastructure. The River Niger serves as the key transportation route in the rainy season.

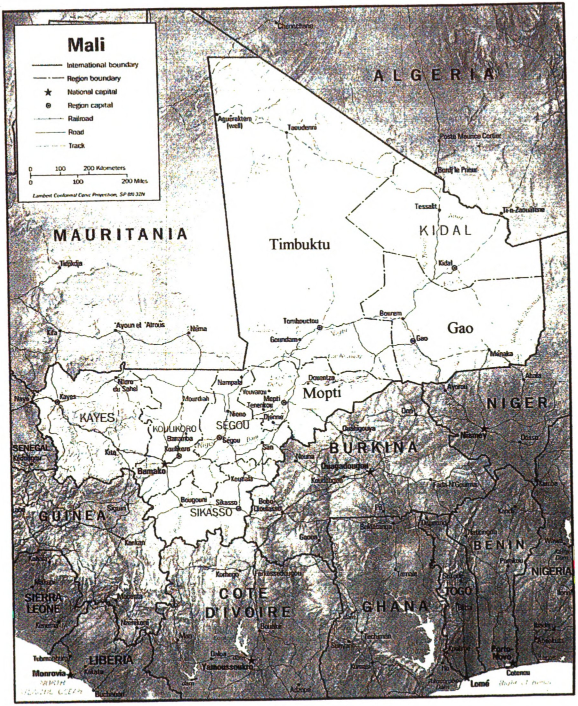
This sparsely-populated former bread basket of French West Africa is mostly covered with desert or semi-desert. Table 2.4 provides some general information on Mali's climate and topography.

Table 2.4 Mali's Climate and Topography

	subtropical to arid; hot and dry February to June; rainy, humid, and mild June to November; cool and dry November to February
	mostly flat to rolling northern plains covered by sand; savanna in south; rugged hills in northeast
Land cover	arable land: 2% permanent crops: 0% meadows and pastures: 25% forest and woodland: 7% other: 66%

Source: ESA-ESARIN, 1998

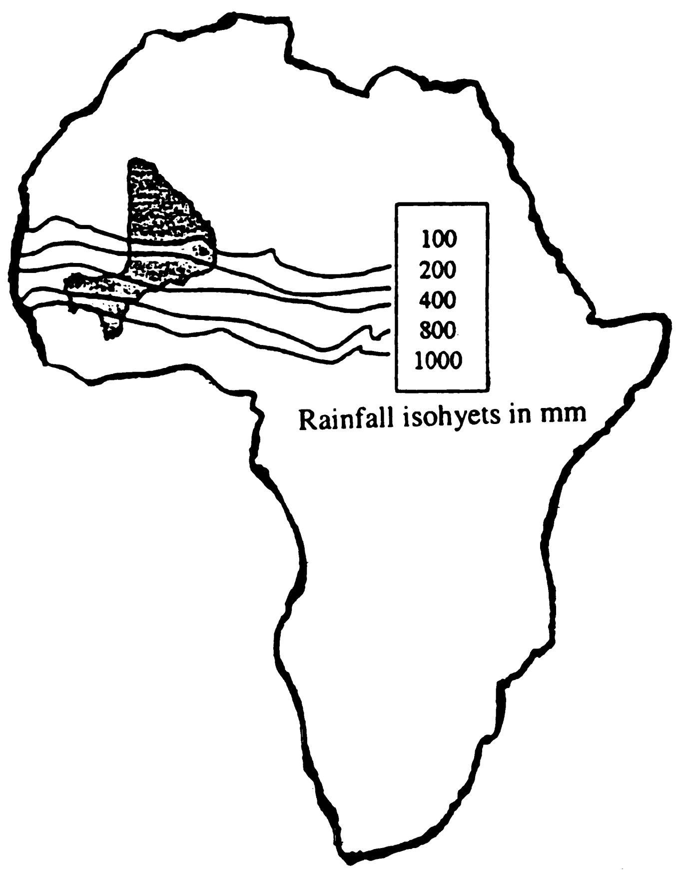
Figure 2.1 Map of Mali



Source: Mike Lipsey, Michigan State University (2001)

The country is 1,240,142 sq km, slightly less than twice the size of Texas, and spans five agroecological zones that are differentiated by rainfall levels. About 780 sq km is irrigated by the River Niger. This research centers on the Sudanic, Sahelian, and Sahelian-Sahara zones, which receive annual rainfall levels of 350-600 mm, 200-350 mm, and less than 200 mm, respectively (see Figure 2.2). Rainfall and Sahelian zone flood levels of the River Niger are the key determinants of food production. The south is the productive region, whereas the population of the Sahelian north suffers significantly lower average income per capita of rural producers, estimated at $100 in 1990 (Davies, 1996).

Figure 2.2 Mali: Rainfall Isohyets (Davies, 1996)



While there have been numerous accounts of drought in the Sahel throughout history, the onsets of such have rarely resulted in famine in Mali. Mali has suffered two widespread famines in the last 50 years, in 1972-3 and 1984-5. Malian Sahel and Inner Niger Delta are not characterized by acute shortages that lead to famine, but rather by chronic seasonal food insecurity in most years that can degenerate into acute shortages for some groups (Davies, 1996). The civil unrest that has perpetuated and supported famine in other African regions was absent in Mali in the 1970's and 80's, which contributed to fewer onsets of famines after drought. In the early 1990's, conflicts between the Malian army and the Tuareg, and between rival groups in the north, were negotiated into settlements. Further conflicts have been sporadic. While famine is a relatively rare occurrence in Mali, chronic seasonal food insecurity for certain groups is a reality in Northern Mali. Table 2.5 offers a very rough overview of droughts and the onset of famines in the Sahel from 1740 to present.

Table 2.5 Principal Droughts in the Sahel since 1740

1740	Drought, famine
1750	Drought, famine
1790	Drought
1855	Drought
1900-3	Drought
1911-14	Drought, famine
1931-4	Drought, famine
1942	Drought
1950	Drought
1968-73	Drought, famine
1983-5	Drought, famine
1987	Drought
1990	Drought
1992	Drought

Source: Moorehead (1991) and Davies (1996)

Famine Early Warning in Mali

Since 1986, no famines have occurred in Mali, yet many areas have experienced food crises. The early warning capacity has improved information flows, and has helped facilitate national policy makers and donors in their response decisions. The development of a market information system (SIM), cereal market reforms, and SAP have proved useful tools for mitigating crises, and have still greater potential as development planning tools. Current famine early warning systems, like FEWS and SAP, tend to be focused on local food supplies.

Famines, however, do not occur only due to declines in local production. Declines in incomes and other factors prevent households from getting adequate access to food; thus, famines can result even in the presence of ample food supplies. In Mali, poverty and weather fluctuations tend to be the primary factors contributing to food insecurity. The areas selected for monitoring by SAP (all arrondissments above the 14th parallel in the regions of Mopti, Kayes, Kidal, Gao, Timbuktu, Segou, and Koulikoro) are prone to food insecurity for a variety of reasons, including livelihood vulnerability, where external events such as drought can move a household from subsistence to destitution fairly rapidly due to the household's dependence on agriculture for income sources. One could say that the regions are prone to entitlement failures when there are shortfalls in regional production.

Local committees convene monthly to review the food situation in the arrondissment. The committees are composed of technical experts from the Ministry of Rural Development, the weather service, livestock service, hydrological service, NGO's, as well as members of civil society. They debate and discuss the food security situation and come to agreements in order to fill out the standard questionnaire. The questionnaire is then validated by Cercle-level officials, and sent on to regional capitals. The regional SAP representative synthesizes the questionnaires and generates a regional report, which is sent to SAP headquarters in Bamako. Bamako officials consider the situation in each zone, assessing whether any production shortfalls (especially in food-production-deficit zones) can be offset by acquiring food through markets and other transfers. Monthly reports summarize the findings and provide an assessment of each arrondissement's food situation using the following classifications (Table 2.6):

Table 2.6 SAP Vulnerability Classifications

Acronym	Meaning	Government Relief Action Undertaken through SAP
RAS	Nothing to report	None
DEL	Some economic difficulties	None
DES	Severe economic difficulties	None
DA	Food Deficit	3 months distribution of "half ration" to everyone in the arrondissement (9kg/person/mo) during the soudre (June-Sept)
CA	Food Crisis	7 months distribution of "half ration" to everyone in the arrondissement (9kg/person/mo) from January through September
FA	Famine	Full ration (18kg/person/mo, plus salt and dried fish) distributed until the situation improves.

This classification system has been in place since SAP's inception. It is important to note the early warning and response connection developed in this early warning system. Since 1986, no arrondissement has ever been classified as FA. If an arrondissement is designated as DA or worse, SAP launches a special socio-economic study that looks at markets, health, livestock and the area's nutritional situation. If the situation worsens, SAP sends a team to conduct medico-socio-nutritional studies that include anthropometry (SAP, 1986-1999 and Staatz, 1997 through personal correspondance) .

This research relies on the monthly SAP reports and FEWS for time-series data and other information. How this information is used to develop a vulnerability index is discussed in the following chapters.

CHAPTER 3
A Reference Cycle for the State of Vulnerability to Food Insecurity in Mali

3.1 Introduction

The aim of this chapter is to produce a reference cycle that can be used as a comparison to the more complex indexes developed later in this research. In business cycle research, reference cycles provide a depiction of actual business or socio-economic conditions and create a narrative framework with which to compare the results from simulating or estimating an econometric model. Widely accepted notions of reference cycles in business cycle research are readily available because there exist well-defined measures of economic downturns such as recessions (defined as two or more quarters of negative growth in GNP).

Such a widely accepted notion of an 'objective' measure of vulnerability to food insecurity does not exist in the economic development literature, among international development organizations, or among donors. However, famine early warning systems such as Mali's SAP and USAID FEWS do track certain qualitative and quantitative measures in an effort to document the factors contributing to periods of vulnerability to food insecurity. In this research, we develop reference cycles based on the qualitative assessment of famine conditions using the monthly bullitens published by SAP in Mali. In this chapter, Section 3.3 details the approach to developing the reference cycles and Section 3.4 reports the reference cycles for each region in the study. Section 3.5 provides a simple index of smoothed millet prices to be used as a benchmark for the single index developed in the next chapter. Section 3.6 compares the smoothed millet price index with the qualitative reference cycles developed for each region. The next section provides some background on the regions examined in this research.

3.2 The Regions

The regions selected for this study are those monitored by SAP because they tend to be deficit producers of cereals (with the exception of Segou) and more vulnerable to rainfall variability than the southern regions of Mali. Nicholson (1983) characterizes regions based on rainfall criteria: 100-200 mm for the Sahelo-Saharan Zone, 200-400 mm for the Sahel Zone, and 400-600 mm for the Sahelo-Sudanian Zone.

Over time, the length of the rainy season in the Northest has shortened while variability of precipitation has increased (Steffen, 1995). In general, Davies (1996) notes a trend toward the decline in rainfall levels in the region over the past several decades. Rainfall plays a dominant role in the production of Mali's main agricultural crops: millet, sorghum, maize, rice, cotton and groundnuts. There are three main cropping patterns in regions monitored by SAP: rainfed agriculture, water recession agriculture, and irrigated agriculture. Livestock trade is also an essential economic activity in the region monitored by SAP and FEWS in Mali.

3.2.1 Rainfed Agriculture

Millet and sorghum are the principle cereals grown in the areas monitored by SAP. They have adapted to semi-arid conditions and can produce a minimum yield even in years of generally poor conditions (Steffen, 1995). Sorghum requires a longer growing season and is thus more vulnerable than millet to rainfall volatility. Planting occurs in June and July with harvests in October and November.

3.2.2 Water Recession Agriculture

Water recession agriculture in Mali consists of sequential planting along the river banks of the Niger and other rivers or around seasonal ponds in the desert as water levels receed in the dry season. River recession sorghum planting takes place in February and March. The crop is harvested in September or October in periods of good rains. Semi-sedentary nomads plant pond recession sorghum in September or October around temporary ponds formed in the rainy season with a harvest in January or February (Steffen, 1995)

3.2.3 Irrigated Agriculture

Irrigated agriculture is practiced along the Niger, Bani and Diré Rivers and in lake zones. There are two annual rice crops. The main crop is planted in July and harvested in December. The off-season rice crop is planted in January and harvested in June (Steffen, 1995). The PPIV, established in 1991, operates in the Northeast to promote rice cultivation and distribution.

3.2.4 Wild Cereals

Wild cereals such as fonio and cram-cram are gathered to fill the cultivated cereals gap during the hungry season. The wild cereals mature in August and September. Since the droughts of the 1970's and 1980's the stigma associated with consumption of wild cereals has lessened. However, consumption of these cereals serves as a signal of household food stress and is reported in the SAP reports as such. Fonio can be stored for long periods and is relied upon by nomads and poorer households in the hungry season (Davies (1995), Steffen (1995).

The cercles(regions) examined in this research are Gao, Mopti, Timbuktu, Segou, and four cercles in Mopti Region: DJenne, Douentza, Tenenkou, and Youvarou. For the analysis in Chapter 3 and Chapter 4, the research discussion and results for Gao, Mopti and Timbuktu are presented in the main body of the dissertation while the background and findings for the remaining regions are presented in appendices.

3.2.5 Regional Descriptions

Gao

The cercle of Gao is located in Northeastern Mali bordered by the regions of Timbuktu to its west and Kidal to its north with Burkina Faso and Niger along its southern and eastern border. The annual rainfall level is 185mm. Gao is a cercle which has experienced tremendous changes due to civil conflicts and environmental factors. Kidal, to the north separated from Gao in 1990 while conflicts of the early 1990's also contributed to a great deal of upheaval and uncertainty in the region. Along with Timbuktu, Gao serves as the northern most boundary of pasture for pastoralists. Gao is connected to Bamako and other eastern areas by a paved road and is situated along the Niger River. These factors support Gao Cercle as an important center of trade in the Northeast of Mali. A deficit region in the production of cereals, agro-pastoralists and pastoralists tend to play a dominant economic role in the region.

Mopti

The cercle of Mopti is the administrative center of the Mopti Region and serves as a barometer for local, regional and in the case of fish and livestock, international commerce, rural-urban migration, and the general economic health of the region (Davies, 1996). Average annual rainfall is under 500mm. As a transportation node, all trade to the north passes through Mopti which is located where the rivers Niger and Bani converge with the Seno drylands to the east and south. Trade to Timbuktu passes through by road (when the flood has retreated) or by river and to Gao by road (see Figure 2.1). Regionally, Mopti is the pathway for trade for imports and exports for the Mopti, Gao, Kidal and Timbuktu regions. Cereals from southern regions are the most important imports for subsistence producers along with manufactured household items. Exports from Mopti include dried and smoked fish. Livestock markets are less concentrated in the region such that Fatoma and Douentza are also important trading centers. Trade in Mopti serves as an indicator for regional prosperity: merchants serve as creditors and cereal traders in times of deficits and suppliers of productive equipment and consumer goods in times of surplus. Migrants in search of urban employment, which is difficult to come by in bad years, pass through Mopti. Since the drought of 1984-5 more displaced persons have stayed on in the cercle (Davies, 1996).

Timbuktu

Timbuktu is the northern most cercle in Mali and is bordered by Algeria, Mauritania and Niger Gao, Kidal and Mopti. In the 1990's the region experienced a long period of unrest and armed conflict which was peacefully defused culminating in an historic bonfire of the armaments from disputing parties (Poulton and Youssouf, 1998). Due to this regional conflict and those in surrounding areas, Timbuktu has experienced large movements of displaced persons. In the mid-1990's repatriation of refugees who fled the conflict further stressed the resource and administrative capacities. In addition, environmental factors such as declining rainfall levels and desertification have put enormous pressure on already vulnerable communities. Timbuktu receives approximately 160mm of rainfall each year and, like Gao serves as the northern boundary of pasture for pastoralists.

3.3 The Approach: Deriving Reference Cycles for the State of Vulnerability

The indicators used in this study are transformed such that an increase in their value is associated with increasing vulnerability. For example, as millet prices increase, household purchasing power declines, all else being unchanged, thereby negatively affecting the household's level of food security. As indicated earlier, there does not yet exist a formal model such as a leading indicator model of vulnerability nor is a formal quantifiable definition of vulnerability widely used. Therefore unlike the case with Stock and Watson's approach to the NBER Coincident Index, where an index exists and an accepted definition of recession also exists, a conventional measure to be used as a basis for comparison for vulnerability indexes constructed in this research is not available. For the purposes of this study, reference periods have been developed from the qualitative assessments made by local and regional officials in the monthly SAP reports.

The SAP reports provide a monthly summary for each monitored cercle consisting of reports on pasture conditions, the agricultural outlook for seasonal crops such as millet and sorghum and for contra-seasonal crops such as rice, disease outbreaks, the status of household reserves (impressionistic rather than from surveys), migration patterns, fishing outlook, market condition, rainfall levels and the need for food aid. Beyond the broad status characterizations such as *Food Deficit (DA)* and *Famine (FA)* presented in Table 2.6, the summaries provide a considerable amount of data from which to glean information concerning food security conditions. Reference periods depicting events or circumstances that can trigger food security vulnerability are presented in Table 3.1. These criteria were distinguished for the cercle as a whole as well as for localized phenomenon and are used as benchmarks for characterizing vulnerable periods and relating them to the constructed vulnerability indices.

The SAP reports are sometimes criticized as overstating and understating food security conditions (Davies 1996, Buchanan-Smith and Davies 1995) and in failing to clearly authorize food aid with enough lead time to be effective. However, the reports provide the most consistent record of food security conditions, both in terms of time frame and substance, in the region. Table 3.1 outlines the events which were identified as fostering conditions of vulnerability to food insecurity. Table 3.2 presents the method for classifying a period as moderately vulnerable or highly vulnerable. An example of moderate conditions would be a slight increase in prices combined with other factors such as disease outbreaks. A period of high vulnerability is defined as one where there was a sharp and sustained rise in prices and low quantities of staples in the market, for example.

Table 3.1 Characteristics of Reference Periods for Vulnerability Assessments

1.	General qualitative assessment of vulnerability in food security summary
2.	DEL: Some economic difficulties (as presented in Table 2.6) DES: Severe economic difficulties DA: Food Deficit CA: Food Crisis FA: Famine
3.	Household reserves reported as "weak"
4.	Food aid authorized
5.	Sharp increase in staple prices reported
6.	Low level of staples in market reported
7.	Disease outbreaks classified as epidemics (meningitis, cholera and/or measles)
8.	Consumption of wild cereals reported
9.	High level of migration into the cercle reported
10.	Civil Unrest reported

Table 3.2 Classification of the Severity of Food Security Conditions

Classification	Description
Low Vulnerability	Reports of no problems or localized problem areas with a duration of less than two months
Moderate Vulnerability	Sustained pockets of problem areas Price increases sustained over more than one month Low quantities of cereals on the market for one month Moderate damage from pests Household Reserves (HHR) reported as fair or average Consumption of secondary crops
High Vulnerability	Sharp and sustained increase in food prices Sustained decrease in the availability of cereals in the markets High levels of disease cited Sharp increases in off-season migration Civil unrest reported HHR reported as weak Persistent but spread out DES/DA

Periods where there were vulnerability is classified as low, unmarked in the figures, tended to include no significant reports of problems or reporting of isolated problem areas that were not noted for more than two consecutive months. The severity and duration of conditiond are documented such that periods of high vulnerability can be distinguished from periods of low vulnerability. For example, 'sharp increase in food prices', 'off-season migration', and 'very low quantities of cereals marketed' that persisted for more than one month were depicted as highly vulnerable periods. Whereas periods with occurances such as 'some economic difficulties'or 'some disease outbreaks'were viewed as moderately vulnerable periods if these conditions persisted for two months or more. In the next section, we present the reference cycles on a time line for Gao, Mopti, and Timbuktu as representations of the qualitative information gleaned from the monthly SAP reports.

3.4 The Reference Cycles by Cercle

This section provides an overview of vulnerability conditions for each region as expressed as reference cycle mappings. Figures 3.4.1 through 3.4.3 map the qualitative information from the monthly SAP reports month by month for each region. The lightly shaded areas represent moderately vulnerable conditions whereas the darker areas depict periods of high vulnerability to food insecurity. These shaded areas are descriptive and based on the narratives provided in the SAP reports such that the volume of food aid distributions or the severity of a disease outbreak are not captured only their presence or absence or their persistence. Each regional summary is followed by the reference cycle mapping for the cercle (Figures 3.4.1 through 3.4.3) as well as detailed chronologies for each region (Tables 3.4.2 to 3.4.4). Table 3.4.1 provides a summary of reference cycle classifications for Gao, Mopti and Timbuktu.

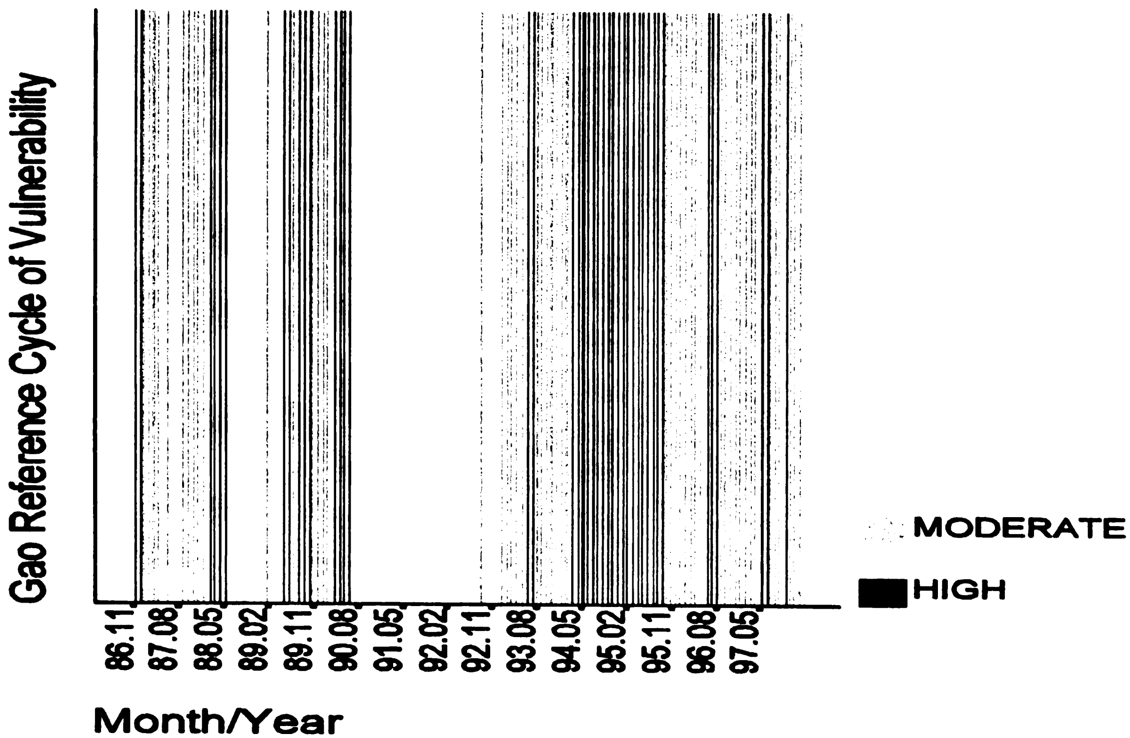
Table 3.4.1 Summary Classifications for Reference Cycles

Region	Periods of Moderate Vulnerability	Periods of High Vulnerability
Gao	January 1987 to June 1987 September 1987 to January 1988 November 1989 to February 1990 September 1992 January 1993 to February 1994 October 1995 to May 1996 September 1996 to January 1998	November 1986 to December 1986 February 1988 to May 1988 March 1990 to June 1990 June and July 1993 March 1994 to September 1995 June 1996 to August 1996 May and June 1997 October 1997
Mopti	January 1987 to July 1987 October 1989 January 1990 to May 1990 July 1991 October 1991 to March 1992 February 1993 December 1993 to May 1994 March 1995 September 1996 February 1997	November and December 1986 August 1987 to July 1988 June 1990 to October 1990 April 1992 to July 1992 April 1995 to August 1996 March 1997 to January 1998
Timbuktu	January 1988 to August 1988 March 1989 to August 1990 April 1991 July and August 1991 January and February 1992 June to August 1992 December 1992 to December 1993 January and February 1995 (some areas)	October 1986 to July 1987 June 1989 February 1990 and March 1990 May and June 1991 September 1991 to December 1991 March 1992 to May 1992 June 1994 to January 1998

Gao

We turn to Figure 3.4.1 which maps the reference cycle of vulnerability to food insecurity in Gao. The time period under investigation is November 1986 through January 1998.

Figure 3.4.1 Gao Reference Cycle Mapping of Vulnerability to Food Insecurity November 1986 to January 1998



The SAP reports note that October 1986 was a period of significant vulnerability, exacerbated by the hardship of famine during 1984 and 1985 that weakened or exhausted household resources. The SAP bulletins for November and December 1986 indicate with migration pressures into Gao cercle from outlying areas in search of food during this period. In addition, consumption of wild cereals is noted as a strategy to maintain levels of household reserves. N'Tillit is noted as especially vulnerable in June 1987 but an isolated case. Food aid deliveries throughout the period (May, June, August and December) appear to mitigate food security crisis in the cercle although vulnerability persists with a poor harvest in October/November 1987.

January 1988 is a period of increasing vulnerability with migration pressures and markets poorly stocked in cereals. February through May 1988 are declared periods of food insecurity in the cercle. Food aid deliveries are spaced out during this period and appear to mitigate further deterioration in conditions. Food security conditions improve with the release of food aid and with harvests in October and November of 1988.

In January, 1989 the SAP reports make note of N'Tillit as an isolated problem where there are increasing prices. April 1989 reports describe the onset of a vulnerable period. In March and April 1989 high volatility in prices of staples is noted with a trend of increasing prices as well as an increase in the consumption of wild cereals in the cercle in general. In May conditions deteriorate with disease outbreaks, high price volatility, lower levels of cereals in the market and irregular migration. August and September are found to be moderately vulnerable times with migrant workers returning with low levels of resources, higher prices and a scarcity of cereals in markets. A food aid delivery in November assists those in the most vulnerable regions. Several areas in the cercle continue to be under surveillance. In February more isolated problems are reported with additional pressures with the arrival of refugees from Algeria. In May and June 1990 food aid distributions and wild cereals mitigate food security problems where a average harvest is expected.

After August 1990, the qualitative assessments do not indicate conditions detrimental to food insecurity for some time. There are some isolated problems in Djebock in the first part of 1991 and a food aid delivery in July after which the qualitative reports do not indicate any further problems. No major problems are reported in 1992, however, the formerly secondary strategy in food insecure periods of consuming wild foods has become a typical way to supplement household reserves. A food aid delivery in November 1992 serves to assist the most vulnerable. Djebock and N'Tillit are declared to be having economic difficulties from January through August 1993. In April and May disease outbreaks are reported cercle-wide. In June pressures mount with an increase in migration from Algeria due to civil conflict. In July, the United Nations High Commission on Refugees establishes a camp in Gao. In August 1993, an expected poor harvest is realized and sharp increases in millet prices around the cercle reported in September and October such that there is an increase vulnerability to food insecurity throughout the rest of 1993.

These conditions of high prices and migration due to civil conflict persist throughout 1994 and 1995 such that populations are growing more and more vulnerable. The negative effects of devaluation on millet prices and the increase in the adjusted NDVI during this period indicate a threat to food security. The decline in vegetative cover may depict the disruptions to farming due to civil conflict and the deterioration of environmental conditions in the region. The remaining months in the sample are times of high vulnerability in Gao cercle primarily due to the disruptions caused by civil conflicts and then with repatriation of displaced persons. There were high levels of disease in this period as well. Significant food aid deliveries in April, May, and August 1997 served to mitigate food insecurity somewhat but only with short-run impacts.

Table 3.4.2 Vulnerability Assessments for Gao based on SAP Reports

Year	Vulnerability Assessment based on SAP Reports
1986	October through December: vulnerable HHR: weak
1987	January through April, October, November: vulnerable due to migration pressures(those in search of food) June: N'Tillit especially vulnerable May, June, August, December: Food aid delivery September through December: vulnerable due to poor harvest
1988	January increasing vulnerability with migration and markets poorly stocked in cereals February through May declared DA, June stable July: Increasing vulnerability August: HHR weak, consumption of wild cereals noted
1989	January through May: N'Tillit isolated problems Increasing consumption of wild cereals in cercle Prices increasing with quantities decreasing March/April: Volitility in markets noted, Prices increasing May: Some disease outbreaks, high price volitility, diminished quantities of cereals marketed, inhabitual migration August: Return of migrant workers with low levels of resources September: Prices increasing with low levels of cereals in market November: N'tillit under surveillance, Food Aid delivered
1990	February: Isolated problems reported March - June: Increased migration from Algeria May and June: Food Aid Livestock markets volatile Fonio and cram-cram (wild cereals) fill HHR gaps
1991	February through July isolated problems (Djébock)...not entire cercle July: Food aid in N'Tillit
1992	November: Food aid distribution September: Fonio supplements HHR

1993	January through August: Djebock and N'Tillit DE April and May: Food aid delivery Noted increase in disease outbreaks, Tabaski Festival in May June: Increase in migration from Algeria due to civil conflict July: HRC camp established, Poor Ag outlook, Sharp increase in millet prices
1994	February: Increases in millet prices March: Sporadic measles outbreaks April: Increase in spread of disease, Tabaski Festival May: Migration from Djebock due to insecurity June: Increase in disease, sharp price increases, continued migration July: Markets not necessarily functioning well, blocked due to civil unrest Food Aid delivery....Entire cercle AT RISK. Sharp increase of exports to Burkina Faso and Niger...high prices for goats August and September: Increased migration due to civil insecurity October and November: Monitoring problems due to insecurity December: Some areas not reporting due to civil unrest, high level of displaced persons
1995	January: Djebock and N'Tillit no report due to civil unrest February: Migration back to Djebock, Steep price increases April through June: Repatriation after conflict Sharp price increases for millet, sorghum and rice March through May: Food Aid deliveries (questionnaires were not distributed at local level) July: Low levels of Rainfall, declining terms of trade, Food Aid August: Food Aid, Problems in Djebock and N'Tillit September: Repatriation esp around Djebock October: Poor Ag outlook, more repatriation with poor reserves November and December: DA in N'Tillit (many areas not reporting)
1996	January through August: N'Tillit (DA) April through September: HHR weak May: Epidemic menigitis June: Food aid June through December: economic problems (DE) June through August : food insecure (DA)

1997	March, April, and August: Food Aid Distribution May and June: Disease outbreak October: HHR weak
1998	January: Food Aid distribution

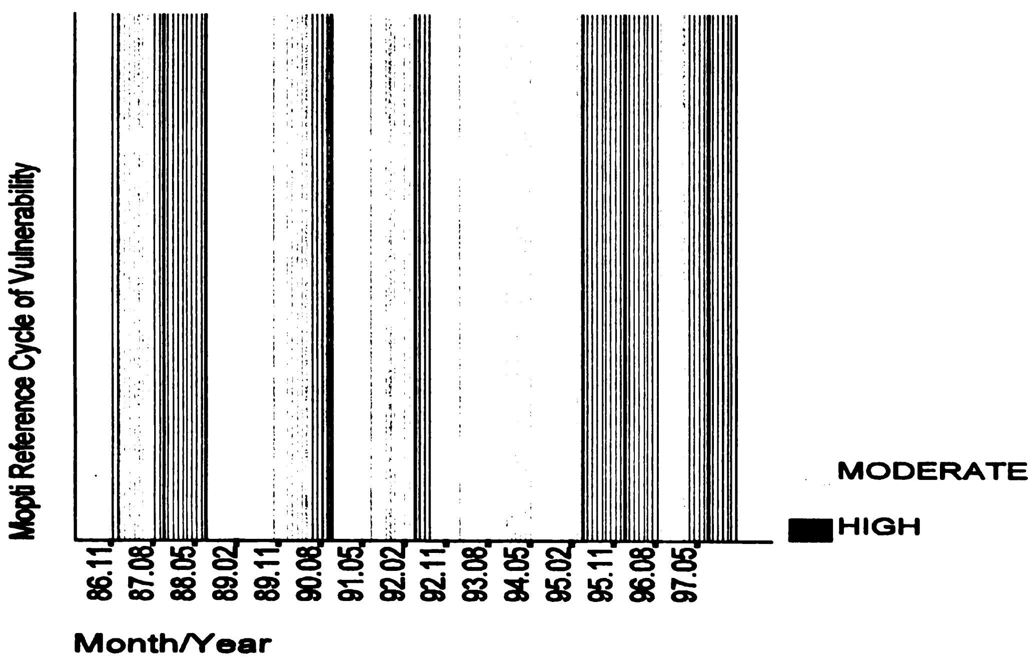
Source: SAP

Mopti

At the beginning of the sample period, October 1986, conditions of food insecurity in Mopti are 'high vulnerability' as the SAP summaries report weak household reserves, high levels of disease outbreaks and a qualitative assessment of generally poor conditions (see Figure 3.4.2). Post-harvest in January through May 1987 there is a decline in the severity of vulnerability with food aid deliveries in February, March and April and June 1987. Beginning in May 1987 there is an increase on demands for foods with an increase in migration to the area, the impact on prices is dampened with the food aid distributions. By August, sharp increases in prices are reported followed by an even higher level of migration from Timbuktu. A poor harvest and increasing migration pressures cause a steep increase in vulnerability in the region which does not truly diminish until just before harvest in 1988. From January through July 1988, increasing vulnerability is reported with household reserves weak or exhausted, out-migration from villages and the selling off of animals. After a significant food aid distribution in June, conditions begin to show improvement in August when households improve their reserves with the consumption of wild cereals and with a good harvest for 1989. There is localized vulnerability in Korientze where food aid is recommended. There is a sharp increase in prices in November and December but a good harvest replenishes household reserves.

The vulnerability conditions are moderate when compared to the period prior to August 1988 and this seems reflected in the index. For most of 1990, Korientze is

Figure 3.4.2 Mopti Reference Cycle Mapping of Vulnerability to Food Insecurity November 1986 to January 1998



declared an area at risk and food aid is requested. Migration pressures persist. Beginning in September 1990 there are sharp increases in cereal prices with low levels in the market as well as migration pressures around Fatoma, Korientze and Sendegue. Food aid deliveries arrive in June and July. Conditions stabilize overall after harvest yet some areas are still vulnerable.

In January 1991 there is a steep increase in prices and many areas are under surveillance: Korientza, Sendegue, Fatoma, Konna, Soufouroulaye and Soye. This is reflected in the vulnerability index. An April food aid delivery appears as a decline in the vulnerability index which turns upward again right after the delivery. In July 1991 an increase in millet prices is noted as well as consumption of wild cereals and the onset of measles outbreaks. A moderately vulnerable period continues into August of 1992 when a measles epidemic subsides and significant food aid deliveries in June arrest further deterioration in food security conditions.

The situation stabilizes and improves until post-harvest of 1993 when poor harvests cause migration and several areas grow increasingly more vulnerable. Problems persist throughout the first part of 1994 and conditions appear to improve after three significant food aid distributions in April, May, and June and with the harvest. March of 1995 is the onset of a very vulnerable period with high disease and sharp price increases. Added to these poor conditions is the pressure of migration into the region by refugees as well as a poor harvest. Food aid deliveries appear to assist in the most vulnerable areas and the situation improves with the harvest. Food security begins to deteriorate in 1997 and problems persist for the rest of the sample period. Sharp price increases, disease, and weak household reserves characterize most of 1997 and January 1998.

Table 3.4.3 Vulnerability Assessments for Mopti based on SAP Reports

Year	Vulnerability Assessment based on SAP Reports
1986	October through December: vulnerable, especially Korientzé HHR: weak, high level of disease outbreaks
1987	January through May: somewhat vulnerable, some disease outbreaks North at risk (Korientzé and Doko) February, March, April and June: Food aid May through December: vulnerable or food insecure due to increased migration pressures August: Sharp price increases September: Area under watch, high level of immigration from Timbuktu. Food Aid October: Poor harvest assessment, only good in Korientze and Senegue Continued migration from Timbuktu November: HHR weak. Poor pasture conditions December: Poor rice harvest, stable but poor conditions overall Food Aid and increase in migrations from Timbuktu
1988	January through July: increasing vulnerability, HHR weak or exhausted, out migration from villages and selling off of small animals June: Food aid August: HHR weak but stable with consumption of wild cereals
1989	October: Food aid recommended for Korientze, Sharp increase in prices Good harvest for 1988/89 mitigates HHR problems in November and December

1990	January and February: Migration pressures, food aid requested for Korientze, Oua-Mody, Fatoma, and Konna Migrants enter with poor resources March through June, October, November: Isolated problems in Korientzé: vulnerable September and October: Increasing prices, low level of cereals in market. Migration around Fatoma, Korientze and Sendegue June and July: Food aid November and December: Stabilizing HHR
1991	January: Under watch- Korientze, Sendegue, Fatoma, Konna, Soufouroulaye and Soye. Sharp increase in millet prices April: Food aid to Korientze July: Millet Price increases June and July: Food aid distributions February through August: Korientzé precarious June and July: consumption of wild cereals in some areas September: Food aid authorized increase in measles outbreaks October through December: increase in measles, some migration for food Korientze still highly vulnerable
1992	February: Disease and DEL in Fatoma and Sendegne April through August: Measles epidemic June: Food Aid to vulnerable areas, then improvement
1993	February: Poor rice harvest causes vulnerability in some areas (DA) October through December: some areas vulnerable Poor harvest causes migration Konna, Diallobou, Korientze at risk
1994	January, February, and March: Isolated areas vulnerable, (DA) in some areas Rice harvest poor for most of the cercle Devaluation causes a sharp increase in cereal prices, Konna DA April: Konna DA, Food aid sharp increase in disease May: Migrant workers arrive with poor resources, HHR weak Meningitis spreads, Additional food aid requested for Konna May and June: Food aid

1995	March: Meningitis outbreak April: Increase in diseases and rising prices FOOD AID May and June: Cholera and meningitis high July: Food aid, prices increasing, disease prevalent August: Pest and bird- crop damage February through September, December: Cholera outbreak November and December: Food aid, increase in disease Camp created for Mauritanian refugees
1996	January: Prices sharply increasing, increase in disease February through May: HHR weak February and July: poor supply of cereals in markets, high prices noted High level of disease(measles, meningitis, cholera): Worst April through August August: Food aid, markets poorly supplied prices increasing September: prices still increasing, disease outbreaks stabilized
1997	March and April: continued disease outbreaks, price increases March through May: many areas of vulnerability (North) May and June: increase in disease, HHR weak July: Sharp prices increases in some areas, HHR weak, FFW in Konna Disease outbreaks stabilize August: HHR weak, FFW, migrant workers with poor resources September: HHR weak, FFW, Poor ag outlook October: DEL in Fatoma, Korientze, Dialloube, poor harvest overall June, August, September: Food aid November and December: Poor agricultural outlook=>economic problems(DE) and some areas severe (DES) Refugees begin retourn to Burkina Faso
1998	January: Some areas DEL Food aid

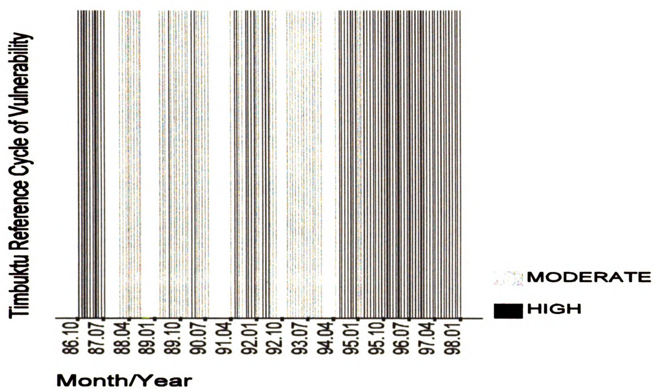
Source: SAP

Timbuktu

The reference cycle for Timbuktu is presented in Figure 3.4.3. For Timbuktu there are consistent reports of poor to moderate food security conditions from October 1986 through the harvest of 1988. Consistent deliveries of food aid and Food for Work programs appear to mitigate some problems. There are improvements in the cercle with consumption of fonio. In is an onset of poor conditions for food security as reported in March and persist through August 1989 then conditions stabilize with harvest. Migration pressures with refugees from Algeria are noted in February 1991 in conjunction with sharp increases in prices throughout the rest of the year create conditions of vulnerability through September when household reserves begin to be reconstituted with fonio and harvested millet. November food aid serves to decrease risks to displaced households.

The problems of high disease and prices are reported in April 1992 as a cercle-wide phenomenon. By May and June civil unrest prevents full reporting of conditions in the cercle, conditions of food insecurity are reported throughout the year but significant and consistent food aid deliveries seem to mitigate insecurity in the short-run. In late 1992, nomad populations are at risk and deterioration in conditions persist as civil conflict persists into 1993 and 1994, again significant food aid distributions seem to stabilize prices. A sharp increase in vulnerability to food insecurity occurs at May 1994. Devaluation and continued civil unrest contribute to household resources being weak as noted in June 1994 in the SAP reports. Conditions deteriorate for the rest of the year and into the next such that by June 1995 the entire cercle is DA. Prices drop somewhat with harvest and food aid but are still relatively high due to a poor harvest.

Figure 3.4.3 Timbuktu Reference Cycle Mapping of Vulnerability to Food Insecurity October 1986 to January 1998



Vulnerability conditions are still poor from January through September 1996 with cholera and measles outbreaks, repatriation of refugees and weak household reserves due to a poor harvest in 1995, post-harvest conditions of moderate vulnerability persist. By September 1997 the region is once again declared DA with price increases, high migration and weak household reserves. A hard hungry season is expected for 1998, with December 1997 reflecting sharp price increase.

In the next section, a simple index is developed as a method to depict turning points for conditions of vulnerability to food insecurity.

Table 3.4.4 Vulnerability Assessments for Timbuktu based on SAP Reports

Year	Vulnerability Assessment based on SAP Reports
1986	October through December: At risk High cereal prices
1987	January through June: Out-migration from villages for Food for Work Increase in infants at feeding centers February through June: Food aid delivery, prices stable February and March: Sharp increase in prices of cereals in some areas UNICEF reports malnutrition December: Food Aid distributions
1988	January through March: increasing vulnerability, migration from Groundam February through August: Increasing food aid distributions May through July: Decrease in number of meals/day for nomads May through September: Consumption of wild cereals reported September and October: improvements in HHR with consumption of fonio
1989	March: Entire cercle under watch April, May and July: Weak HHR reported for non-ag households June: Nomads weak HHR, Tabaski HHR very weak in Ber, Agal, Tin-agielhadj and Timbuktu Central August through December: Stabilize with good harvest although still areas under surveillance.
1990	February: Marked increase in migration from Algeria July and August: thin markets reported, FOOD AID Increase in prices, ag outlook poor September through December: some areas vulnerable October: Improve HHR with harvest of fonio...mitigates mil/sorg losses due to crop damage done by birds November: better HHR with Fonio and rice, FOOD AID to Algerian refugees

1991	February and March: Localized problem Bourem-Inaly at risk General price increases April: Price increases, increase in disease May and June: Many areas of concern, could not gather all reports due to civil conflict July: Consumption of famine foods, low quantities of staples in markets March through September: Food aid distributions June through August: Consumption of wild cereals June through September: disease outbreaks November: Civil unrest continues with migration from Ber as consequence Food aid December: Entire region under surveillance due to civil conflict
1992	March through May: Problems for displaced persons/refugees (DE/DA) Consumption of wild cereals in May March through August: at risk in some areas "pockets of insecurity" February, May through August: High levels of FOOD AID throughout region (NGOs) November through December: Nomads at risk, in very poor health
1993	January through October: Nomads' situation precarious May: Measles outbreak Many reports not in due to conflicts in the region
1994	Reports not in due to conflict in region May: Many displaced persons on food aid especially in Ber and Timbuktu Central June and July: Migration due to conflict April through June: Food aid distributions June: HHR weak in some areas
1995	January: Reports not in as enumerators feel at risk in travel February through December: Repatriation as conflict diminishes March through September: some vulnerability and disease outbreaks June: most of cercle DA July and August: Problems for displaced persons/refugees September: 186 families are refugees coming from Burkina Faso and Mauritania November: Food aid and increases in disease Migrations due to poor harvest from Bourem-Inaly and Aglal December: FOOD AID, more refugees, cholera outbreak

1996	January through September: Increasing vulnerability and high disease outbreaks July, November and December: Increased migration from Burkina Faso October through December: HHR weak even after harvest
1997	April through September: Continued repatriation of displaced persons Food aid April through June: HHR weak, FFW September through December: Food insecure (DA) November: Pastures poor, prices decline with harvest, HRC-repatriation of refugees from Mauritania December: Price increases- entire region marked as DA
1998	January: Food Insecure (DA) Food aid HHR reconstituted with rice harvest although poor harvest except for PPIV areas

Source: SAP

3.5 Smoothed Millet Prices

One approach to developing an index is to take an existing vulnerability indicator and run a basic smoothing algorithm on the time series to produce a measure of the dramatic shifts and investigate how well these shifts correspond to the shifts in the reference cycles.

Exponential smoothing procedures construct forecast functions based on discounted past observations. Each time a new observation is available, the forecast function can be updates in a very straight-forward process which is one of the appealing features of this approach. The drawback of exponential smoothing procedures is that they are ad hoc in that estimates are not generated from a 'properly defined statistical model' (Harvey, 1989). However, these techniques are widely used and are generally effective (Hamilton, 1994).

We use exponential smoothing to develop a simple index of smoothed millet prices as a benchmark with which to compare the more sophisticated vulnerability index developed in the next chapter. Millet prices are an essential vulnerability indicator monitored by FEWS and SAP in Mali and neighboring countries. Figures 3.5.1 through 3.5.3 present the smoothed millet price index for Gao, Mopti and Timbuktu, respectively. These figures also contain the reference cycle mappings developed in the last section.

The simple index (the smoothed millet price index) for Gao has key upward turning points at November 1987, May 1990, and June 1993. The simple indexes were converted to values running from 0 to 1. For Gao, the highest values appear post-1995 and the index increases at an increasing rate during this period. There were three peaks in the sample period.

The Mopti simple index has upward turning points at July 1987, April 1990, May 1993, and August 1995. The Gao and Mopti simple indexes are very similar with three peaks and similarly timed turning points. In addition, the highest values for the Mopti simple index appear at the end of the sample period. The simple index for Timbuktu is less smooth than the Gao and Mopti simple indexes but possesses similar turning points and its highest values also appear after 1995.

In the next section we compare the simple indexes to the reference cycles.

Figure 3.5.1 **Gao Simple Index and Reference Cycle Mapping of Vulnerability to Food Insecurity November 1986 to January 1998**

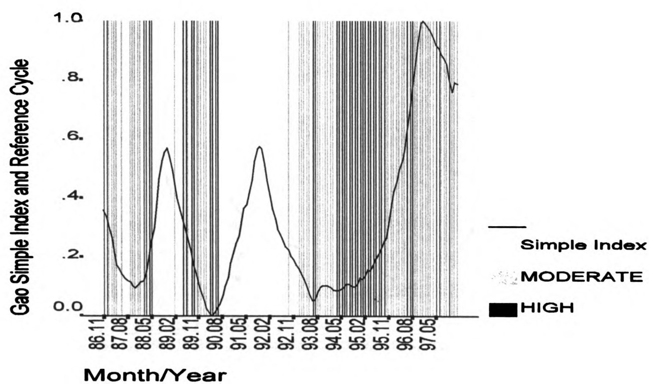


Figure 3.5.2 **Mopti Simple Index and Reference Cycle Mapping of Vulnerability to Food Insecurity November 1986 to January 1998**

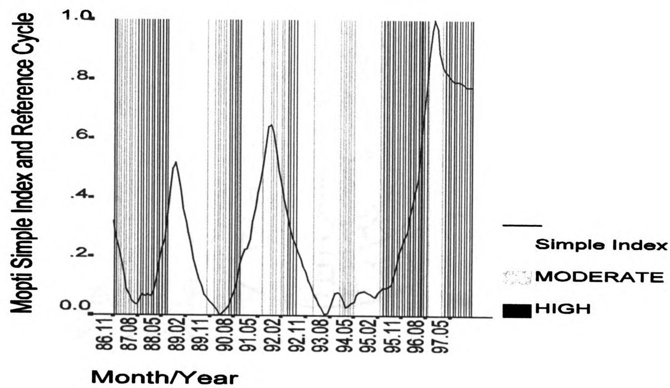
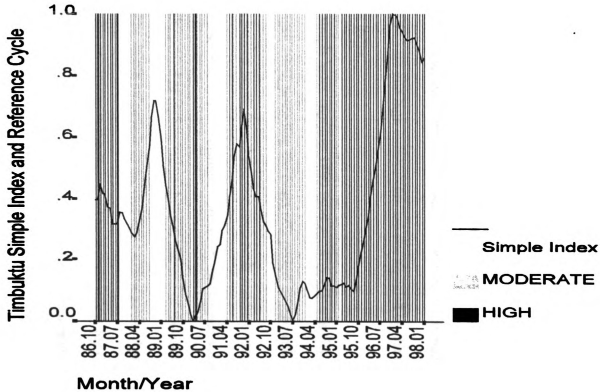


Figure 3.5.3 Timbuktu Simple Index and Reference Cycle Mapping of Vulnerability to Food Insecurity October 1986 to January 1998



3.6 Comparing Smoothed Millet Prices to the Reference Cycle

For the index to be valuable in the predictive sense, the turning points should appear a minimum of one month prior to a period of moderate or high vulnerability to food insecurity (as outline in Section 3.4). Figures 3.5.1 to 3.5.3 present the Gao, Mopti, and Timbuktu simple indexes and their corresponding reference cycles. Table 3.4 provides a summary of the reference cycle classifications and the turning points for each simple index.

In Figure 3.5.1, we find the Gao simple index to capture the increasingly vulnerable conditions at the end of the sample period, commencing in mid-1995. The earlier periods of moderate and high vulnerability are not signaled by the other turning points of the simple index.

The Mopti simple index captures 1990 food security vulnerability conditions with a turning point in April 1990, preceding the onset of a period of high vulnerability by two months. The other turning points do not provide such early warning signals. The later turning point in August 1995 is not as distinct. However, the highest values for the index appear near the period of highest vulnerability at the end of the sample period.

The Timbuktu simple index fails to provide key turning points that correspond to the onset of vulnerable conditions in the region. The highest values for the index appear in late 1996 and 1997 which correlate with conditions of high vulnerability.

Overall, the simple indexes did not consistently provide clear and timely turning points that signaled the onset of moderate or high vulnerability to food insecurity. The

Table 3.4 Comparing the Smoothed Millet Price Index and the Reference Cycles

Region	Periods of Moderate Vulnerability	Periods of High Vulnerability	Key Turning Points in Simple Millet Index
Gao	January 1987 to June 1987 September 1987 to January 1988 November 1989 to February 1990 September 1992 January 1993 to February 1994 October 1995 to May 1996 September 1996 to January 1998	November 1986 to December 1986 February 1988 to May 1988 March 1990 to June 1990 June and July 1993 March 1994 to September 1995 June 1996 to August 1996 May and June 1997 October 1997	November 1987 May 1990 June 1993 Note: Highest values for the index appear post-1995
Mopti	January 1987 to July 1987 October 1989 January 1990 to May 1990 July 1991 October 1991 to March 1992 February 1993 December 1993 to May 1994 March 1995 September 1996 February 1997	November and December 1986 August 1987 to July 1988 June 1990 to October 1990 April 1992 to July 1992 April 1995 to August 1996 March 1997 to January 1998	July 1987 April 1990 May 1993 August 1995
Timbuktu	January 1988 to August 1988 March 1989 to August 1990 April 1991 July and August 1991 January and February 1992 June to August 1992 December 1992 to December 1993 January and February 1995	October 1986 to July 1987 June 1989 February 1990 and March 1990 May and June 1991 September 1991 to December 1991 March 1992 to May 1992 June 1994 to January 1998	January 1987 January 1990 July 1993 August 1995

smoothed millet price does provide some information and could be used in combination with other indicators in the construction of an alternative vulnerability index.

In the next chapter, a more sophisticated index of vulnerability to food insecurity is developed and we compare the results with the reference cycles and with the smoothed millet price index by region.

Chapter 4

A Leading Indicator Model

There is a circularity problem in that until we solve modelling problems and discover the processes that generate economic data, we cannot derive the probabilities of events, and hence cannot know how to appropriately estimate the unknown parameters in any given model. Consequently we must proceed iteratively, stopping at every stage to ascertain what was learnt from each empirical model about the mechanism, and hence whether the original probability model was adequate to explain the evidence.

David F. Hendry, *Dynamic Econometrics*

4.1 Introduction

This chapter provides an overview of the leading indicators approach to measuring economic activity (Appendix Chapter 4 presents the single-index model developed by Stock and Watson in the early 1990's). We extend this single-index framework and develop an application to depict vulnerability to food insecurity in Mali.

4.1.1 What do leading indicators lead?

Early detection of business cycles (early indications of recession or recovery) and business cycle turning points have been of great concern for economists, policy makers, investors, and business people. In the 1930's and 1940's, the National Bureau of Economic Research brought together an extraordinary team of economists to develop a system of leading, coincident and lagging economic indicators. Initially, the charge was to classify economic time series as informative in describing the level of economic activity. The effort produced a listing of leading indicators but not an index. The index composed of these series was not developed until after further analysis in the 1950's. The selected indicators are meant to capture movements related to production time, the ease of adaptation, market expectations, as well as prime movers such as monetary and fiscal policies. Over 400 economic time series have been identified. These include new orders for consumer goods, housing starts, manufacturing labor inputs, money supply, and unemployment insurance claims. This system has been adjusted somewhat over the last five decades and is still part of American and European macroeconomic landscape.

As Lahiri and Moore (1991) note, the leading indicator approach emerges from the idea that economic and business forecasting can benefit from viewing market-oriented economies as driven by business cycles. These business cycles are comprised of sequences that repeat themselves and these sequences form the underpinnings of the business cycle itself. The leading economic indicator (LEI) method is to search for these reoccurring sequences, describe their behavior and meaning, and use them to better understand and forecast the business cycle. The methodology for leading indicators is not restrictive in defining the duration of an expansion or contraction and other characteristics because the "observed sequences -leads and lags- are quite variable over time and are often systematically different at peaks and troughs, and because cycle phases vary widely in duration" (Lahiri and Moore, 1991). As de Leeuw (1991) notes, while the LEI continues to out perform many theoretically based competitors, the system of leading indicators is the least theoretical of forecasting tools. This solid performance of the LEI has led many to answer critics of its lack in theoretical foundations with the query: *If the index works, why not just use it?*

Koopmans (1947) responds to this in "Measurement without Theory" by explaining that such atheoretical models cannot provide the means by which to develop inferences about the outcomes of stabilization policies. Koopman also notes that the LEI approach could not depict how structural changes in the economy might impact indicators. While Koopmans did not protest the value of the index as a forecasting tool, he questioned its ability to assist policy makers in their decision making. The focus on statistical regularities as the basis of selection in this statistical context could not carry over to any other phenomenon in Koopman's view. While the leading indicator approach has been found to hold up over time and space (Lahiri and Moore, 1991), there has been a tremendous amount of research to derive more theoretically based alternatives. The National Bureau of Economic Research (NBER) continues to be a leader in the development of composite indexes to serve in summarizing the state of national macroeconomic activity and the analysis of business cycles. In the effort to construct models relying on econometric and economic foundations, NBER has sponsored or cosponsored many studies. In particular, the models developed by Sargent and Sims (1976), Stock and Watson (1991), and Kim and Nelson (1998) addressed the comovements in various macroeconomic indicators in their analysis of U.S. business cycles. In this research, we follow closely the work of Stock and Watson (1991) in the development of an explicit indicator model of famine early warning. In the appendix to this chapter, we present an overview of the Stock and Watson approach to modeling leading economic indicators. The next section develops an application of this framework to the modeling of an index to capture the state of vulnerability to food insecurity.

4.1.2 An Application of the Single-Index Model to Food Security Vulnerability

Some of the modeling issues facing business cycle analysts resemble the process of developing methods to ascertain the state of vulnerability to food insecurity. As noted in the introductory chapters, famine early warning systems follow a variety of socio-economic, epidemiologic and agroclimatic indicators to track food security conditions in vulnerable regions in Africa. Some of these indicators have been identified as coincident, leading or lagging in their ability to depict times of food insecurity. This state of vulnerability to food insecurity is an unobservable state in the same sense as the state of the economy in the work by Stock and Watson (1991) and Kim and Nelson (1999).

In defining the unobserved variable theoretically, Stock and Watson (1991) query: *what do leading indicators lead?* In formulating FEWS, the indicators of focus were selected as signals of the state of vulnerability for food insecurity from a donor perspective. They offer indicators at the late stages of vulnerability, famine or near famine conditions, rather than the early indications of vulnerability of communities to diminished access to food or the insecurity of livelihoods.

Households employ a variety of coping strategies when faced with food insecurity. Watts (1983), Corbett (1988), and Davies (1995) found that households respond to changes in their economic status through strategies that may be employed sequentially or concurrently in an effort to conserve resources. FEWS (1999) notes that there is a "general progression of types of activities that forms a broad pattern that can be applied to virtually any household and region". These types of activities include (listed in order of action in response to increasing insecurity): adaptation, divestment of liquid assets, divestment of productive assets, and outmigration. Figure 4.1 illustrates these household responses to food security crisis. Under *adaptation*, there is a shift in household consumption from preferred foods to those more readily available. At this stage one would expect the market to reflect the aggregate effect of households' adaptive behavior through an increase in cereal prices. This scenario might be generated by agroclimatic factors or a general economic decline that decreases the demand for labor and depresses household income. When adaptation is no longer effective, households may choose to implement the strategy of *divestment of liquid assets* where a household begins to sell off small animals, jewelry, or seek loans from informal sources. In this phase, one would expect to see a decline in the prices for small animals and a further increase in cereal prices with a continued decline in the terms of trade (cereal per animal). In the next stage, there is the *divestment of productive assets* such as draft animals, large animals, and farm equipment. One would expect a decline in the price of draft and large animals, decrease in land prices, and a continued increase in cereal prices. *Outmigration* is a final strategy where households relocate in search of food and work. At this final stage, there would be dramatic increases in malnutrition, disease, and mortality.

FEWS incorporates this depiction of household strategies under food security emergencies into its selection of indicators of vulnerability. The prices of cereals, livestock, famine foods, and terms of trade between cereals and animals are affected at each stage. In addition, the agroclimatic indicators such as vegetative cover and rainfall estimates reflect the conditions that can prompt households to invoke these strategies.

Table 4.1 presents the operating assumptions used by FEWS in its vulnerability analysis.

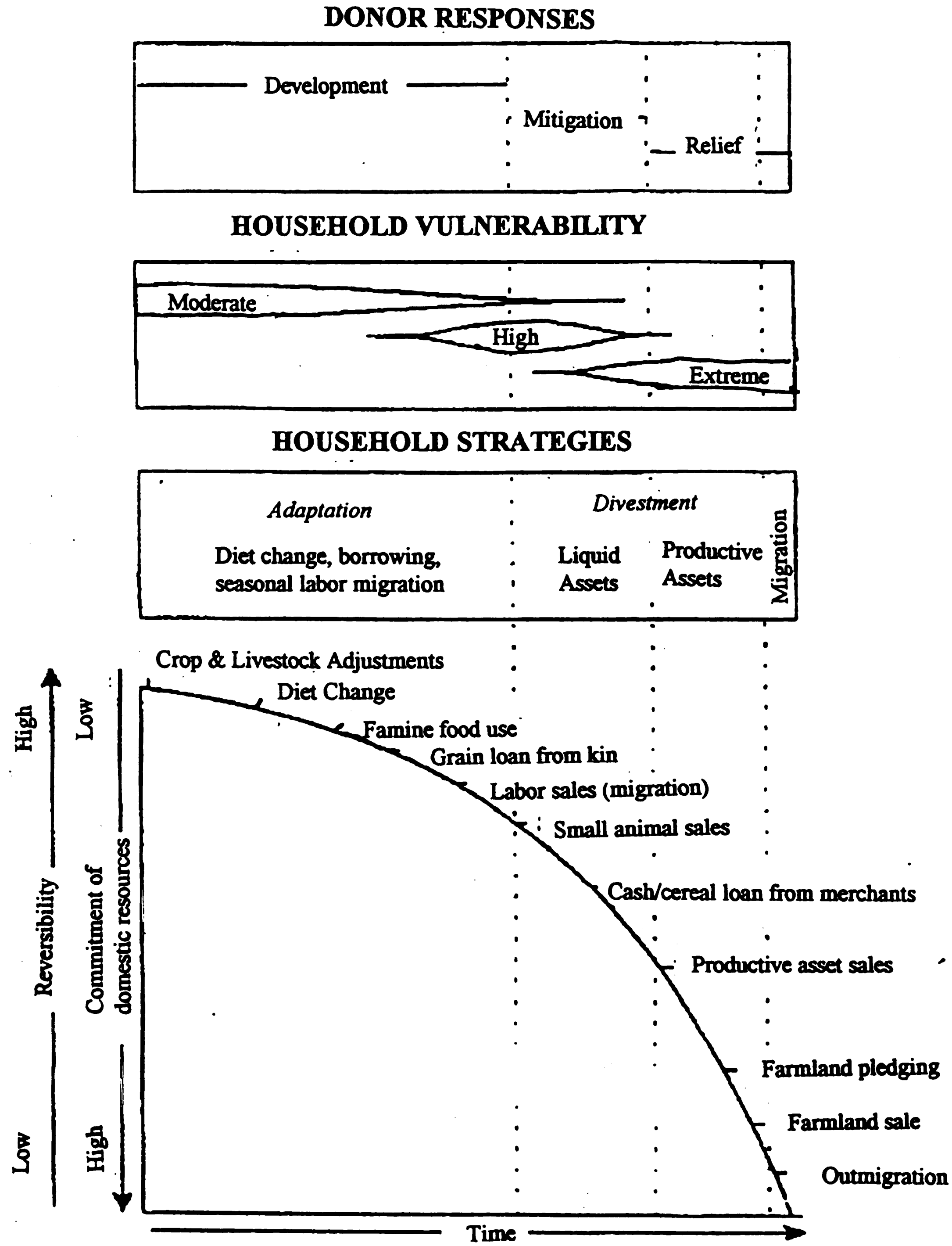


Figure 4.1 Source: FEWS,1998

Table 4.1 Operating Assumptions used by FEWS
1. Households respond rationally to changes in their economic condition.
2. Households seek to conserve their resources.
3. Markets exist in some form virtually everywhere and respond to the forces of supply and demand with varying degrees of efficiency.
4. The ability of households to maintain acceptable levels of food consumption is conditioned by (a) the depth, diversity and quality of their resource base, (b) the breadth of their income portfolio, and (c) their relationship to economic, social, and political hierarchies.
5. Household food security status can be inferred from aggregate secondary data.
6. Vulnerability assessments contain information that can guide both relief and development activities.

Source: FEWS, 1999

This focus on the late stages of food insecurity (famine) has been a criticism of early warning systems from their onset (Davis and Buchanan, 1991, Campbell, 1981, Walker, 1979, Sen ,1989, Glantz 1987, 1992, and Desrai,1991). However, one must consider the context of the development of institutions such as FEWS. In the case of FEWS, donors sought the perceived "best" information in order to be effective in their response to crisis, famine, situations. So, the indicators outlined above serve their purpose from a donor's perspective. FEWS is more concerned with identifying groups or regions of vulnerability rather than arriving at specific figures. Further, as outlined in Table 4.1, FEWS has worked to eliminate the schism between the development process (enhancing or securing livelihoods) and the functioning of early warning systems. As early warning systems evolve, there seems a desire for a more comprehensive approach to early warning which includes livelihood security indicators as an important component in assessments. However, the indicators such as terms of trade and prices still dominate current vulnerability assessments and will be used in this research.

So back to the question *what do leading indicators lead?* The indicators of cereal prices, livestock prices, rainfall estimates, vegetative indexes and terms of trade can serve to depict the vulnerability of households to food insecurity on an aggregate level. FEWS uses the *convergence of evidence* approach to arrive at its vulnerability assessments. The model presented here seeks to analyze in a more formal approach the existing methods of famine early warning using information FEWS has relied upon since their inception. This leading indicators model could be useful and complement existing modes of analysis in the systems. Stock and Watson (1991) found that their alternative index to the Index of Coincident Economic Indicators provided a mathematical underpinning to the existing framework developed by business cycle pioneers. In this research the goal is to provide a model with appropriate mathematical underpinnings and a framework that enhances current famine early warning capacities.

The model developed here takes as a foundation that comovements in agroclimatic and socioeconomic variables have a common element, a dynamic common factor, that can be captured by a single underlying unobservable variable. The unobserved variable is taken to represent the "state of vulnerability to food insecurity". The problem is to estimate the current state of vulnerability which is some common element of the fluctuations in key time-series variables. The unobserved variable must be identified and estimated.

As in the Stock and Watson approach, we develop a parametric "single-index" model in which the state of vulnerability to food insecurity, V_t, is an unobserved component of multiple time series. The Kalman filter is used to construct the Gaussian likelihood function because the model is linear in the unobserved variables. We estimate unknown parameters of the model by maximum likelihood keeping in mind that the Kalman filter automatically computes the minimum mean square error of V_t, using all information available through period t. The resulting scalar estimate, $V_{t|t}$, serves as the index for depicting the state of vulnerability to food insecurity.

The single index is estimated using data on agro-climatic and socioeconomic factors for eight cercles in Mali: Mopti, Gao,Timbuktu, Segou, DJenne, Douentza, Tenenkou, and Youvarou (recall that Segou, Djenne, Douentza, Tenenkou, and Youvarou are presented in the appendices) . We use monthly data to construct the model for each region for the period of October/November 1986 - January 1998. Our index is then compared to the reference cycles developed in Chapter 3. Recall that these reference cycles are based on the vulnerability assessments issued in the monthly SAP reports which are formulated by consolidating assessments by local, regional, and national officials in Mali.

Identification and estimation of the single index model creates a variety of challenges. First, while there exist reference cycles that are well defined in the analysis of economic downturns and recovery (the Department of Commerce's index of coincident economic indicators, for example), such well accepted and well- defined concepts have not been constructed or generally accepted as common to famine early warning operations. This creates a problem in referencing or defining periods of historical vulnerability to food insecurity a priori. Second, the interpretation of the estimate for the unobserved index presents numerous challenges related to the lack of any existing index or reference cycle methodology. In contrast to the efforts of Stock and Watson (1991), there is no basis for comparison, no clear quantitative benchmarks for the evaluation of the performance of the outputs of this model. These issues were addressed in Chapter 3 of this research where we used the reports developed by the Système d'Alerte Précoce (SAP) to create a reference cycle for each region under investigation in Mali. Qualitative assessments by local and regional officials were used to develop the reference periods of vulnerability to food insecurity.

We also compare the results for the single index of vulnerability to food insecurity with the simple index (exponentially smoothed millet prices) developed in Chapter 3 as a benchmark.

4.2 The Model

Stock and Watson (1991) and later Kim and Nelson (1999) formulate a probability model that provides a mathematical definition of the state of the economy. While there may be multiple indexes that depict aspects of the state of economy, they view their construction of a single-index model as a useful first approximation. Koopmans offers the following insight in his review of Burns and Mitchell's (1946) seminal work:

> The notion of a reference cycle itself implies the assumption of an essentially one-dimensional basic pattern of cyclical fluctuation, a background pattern around which the movements of the individual variables are arranged in a manner dependent on their specific nature as well as on accidental circumstances...This "one-dimensional" hypothesis may be a good approximation, in the same sense in which the assumption of circular motion provides a good first approximation to the orbits of the planets. It must be regarded, however, as an assumption of the "Kelper stage", based on observation of many series without reference to the underlying economic behavior of individuals.

Stock and Watson present a parametric "single-index" model in which the state of the economy, C_t, is an unobserved component of multiple time series. The Kalman filter is used to construct the Gaussian likelihood function because the model is linear in the unobserved variables. They estimate unknown parameters of the model by maximum likelihood keeping in mind that the Kalman filter automatically computes the minimum mean square error of C_t using all information available through period t. The resulting scalar estimate is the index for depicting the state of economic activity (see the appendix).

Following closely the Stock and Watson approach, the next section provides a general overview of the development of a single index of vulnerability to food insecurity. This endeavor aims to develop a 'first approximation' to depicting the complex phenomenon of vulnerability in the spirit of Koopmans assessment as quoted above. The Kalman Filter and State-Space Representation are presented in this chapter.

4.2.1 The single-index model for vulnerability to food insecurity

This section presents the single-index model as it is developed in Kim and Nelson (1999) and Stock and Watson (1991) building on the approach presented earlier. In this chapter, the dynamic structure of the single-index model of vulnerability to food insecurity based on the characteristics of the Malian data is fully developed for each cercle and builds from the model presented here. Let X_t denote a $k\ x\ 1$ vector of agroclimatic and socioeconomic time-series variables which are hypothesized to move contemporaneously with general food security conditions. In this study these variables consist of millet prices and an index of vegetative cover. As developed in Stock and Watson (1991) and Kim and Nelson (1998), the single-index model X_{it} consists of two stochastic components: the common unobserved scalar time-series variable, or "index", V_t, and a k-dimensional component that represents idiosyncratic movements in the series and measurement error, v_t. In keeping with the Stock and Watson (1991) formulation, both idiosyncratic components, D_i, and the unobserved index are modeled as having linear structures and V_t is assumed to appear contemporaneously in each variable.

The model is written as:

(4.1) $$X_{it} = D_i + \gamma_{ij}\Gamma_{ij}(L)V_t + v_{it} \qquad i=1,\ldots,k,\ j=0,1,..q_i$$

(4.2) $$\tilde{\phi}(L)V_t = \delta + \omega_t \qquad \omega_t \sim i.i.d.N(0,\sigma^2_{\bullet})$$

(4.3) $$\mathrm{v}_{it} = \psi_{i1}\mathrm{v}_{i,t-1} + \psi_{i2}\mathrm{v}_{i,t-2} + \mathrm{e}_{it} \qquad \varepsilon_{it} \sim i.i.d.N(0,\sigma_i^2)$$

L denotes the lag operator $\tilde{\phi}(L)$ is a scalar polynomial that is depicted as second order which is common in the literature. This also seems reasonable for modeling the vulnerability index since a two month lag in the monthly series is able to reflect cyclical characteristics. $\Gamma_{ij}(L)$ is a scalar polynomial that depicts the number of lags of the state variable that appears in each indicator equation. This representation implies that the equation for the ith indicator will be expressed as a function of j lags of the unobserved state variable. Idiosyncratic components, D_i, are assumed to be time-invariant (intercepts), and the unobserved component enters each equation in (4.1) with different weights, contemporaneously. To reflect these considerations, we rewrite equation (4.2) as

(4.4) $$V_t - \delta = \phi_1(V_{t-1} - \delta) + \phi_2(V_{t-2} - \delta) + \omega_t$$

The next step in building this model is to develop sufficient identifying restrictions on the model in order to estimate unknown parameters and to extract estimates of V_t. Sargent and Sims (1977) and Stock and Watson (1991) note that the main identifying assumption in the model expresses the fundamental notion that the comovements of the time series are driven by a single source, V_t. This implies that $(e_{1t}, e_{2t}, \ldots, V_t)$ are mutually uncorrelated at all leads and lags. However, individual series may be autocorrelated. This restriction essentially means that dependence on the single-index accounts for all the observed cross-relations among the coincident indicators. In addition, a normalization to scale V_t is identified by setting var(ω_t)=1 (Stock and Watson (1991), Sargent and Sims (1977), Kim and Nelson (1999) and Harvey (1989)). It is important to note that the above specification results in the parameters D_i and δ not being separately identified in the first sample moment of the ith indicator X_{it}. From (4.1) we see that the first population moment for the ith indicator, X_{it}, consists of two parameters:

(4.5) $E(X_{it} = D_i + \gamma_i \Gamma_{ij}(L) V_t + e_{it}) = D_i + \gamma_i \delta$

Stock and Watson (1991) suggest writing the model in the form of deviations from means in order to solve the identification problem in MLE. This concentrates $D_t + \gamma_i \delta$ out of the likelihood function:

Model in Deviation from Means

(4.6) $x_{it} = \gamma_{ij}\Gamma_{ij}(L)v_t + e_{it}$ i=1,....,k, j= 0,1,2,...q_i

(4.7) $v_t = \phi_1 v_{t-1} + \phi_2 v_{t-2} + \omega_t$

(4.8) $e_{it} = \psi_{i1} e_{i,t-1} + \psi_{i2} e_{i,t-2} + \varepsilon_{it}$

where $x_{it} = X_{it} - E(X_{it})$ and $v_t = V_t - \delta$.

After this reformulation, the model is written in state-space form after which the Kalman filter is used for maximum likelihood estimation of the model based on prediction error decomposition and for inferences on v_t .

4.2.2 State-Space Representation of Single-Index Model of Vulnerability

In constructing the state-space representation for the vulnerability index, we will allow for some dynamics in the system in the sense that the indicators will not necessarily be coincident. We would expect some agroclimatic and socioeconomic indicators to lead or lag others. Stock and Watson focused on coincident and contemporaneous indicators so did not build in such relationships in their work. To illustrate this formulation, a state-space representation of the single-index model from equations (4.6) through (4.8) where we allow the number of indicator variables, to be four, k=4, is:

Measurement Equation (4.9)

$$\begin{bmatrix} x_{1t} \\ x_{2t} \\ x_{3t} \\ x_{4t} \end{bmatrix} = \begin{bmatrix} \gamma_1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \gamma_{20} & \gamma_{21} & \gamma_{22} & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ \gamma_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ \gamma_{40} & \gamma_{41} & \gamma_{42} & \gamma_{43} & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} v_t \\ v_{t-1} \\ v_{t-2} \\ v_{t-3} \\ e_{1t} \\ e_{1,t-1} \\ e_{2t} \\ e_{2,t-1} \\ e_{3t} \\ e_{3,t-1} \\ e_{4t} \\ e_{4,t-1} \end{bmatrix}$$

Transition Equation (4.10)

$$
\begin{bmatrix} v_t \\ v_{t-1} \\ v_{t-2} \\ v_{t-3} \\ e_{1,t} \\ e_{1,t-1} \\ e_{2,t} \\ e_{2,t-1} \\ e_{3,t} \\ e_{3,t-1} \\ e_{4,t} \\ e_{4,t-1} \end{bmatrix}
=
\begin{bmatrix}
\phi_1 & \phi_2 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & \cdots & 0 & 0 \\
0 & 0 & 0 & 0 & \psi_{11} & \psi_{12} & \cdots & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & \cdots & 0 & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \cdots & \psi_{41} & \psi_{42} \\
0 & 0 & 0 & 0 & 0 & 0 & \cdots & 1 & 0
\end{bmatrix}
\begin{bmatrix} v_{t-1} \\ v_{t-2} \\ v_{t-3} \\ v_{t-4} \\ e_{1,t-1} \\ e_{1,t-2} \\ e_{2,t-1} \\ e_{2,t-2} \\ e_{3,t-1} \\ e_{3,t-2} \\ e_{4,t-1} \\ e_{4,t-2} \end{bmatrix}
+
\begin{bmatrix} w_t \\ 0 \\ 0 \\ 0 \\ \epsilon_{1t} \\ 0 \\ \epsilon_{2t} \\ 0 \\ \epsilon_{3t} \\ 0 \\ \epsilon_{4t} \\ 0 \end{bmatrix}
$$

The above representation treats indicators variables x_{2t} and x_{4t} as lagging the other indicators in the model. As in the case of the Stock and Watson model, from this state-space representation, estimates for the model parameters can be derived using maximum likelihood estimation based on prediction error decomposition. With these estimates, the Kalman filter is used to estimate the state vector conditional on information up to time t. We find the (1,1) element of the state vector is $v_{t|t}$.

4.2.3 The construction of the single index of vulnerability to food insecurity

The vulnerability index derived from the single-index model is the minimum mean square error estimator of V_t constructed using data on the coincident variables through time t. We denote this as $V_{t|t}$. A further identifying assumption is that the estimate of the mean for V_t can be expressed as a weighted average of the observed indicators. The weights are retrieved from the Kalman filter matrices (Stock and Watson (1991) and Kim and Nelson (1999).

Given $v_{t|t}$, t = 1, 2, ..., T, we need to estimate δ to construct the new index, $V_{t|t}$. This follows from the expression

(4.11) $$V_{t|t} = v_{t|t} + \delta$$

If all the parameters of the model (4.6) to (4.8) are known and we apply the Kalman filter we can

obtain $V_{t|t}$.

The relationship between $V_{t|t}$ and the observed variables, $X_t = \left[X_{1t}, X_{2t}, \dots X_{kt}\right]'$ can be expressed as

(4.12) $$V_{t|t} = W(L)X_t$$

where *W(L)* is a polynomial lag operator that relates the transformed vulnerability index to current and past values of the observed variables. We find:

(4.13) $$E[V_{t|t}] = E[W(L)X_t]$$

We retrieve the mean of the unobserved variable since $\delta = W(1)E(X)$ and $\delta = W(1)\overline{X}$.

Once W(1) is identified, δ is estimated given $\overline{X}$. Kim and Nelson (1999) note that the relationship between $v_{t|t}$ and x_t can also be expressed as

(4.14) $v_{t|t} = W(L)x_t$,

which suggests that we can retrieve *W(1)* from the model expressed as deviation from means

(4.6) to (4.8). Stock and Watson (1991) identify *W(1)* from the last recursion of the Kalman filter applied to the state-space model written as a deviation from means. A full derivation of the Kalman Filter can be found in Section 4.3.

In Section 4.4, we investigate the univariate characteristics of the monthly agroclimatic and socioeconomic data we will use to construct the vulnerability indexes for eight regions in Mali. In Section 4.5, we present the empirical results of the models as well as the interpretation of the vulnerability indexes by region and discuss their performance as the indexes are compared to the reference cycles developed from the monthly SAP reports.

4.3 Estimation

4.3.1 The Kalman Filter Approach

The Kalman filter can be used to compute the Gaussian likelihood function for a trial set of parameters. The filter recursively constructs the minimum mean square error estimates of the unobserved state vector given data on observed variables (Kim and Nelson (1999), Harvey (1989), Hamilton (1994)). The filter consists of two sets of equations, *the prediction and updating equations*. This framework also allows the construction of retrospective estimates of the state vector, and in particular $C_{t|T}$, the state of the economy in Stock and Watson's model. These estimates of the state vector based on the entire sample are computed using the Kalman smoother (Kim and Nelson (1999), Harvey (1989), Harvey (1981), Hamilton (1994)).

The Kalman filter is a recursive procedure for computing the optimal estimator of the state vector at time t, based on information available at time t. This information includes the entire history up to t. The Kalman Filter provides a mechanism that continually updates the state vector as new observations become available. An important feature of the Kalman Filter is that when the disturbances and the initial state vector are normally distributed, the likelihood function can be calculated through prediction error decomposition. As Harvey (1989) notes, a standard result on the multivariate normal distribution is then used to show how it is possible to calculate recursively the distribution of the state vector, conditional on the information set at time t, for all t from 1 to T. These conditional distributions are themselves normal and thus completely specified by their means and covariance matrices. It is the values in these matrices that the Kalman

Filter computes. A detailed overview of the Kalman Filter using a time varying paramter model as an example is provided in the following section.

This section draws from the excellent presentation found in Kim and Nelson (1999). Consider this example of a time varying parameter model to illustrate the Kalman Filter algorithm:

(4.15) $$y_t = x_t\beta_t + e_t, \quad t = 1,2,3,....T \qquad e_t \sim \text{i.i.d.}N(0, R)$$

(4.16) $$\beta_t = \mu + F\beta_{t-1} + v_t, \quad v_t \sim \text{i.i.d.}N(0, Q)$$

Here, y_t is 1x1; x_t is 1x k vector of exogenous predetermined variables; it is assumes the innovations are independent. β_t is k x 1; F and Q are k x k.

The Kalman filter provides the means to compute the optimal estimate of the unobserved-state vector β_t, t = 1, 2, ..., T, based on the appropriate information set, assuming that μ, F, R, and Q (hyperparameters) are known. The basic filter refers to an estimate of β_t based on information available up to time t, and smoothing to an estimate of β_t based on all the available information in the sample through time T. If some of the hyperparameters are not known, they need to be estimated before one can make inferences concerning β_t. Maximum likelihood is usually used to estimate the model's unknown hyperparameters.

We use Kim and Nelson's (1999) following notation and description of the Kalman Filter and state space representation:

ψ	the information set.
$\beta_{t\|t-1} = E[\beta_t \| \psi_{t-1}]$	expectation (estimate) of β_t conditional on information up to $t - 1$.

$P_{t\|t-1} = E[(\beta_t - \beta_{t\|t-1})(\beta_t - \beta_{t\|t-1})']$	covariance matrix of β_t conditional on information up to $t - 1$.
$\beta_{t\|-t-1} = E[\beta_t \| \psi_t]$	expectation (estimate) of β_t conditional on information up to t.
$P_{t\|t} = E[(\beta_t - \beta_{t\|t})(\beta_t - \beta_{t\|t})']$	covariance matrix of β_t conditional on information up to t.
$y_{t\|t-1} = E[y_t \| \psi_{t-1}] = x_t\beta_{t\|t-1}$	forecast of y_t given information up to time $t - 1$.
$\eta_{t\|t-1} = y_t - y_{t\|t-1}$	prediction error.
$f_{t\|t-1} = E[\eta^2_{t\|t-1}]$	conditional variance of the prediction error.
$\beta_{t\|T} = E[\beta_t \| \psi_T]$	expectation (estimate) of β_t conditional on information up to T (the whole sample).
$P_{t\|T} = E[(\beta_t - \beta_{t\|T})(\beta_t - \beta_{t\|T})']$	covariance matrix of β_t conditional on information up to T (the whole sample).

Assuming that x_t is available at the beginning of time t and a new observation of y_t is made at the end of time t, the Kalman filter (basic filter) consists of the following two steps:

1. *Prediction*: At the beginning of time t, we may want to form an optimal predictor of y_t, based on all the available information up to time $t - 1$: $y_{t|t-1}$. To do this, we need to calculate $\beta_{t|t-1}$.

2. *Updating*: Once y_t is realized at the end of time t, the prediction error can be calculated: $\eta_{t|t-1} = y_t - y_{t|t-1}$. This prediction error contains new information

about β_t beyond that contained in $\beta_{t|t-1}$. Thus, after observing y_t, a more accurate inference can be made of β_t. $\beta_{t|t}$, and inference of β_t based on information up to time t, may be of the following form: $\beta_{t|t} = \beta_{t|t-1} + K_t\eta_{t|t-1}$, where K_t is the weight assigned to new information about β_t contained in the prediction error.

To be more specific, the base filter is described by the following six equations:

Prediction

(4.17) $\beta_{t|t-1} = \mu + F\beta_{t-1|t-1}$,

(4.18) $P_{t|t-1} = FP_{t-1|t-1}F' + Q$,

(4.19) $\eta_{t|t-1} = y_t - y_{t|t-1} = y_t - x_t\beta_{t|t-1}$,

(4.20) $f_{t|t-1} = x_tP_{t|t-1}x_t' + R$,

Updating

(4.21) $\beta_{t|t} = \beta_{t|t-1} + K_t\eta_{t|t-1}$,

(4.22) $P_{t|t} = P_{t|t-1} + K_tx_tP_{t|t-1}$,

where $K_t = P_{t|t-1}x_t'f_{t|t-1}^{-1}$ is the Kalman gain, which determines the weight assigned to new information about β_t contained in the prediction error.

In equation (4.17), an inference on β_t given information up to time t-1 is a function of an inference on β_{t-1} given information up to t-1 by construction of the time-varying parameter model. Thus uncertainty underlying $\beta_{t|t-1}$ is a function of the uncertainty underlying $\beta_{t-1|t-1}$ and Q, the covariance of the shocks to β_t. The prediction error of the time-varying parameter model consists of: 1) the prediction error due to error in making an inference about β_t, and 2) the prediction error due to the random shock e_t. Thus in equation (4.20), the conditional variance of the prediction error is a function of the uncertainty associated with $\beta_{t|t-1}$ and of R, the variance of e_t.

The updating equation in (4.21) depicts $\beta_{t|t}$ as a sort of weighted average of $\beta_{t|t-1}$ and new information contained in the prediction error $\eta_{t|t-1}$, the weight assigned to new information being the Kalman gain, K_t. In this characterization, as the uncertainty associated with $\beta_{t|t-1}$ increases, relatively more weight is given to new information in the prediction error, $\eta_{t|t-1}$. Thus, $\eta_{t|t-1}$ becomes a more valued source of information.

Figure 4.2 maps the flow of the Kalman Filter procedure. Given the initial vales of $\beta_{0|0}$ and $P_{0|0}$, the six equations of the basic filter, (4.17) through (4.22) can be iterated for t=1,2,...,T. This provides us with the minimum mean squared error estimate of β_t, given information up to time t or t-1. For the stationary β_t in equation (4.16), the unconditional mean and covariance matrix of β_t may be employed as the initial values, $\beta_{0|0}$ and $P_{0|0}$. The unconditional mean of stationary β_t is derived as

(4.23) $E[\beta_t] = \tilde{\mu} + FE[\beta_{t-1}] + E[v_t]$,

(4.24) $\beta_{0|0} = \tilde{\mu} + F\beta_{0|0}$ (At Steady State),

(4.25) $\beta_{0|0} = (I_k - F)^{-1} - \tilde{\mu}$.

The unconditional covariance matrix of stationary β_t is derived as

(4.26) $Cov(\beta_t) = FCov(\beta_{t-1})F'f + Cov(v_t)$,

(4.27) $P_{0|0} = FP_{0|0}F' + Q$, (At Steady State),

(4.28) $\mathrm{vec}(P_{0|0}) = \mathrm{vec}(FP_{0|0}F') + \mathrm{vec}(Q)$, (4.29) $\mathrm{vec}(P_{0|0}) = (F \otimes F)\mathrm{vec}(P_{0|0}) + \mathrm{vec}(Q)$

(4.30) $\mathrm{vec}(P_{0|0}) = (1 - F \otimes F)^{-1}\mathrm{vec}(Q)$

as $\mathrm{vec}(ABC) = (C' \otimes A)\mathrm{vec}(B)$.

Smoothing ($\beta_{t|T}$) provides a more accurate inference on β_t, because it uses more information than the basic filter. Equations (4.31) and (4.32) can be iterated backwards for t= T-1, T-2, ...1, to retrieve the smoothed estimates:

Smoothing

(4.31) $$\beta_{t|T} = \beta_{t|t} + P_{t|t}F'P_{t+1|t}^{-1}(\beta_{t+1|t} - F\beta_{t|t} - \mu),$$

(4.32) $$P_{t|T} = P_{t|t} + P_{t|t}F'P_{t+1|T}^{-1}(P_{t+1|T} - P_{t+1|t})P_{t+1|t}^{-1'}FP_{t|t}'$$

$$\beta_{0|0},\ P_{0|0},\ l(\theta) = 0$$

$$\downarrow$$

$$\downarrow$$

$$\beta_{t|t-1} = \tilde{\mu} + F\beta_{t-1|t-1}$$

$$P_{t|t-1} = FP_{t-1|t-1}F' + Q$$

$$\downarrow$$

$$\eta_{t|t-1} = y_t - y_{t|t-1} = y_t - H_t\beta_{t|t-1} - Az_t$$

$$f_{t|t-1} = H_t P_{t|t-1} H_t' + R$$

$$\downarrow$$

$$l(\theta) = 1(\theta) - \frac{1}{2}\ln((2\pi)^n |f_{t|t-1}|) - \frac{1}{2}\eta_{t|t-1}' f_{t|t-1}^{-1}\eta_{t|t-1}$$

$$\downarrow$$

$$\beta_{t|t} = \beta_{t|t-1} + P_{t|t-1}H_t' f_{t|t-1}^{-1}\eta_{t|t-1}$$

$$P_{t|t} = P_{t|t-1} - P_{t|t-1}H_t' f_{t|t-1}^{-1} H_t P_{t|t-1}$$

$$\downarrow \qquad t - 1 = \tau$$

$$\downarrow$$

$$l(\theta) = -\frac{1}{2}\Sigma\ln((2\pi)^n |f_{t|t-1}|) - \frac{1}{2}\Sigma\eta_{t|t-1}' f_{t|t-1}^{-1}\eta_{t|t-1}$$

Figure 4.2 Flowchart for the Kalman Filter (Kim and Nelson, 1999)

The above derivation assumes that the model's parameters are known. When this is not the case, most often the parameters are unknown, they must be estimated before any inferences can be made on β_t. Thus, β_t is conditional on these estimated parameters. It is possible to evaluate the likelihood function based on prediction error decomposition. This means that when the observations are normally distributed, insofar that we have the prediction error and its variance, the log likelihood can be calculated. For the given parameters in the model, the Kalman filter provides us with prediction error , $\eta_{t|t-1}$, and its variance, $f_{t|t-1}$ in equations (4.19) and (4.20) as by-products. In addition, if β_0 and the shocks in equations (4.15) and (4.16) are Gaussian, the distribution of y_t conditional on the information set, ψ_{t-1}, is also Gaussian:

(4.33) $\quad y_t | \psi_{t-1} \sim N(y_{t|t-1}, f_{t|t-1}),$

and the sample log likelihood is depicted as

(4.34) $\quad \ln L = -\frac{1}{2} \sum_{t=1}^{T} \ln(2\pi f_{t|t-1}) - \frac{1}{2} \sum_{t=1}^{T} \eta'_{t|t-1} f_{t|t-1}^{-1} \eta_{t|t-1},$

which can be maximized with respect to the unknown parameters of the model.

4.3.2 State-Space Representation and the Kalman Filter

The aim of the state-space formulation is to clearly express dynamic systems that involve unobserved state variables and construct the corresponding state vector in such a way that it contains the relevant information of the system at time t and that it does so by having as small a number of elements as possible. Such a state space form is known as a *minimal realization* (Harvey, 1989).

State-Space form consists of two equations: a *measurement equation* and a *transition equation*. The measurement equation depicts the relationship between the observed variables with the unobserved state variables while the transition equation describes the dynamics of the state variables.

A representative state-space model is as follows:

Measurement Equation

(4.35) $y_t = H_t\beta_t + Az_t + e_t\,,$

Transition Equation

(4.36) $\beta_t = \mu + F\beta_{t-1} + v_t\,, \qquad v_t \sim \text{i.i.d.}N(0,\ Q)$

$e_t \sim \text{i.i.d.}N(0,\ R)$

$v_t \sim \text{i.i.d.}N(0,\ Q)$

$E(e_t v_t') = 0,$

where y_t is an n x 1 vector of variables observed at time t; β_t is a k x 1 vector of unobserved state variables; H_t is an n x k matrix that links the observed variables and the unobserved variables; z_t is an r x 1 vector of exogenous or predetermined variables; μ is k x 1; v_t is k x 1. Elements of the Ht matrix may be either data on exogenous variables or constant parameters.

Once a dynamic time series model is written in this state-space formation, the Kalman filter is the means by which to obtain inferences on the unobserved state vector β_t, conditional on the parameters of the model and the appropriate information set.

There can be several state-space forms to represent the same dynamic system. For the Stock and Watson coincident economic indicators model there are at least three state-space representations in the literature (Stock an Watson (1991), Hamilton (1994), Kim and Nelson (1999)). These representations are used with the Kalman filter to produce identical results for estimates of the trial parameters.

4.4 Data and Preliminary Analysis

4.4.1 Description of Data

There are several vulnerability indicators monitored by FEWS and SAP. The data considered for a single-index model of vulnerability to food insecurity in Mali are regional rainfall levels, river levels, remote sensing data on vegetative cover (NDVI), market prices for staple cereals and grains, and market prices for livestock. This research proposes a parsimonious model involving NDVI and millet prices. Selecting just two variables facilitate the detection of incremental improvements over the simple index, our benchmark index. We are better able to note the contributions of the single index methodology and the value of the content of the adjusted NDVI relative to an index based soley on millet prices. Work to expand the number of indicators used in the construction of the single-index of vulnerability is left for further research. The series are monthly observations for the period October/November 1986 through January 1998 for Gao, Mopti, Timbuktu, Djenne, Douentza, Tenenkou and Youvarou. SAP extended its monitoring reach to include cercles such as Segou after 1986. The time period under investigation for Segou is April 1988 through January 1998 (see appendix).

Prices

Monthly data were accessed from FEWS' Priceman data management system. FEWS gathers secondary data on prices from SAP and Mali's Market Information System (SIM). Retail prices used are for millet and goats (used in Chapter 5). Millet is a crop closely monitored by early warning systems and is a prime indicator of vulnerability (vulnerability is increasing as millet prices increase). The millet prices were not seasonally adjusted because these seasonal components capture both the height and driving forces of the hungry season. These feature provide strong explanatory power in terms of levels and key turning points for the context of depicting vulnerability to food insecurity. As described in the previous chapter, the livestock to grain terms of trade is also used as an indicator related to food security and can serve as a confirming indicator of food stress. Missing values in the price series were filled in with the average of the two nearest points. This method produced reasonable results and is easily reproduced should this research be developed for field use.

NDVI

The *Normalized Differenced Vegetative Index (NDVI)* is a measure of vegetative cover gathered from satellite imagery. The NDVI is the difference of near-infrared and visible reflectance values normalized to fall between the values of -1 and 1, where increasing positive values indicate increasing green vegetation negative values represent nonvegetative surface features such as water, ice, and clouds (Eidenshink and Faudeen (1997)). The index is recorded every ten days as a composite. The decal figures supplied by FEWS were transformed into monthly averages. The value of the NDVI is adjusted to reflect the difference from its seasonal mean. This adjustment is then scaled and is increasing when the observation is below the seasonal mean thus reflecting vulnerable conditions. There were no missing values in these data series.

4.4.2 Univariate Analysis

There are many ways to model economic time series. It is an important first step when considering model specification to perform univariate analysis to ascertain whether the series of interest are stationary or nonstationary as well as to determine other characteristics such as the structure of the disturbance term. The distinction between stationary and non-stationary time series has been addressed widely with much controversy in the literature. If a time series is stationary, its mean and variance are well defined and do not vary over time. If, on the other hand, a series is nonstationary, its mean and variance are difficult to interpret because they are not necessarily globally stable (they vary over time). If a time series is stationary after differencing, the series is said to be integrated of order one, I(1) and a stationary series is I(0).

Stationary time series are usually modeled using methods outlined in Box-Jenkins (1976), Harvey (1990), and Hamilton (1994) to name a few, these include autoregressive, moving average, combinations of autoregressive and moving average components (ARMA) representations. These reduced form models have sometimes demonstrated improved predictive capabilities over structural models (Harvey, 1991 and Hamilton, 1994).

The presence of unit roots can have serious consequences in the estimation and inference of time-series models. The existence of unit roots can lead to results such as spurious regressions as highlighted by Phillips (1989) and many others. The controversy surrounding unit root tests centers on characteristics of series that can be treated in deterministic terms rather than as stochastic. Maddala and Im (1999) provide an excellent overview of the literature on unit root testing. The benchmark in the debate is the work of Nelson and Plosser (1989) who apply unit root tests to the most closely watched U.S. macroeconomic time series. Nelson and Plosser found that most of these series possessed at least one unit root. They concluded that any shocks over the period of study resulted in permanent effect on the evolution of the series and that these effects build on one another over time. Structural shifts were ignored.

When considering structural shifts as applied in the Nelson and Plosser data, Perron (1989) provides evidence that contradicted the previous work. Perron evaluated the impacts of events or shocks such as the Great Crash of 1929 and the Oil Shock of 1973 by modeling them as trends breaks or shifts. He incorporated structural breaks into the Augmented Dickey-Fuller framework. This innovation revealed that most of the macroeconomic series should be modeled as consisting of transitory fluctuations around a trend or trend-break.

In Mali, the events of the implementation of a market information system (SIM) in 1989 and the devaluation of the CFA in January 1994 engendered significant structural shifts. Devaluation in particular caused prices of livestock and cereals to increase when demand for these products increased through trade with surrounding countries (Yade, Tefft, Staatz, Kelly 1999). This work uses Augmented Dickey-Fuller (ADF) unit root tests as well as those developed by Perron to investigate the univariate characteristics of the time series.

The ADF test evaluate the null hypothesis of the existence of a unit root in a time series. The estimated equation is as follows with critical values from Table 20.1 in Davidson and MacKinnon (1993):

(4.37) $$\Delta y_t = \mu + \alpha y_{t-1} + \beta t + \Sigma_{i=1}^{T} c_i \Delta y_{t-i} + e_t$$

The Perron tests add structural breaks (an intercept shift, a trend shift , and a combined intercept and trend shift) to the ADF framework, critical values for the estimate of α are found in Perron in Tables IV.B, V.B, and VI.B, respectively . The structural shifts are explored here for the effect of devaluation in January 1994 for all three Perron forms:

(4.38A)

$$\Delta y_t = \mu + \alpha y_{t-1} + \beta t + \gamma DU_t + \Sigma_{i=1}^{T} c_i \Delta y_{t-i} + e_t$$

(4.38B)

$$\Delta y_t = \mu + \alpha y_{t-1} + \beta_1 t + (\beta_2 - \beta_1) DT_t + \Sigma_{i=1}^{T} c_i \Delta y_{t-i} + e_t$$

(4.38C)

$$\Delta y_t = \mu + \alpha y_{t-1} + \beta_1 t + \gamma DU_t + (\beta_2 - \beta_1) DT_t + \Sigma_{i=1}^{T} c_i \Delta y_{t-i} + e_t$$

The tests are conducted with the null hypothesis of a unit root, the estimate of α is compared to critical values appropriate for each test. The null hypothesis is rejected for estimates below the critical values, these values are provided in Table 4.1.0. Tables 4.4.1 through 4.4.3 present the results of the Augmented Dickey-Fuller and Perron tests for the presence of unit roots in the millet price series. Tables 4.2 and 4.3 provide descriptive statistics of the time series used in the construction of the single index of vulnerability to food insecurity. A simple linear regression of the price data on a constant and two trend variables to depict pre-devaluation and post-devaluation are presented here. Figures 4.1.1 through 4.3.2 present graphs of millet prices and the adjusted NDVI.

Table 4.2 Descriptive Statistics for Retail Millet Prices

Cercle	T	Min	Max	Mean	σ^2	Trend t_1= Predeval t_2=Postdeval	S.E.
Gao	135	60	195	99.94	917.45	t_1= -.0160 t_2= 1.31***	24.49
Mopti	135	40	182	84.19	979.92	t_1= .0650 t_2= 1.220***	26.25
Timbuktu	136	50	200	114.89	962.88	t_1= .0510 t_2= 1.052***	26.51

*, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.
Predeval and Postdeval refer to pre-devaluation and post-devaluation, respectively
S.E: refers to standard error of the regression

Table 4.3 Descriptive Statistics for Adjusted NDVI

Cercle	T	Min	Max	Mean	σ^2
Gao	135	-40.80	40.80	-3.1590	385.53
Mopti	135	-40.80	52.50	-0.3515	324.69
Timbuktu	136	-35.40	54.2	-0.3848	428.50

Table 4.1.0 Critical Values for Augmented Dickey-Fuller and Perron Unit Root Tests

Level of significance	ADF	Perron Intercept Shift	Perron Trend Shift	Perron Intercept and Trend Shift
1%	-3.96	-4.42	-4.51	-4.75
5%	-3.41	-3.80	-3.85	-4.18
10%	-3.13	-3.51	-3.57	-3.86

The results for the ADF unit root tests for the adjusted NDVI rejected the null hypotheses of the existence of unit roots. However, the test results for millet prices were ambiguous. There is evidence of stationarity for each price series (the null hypotheses of unit roots were rejected) with both the ADF and Perron tests, except for the DJenne millet price series. For DJenne, the ADF provided strong evidence that leads to the rejection of the null hypothesis of presence of a unit root in the series (see appendix). Since the single index model accounts for idiosyncratic aspects of each indicator, the level of the millet price series is selected as the indicator variable as well as the level of the adjusted NDVI.

Figure 4.1.1 Gao: Retail Millet Price

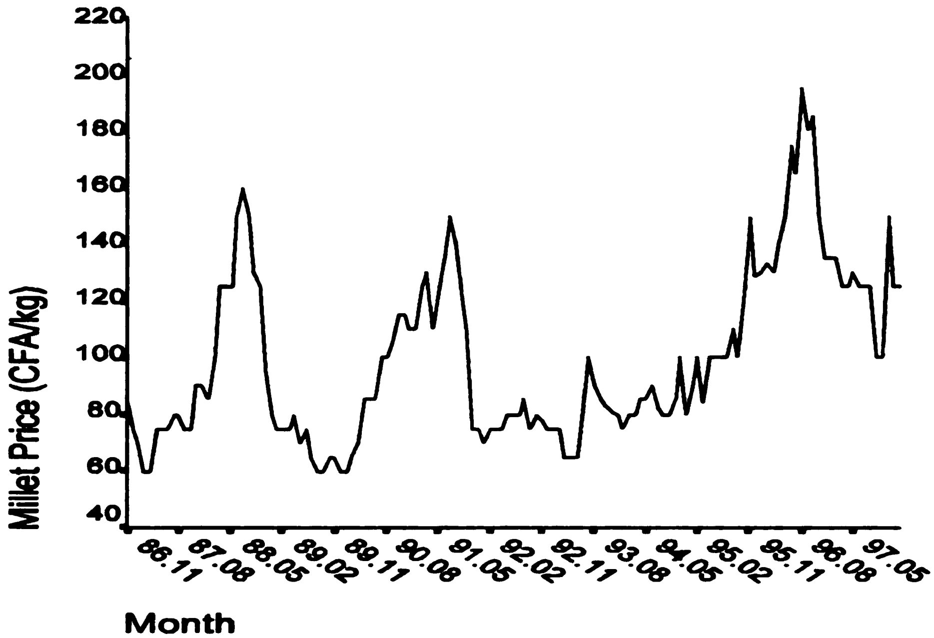


Figure 4.1.2 Gao: Adjusted NDVI

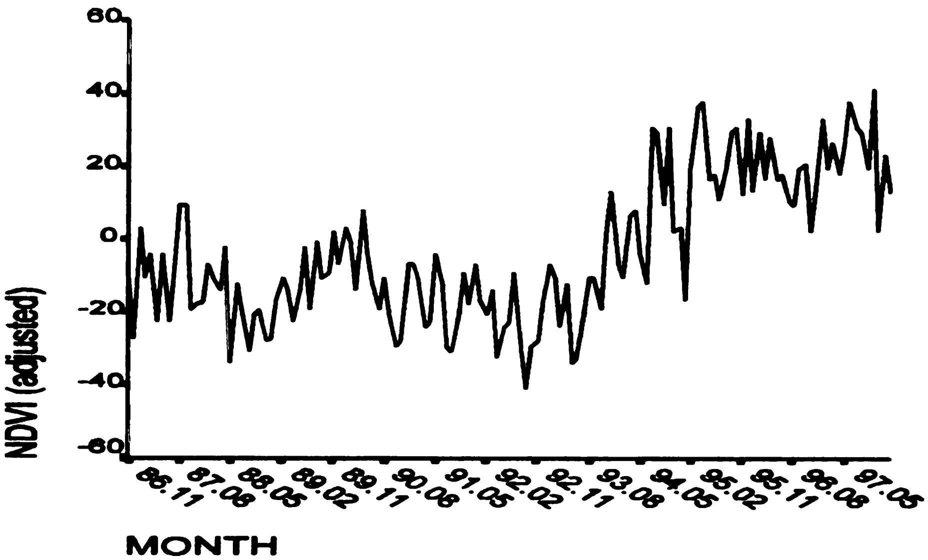


Table 4.1.1 Gao Results from Augmented Dickey-Fuller and Perron Tests of the Null Hypothesis of Non-Stationarity with and without a Structural Shift at Devaluation

Number of Lags	Adjusted NDVI (ADF)		Retail Millet Price Assumes no structural break (ADF)		Retail Millet Price Assuming Structural Break (Intercept Shift) (Perron)		Retail Millet Price Assuming Structural Break Trend Shift (Perron)		Retail Millet Price Assuming Structural Break (Intercept & Trend Shift) (Perron)	
	ADF	Root Value	ADF	Root Value	Critical Value	Root Value	Critical Value	Root Value	Critical Value	Root Value
2	-3.56**	-.300	-2.65	-.108	-3.17	-.309	-2.98	-.342	-3.24	-.329
4	-2.52	-.224	-3.11	-.135	-3.70*	-.385	-3.83**	-.480	-3.89*	-.429
8	-1.87	-.178	-2.65	-.132	-3.39	-.398	-3.45	-.537	-3.49	-.489
10	-2.27	-.223	-3.04	-.163	-3.29	-.452	-4.35**	-.760	-3.73	-.591
12	-2.03	-.211	-2.92	-.176	-3.68*	-.561	-4.57***	-.940	-4.52**	-.837

*, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

Figure 4.2.1 Mopti: Retail Millet Price

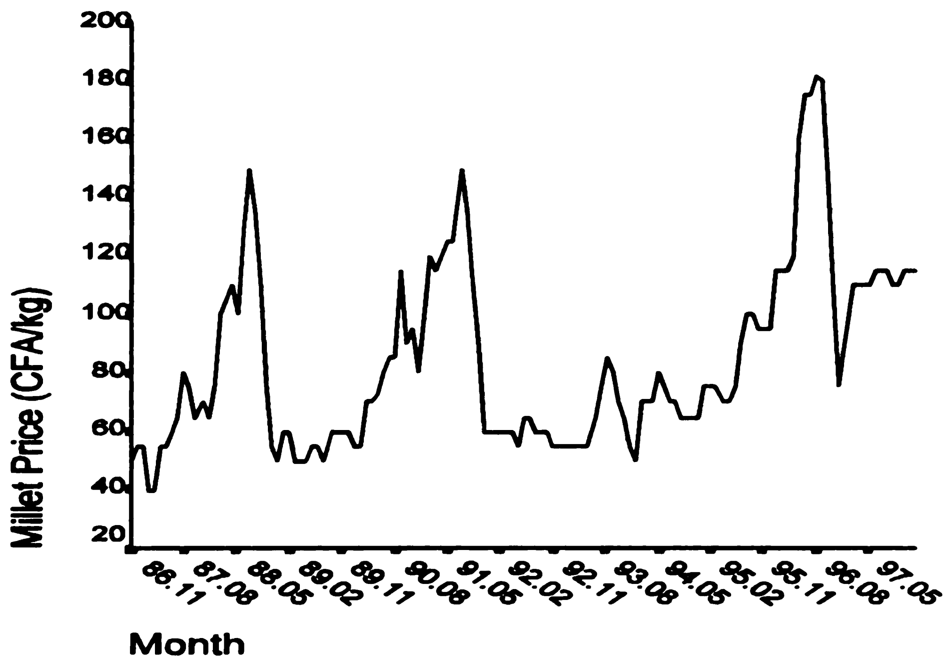


Figure 4.2.2 Mopti: Adjusted NDVI

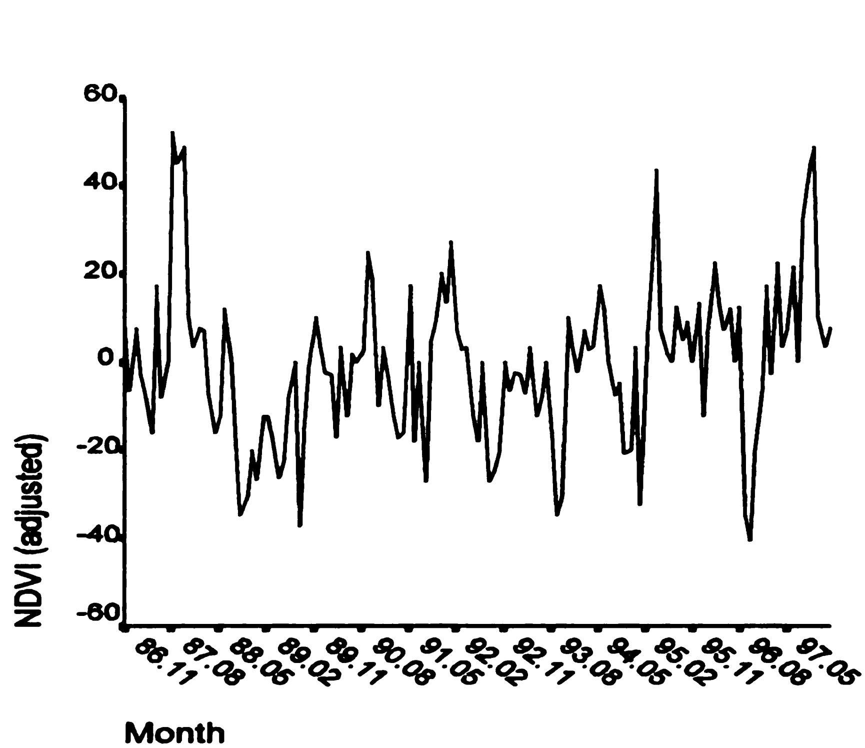


Table 4.2.1 Mopti Results from Augmented Dickey-Fuller and Perron Tests of the Null Hypothesis of Non-Stationarity with and without a Structural Shift at Devaluation

Number of Lags	Adjusted NDVI (ADF)		Retail Millet Price Assumes no structural break (ADF)		Retail Millet Price Assuming Structural Break (Intercept Shift) (Perron)		Retail Millet Price Assuming Structural Break Trend Shift (Perron)		Retail Millet Price Assuming Structural Break (Intercept & Trend Shift) (Perron)	
	ADF	Root Value	ADF	Root Value	Critical Value	Root Value	Critical Value	Root Value	Critical Value	Root Value
2	-5.14***	-.480	-3.47**	-.129	-3.52*	-.332	-3.88**	-.402	-3.77	-.398
4	-4.11***	-.463	-2.99	-.122	-3.05	-.315	-3.47*	-.402	-3.34	-.396
8	-3.19*	-.487	-2.74	-.128	-2.76	-.322	-3.43*	-.473	-3.25	-.466
10	-3.06	-.518	-2.80	-.138	-2.78	-.341	-3.69*	-.546	-3.49	-.546
12	-3.07	-.537	-2.86	-.152	-2.81	-.373	-3.79*	-.635	-3.66	-.669

*, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

Figure 4.3.1 Timbuktu: Retail Millet Price

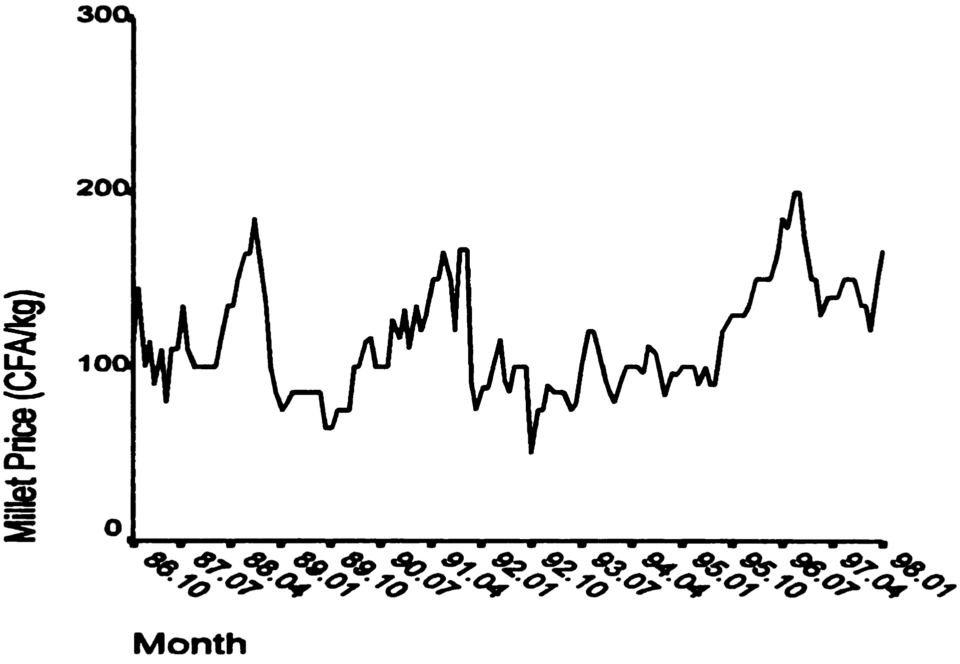


Figure 4.3.2 Timbuktu: Adjusted NDVI

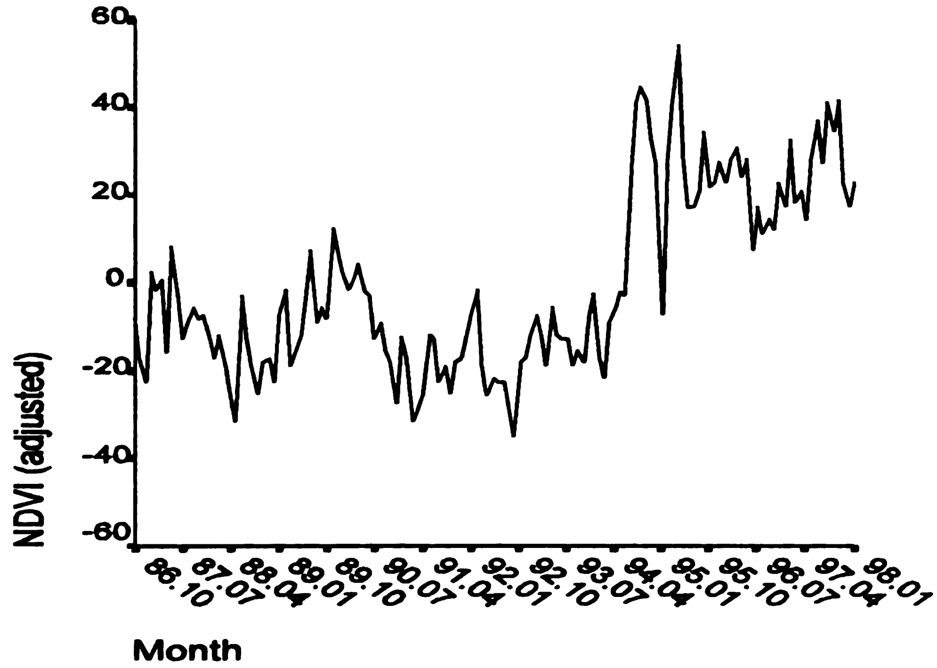


Figure 4.3.2 Timbuktu: Adjusted NDVI

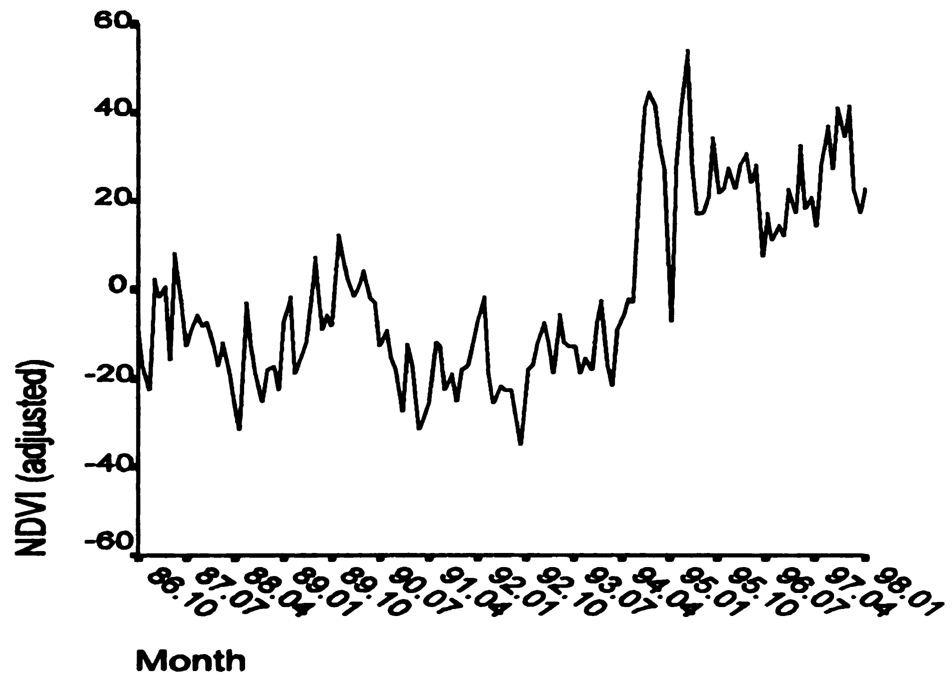


Table 4.3.1 Timbuktu Results from Augmented Dickey-Fuller and Perron Tests of the Null Hypothesis of Non-Stationarity with and without a Structural Shift at Devaluation

Number of Lags	Adjusted NDVI (ADF)		Retail Millet Price Assumes no structural break (ADF)		Retail Millet Price Assuming Structural Break (Intercept Shift) (Perron)		Retail Millet Price Assuming Structural Break Trend Shift (Perron)		Retail Millet Price Assuming Structural Break (Intercept & Trend Shift) (Perron)	
	ADF	Root Value	ADF	Root Value	Critical Value	Root Value	Critical Value	Root Value	Critical Value	Root Value
2	-3.15**	-.195	-3.00	-.159	-2.94	-.298	-4.00**	-.445	-3.86*	-.442
4	-2.38	-.151	-2.81	-.161	-2.84	-.306	-3.87**	-.483	-3.92*	-.501
8	-2.52	-172	-2.14	-.138	-2.14	-.263	-3.22	-.500	-3.47	-.619
10	-2.35	-.171	-2.20	-.150	-2.17	-.285	-3.41	-.581	-4.32**	-.861
12	-2.26	-.175	-2.50	-.181	-2.43	-.340	-4.10**	-.765	-4.17**	-.921

*, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

The results of the ADF and Perron tests for millet prices point to stationarity of the series or to the the significance of the trend shift attributable to devaluation. The ADF tests of the adjusted NDVI for each cercle tend to reject the null hypothesis of a unit root. Gao and Timbuktu have adjusted NDVI series that demonstrate an upward trend point to a deterioration of agricultural conditions in the Northeast of Mali. Segou also exhibits some upward movement in the adjusted NDVI. From these results, the levels of the series rather than the first differences will be used to model the single index of vulnerability to food insecurity (as in Stock and Watson (1991) and Kim and Nelson (1999)). The effects of devaluation, the increase in the prices of millet post-January 1994, as well as the environmental decline as reflected in the adjusted NDVI will then be captured in the single-index framework. A fuller discussion of is presented in the next section.

4.5 Results

4.5.1 Model Specification

Early warning systems such as FEWS use numerous indicators to try to detect turning points in food security levels. For the sample period under investigation, two of the most consistently monitored and reported indicators are millet prices and the normalized differenced vegetative index (NDVI). In this study, the time-series for the adjusted NDVI and the retail price of millet were selected as the key indicators in the construction of a single index to depict vulnerability to food insecurity. The model was kept parsimonious in order to establish a base model for the single index framework in this context. This model could be expanded to include other prices, agro-climatic factors and socioeconomic factors (such as goat prices, river levels and rainfall levels) more explicitly in the future. The adjusted NDVI is used to capture the extent of vegetative cover. The higher the adjusted value the less "green" the area relative to the seasonal mean; vulnerability is viewed as increasing with increases in this measure. The retail price of millet captures the general market conditions in the cercle; vulnerability is assumed to be increasing in the price of this staple. The effect of the 1994 devaluation is essentially treated as a pulse that is averaged out in this model in deviation from means (Harvey, 1996). The single index is constructed so that vulnerability to food insecurity is increasing as the value of the index increases. As discussed in the previous section, the model is specified in levels of the time series rather than in first differences.

The dynamic structure of the vulnerability index is specified in the spirit of Hendry. Because there does not exist another commonly used index of vulnerability to food insecurity, the specification and construction of this model has little previous research to rely on. As Hendry notes, this process of discovering kernels of insight at various stages in the development of a model has its endpoint in providing compelling empirical results. The usefulness of an econometric model is its capacity to synthesize data such that the outcomes from the modeling process convey or frame a narrative. As discussed in earlier chapters, the single-index constructed for each cercle is juxtaposed with qualitative assessments from the monthly SAP reports. These reference periods provide other qualitative information concerning the unobservable state of vulnerability to food insecurity.

Intuitively, one would expect millet price to be a leading indicator, ahead of the adjusted NDVI, of vulnerability to food insecurity. Poor rains are perceived by economic actors and reflected in markets before the effects are manifest in terms of crop greenness.

A poor harvest of millet and sorghum captured as an upturn of the adjusted NDVI should lag millet price increases pre-harvest and post-harvest, assuming no intervention in markets. One would also expect millet price increases if contra-season crops and wild cereals failed to reconstitute household reserves fully. This reasoning was incorporated into the dynamics of the single-index model. In Section 4.2, we developed the econometric framework for the single-index model. Here, the model is specified and estimated in levels for each of the eight regions. The dynamics are captured in the equations for adjusted NDVI and retail millet price through the lags of the unobserved state variable as entered in each expression. Equation (4.6) is rewritten as (4.39) resulting in the state space representation for the vulnerability index as follows:

$$
\begin{aligned}
x_{it} &= \gamma_i V_t + \gamma_{i1} V_{t-1} + \dots + \gamma_{ij} V_{t-j} + e_{it} \\
i &= 1,\ 2 \quad (1 = \text{millet price};\ 2 = \text{adjusted } NDVI) \\
j &= 1,\ 2,\ 3,\ 4
\end{aligned}
\tag{4.39}
$$

Measurement Equation

$$
(4.40)\qquad
\begin{bmatrix} X_{1t} \\ X_{2t} \end{bmatrix} =
\begin{bmatrix}
\gamma_1 & \gamma_{11} & \cdots & \gamma_{1j} & 1 & 0 & 0 & 0 \\
\gamma_2 & \gamma_{21} & \cdots & \gamma_{2k} & 0 & 0 & 1 & 0
\end{bmatrix}
\begin{bmatrix} V_t \\ V_{t-1} \\ \vdots \\ e_{1t} \\ e_{1,t-1} \\ e_{2t} \\ e_{2,t-1} \end{bmatrix}
$$

Transition Equation

$$
(4.41)\qquad
\begin{bmatrix} V_t \\ V_{t-1} \\ \vdots \\ V_{t-j} \\ e_{1t} \\ e_{1t-1} \\ e_{2t} \\ e_{2,t-1} \end{bmatrix} =
\begin{bmatrix}
\phi_1 & \phi_2 & \cdots & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & \cdots & 0 & 0 & 0 & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
0 & 0 & 1 & 0 & \cdots & 0 & 0 & 0 \\
0 & 0 & 0 & \cdots & \psi_{11} & \psi_{12} & 0 & 0 \\
0 & 0 & 0 & \cdots & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & \cdots & 0 & 0 & \psi_{21} & \psi_{22} \\
0 & 0 & 0 & \cdots & 0 & 0 & 0 & 1
\end{bmatrix}
\begin{bmatrix} V_{t-1} \\ V_{t-2} \\ \vdots \\ V_{t-j-1} \\ e_{1,t-1} \\ e_{1,t-2} \\ e_{2,t-1} \\ e_{2,t-2} \end{bmatrix} +
\begin{bmatrix} \omega_t \\ 0 \\ \vdots \\ 0 \\ \epsilon_{1t} \\ 0 \\ \epsilon_{2t} \\ 0 \end{bmatrix}
$$

The models for the eight regions are estimated as outlined in Section 4.3. The results for Segou, Djenne, Douentza, Tenenkou, and Youvarou are presented in the appendix. The lags associated with the adjusted NDVI and retail millet price equations were determined through an iterative process. The hypothesized relationship between the two indicators was featured as coincident or with the adjusted NDVI as a lagging indicator. Millet price will most likely respond to an expected poor harvest or outside conditions more readily than the adjusted NDVI which depicts the greeness of vegetative cover. The number of lags selected for each variable in the eight regions are presented in Table 4.4. The parameter estimates are presented in Tables 4.5.1 through 4.5.3. Model selection was based on the significance and appropriateness of the parameter estimates, the highest likelihood values, and upon whether the index was consistent with the information represented by the individual series. Those models with the highest likelihood function among candidates are presented here. We find that the vulnerability indexes for each region are sinusodal reflecting the cyclical nature of both millet prices and NDVI. These cycles also depict vulnerability conditions such that the hungry season and increasing millet prices should tend to coincide temporally. Parameter estimates for millet prices tended to be significant whereas those for the adjusted NDVI varied. The parameter estimates for the innovations on NDVI tended to be significant for all the models.

Table 4.4 Number of lags of V_t in Adjusted NDVI and Millet Price Equations

Cercle	Retail Millet Price	Adjusted NDVI
Gao	2	4
Mopti	1	3
Timbuktu	1	3
Segou	1	2
DJenne	1	3
Douentza	3	3
Tenenkou	1	2
Youvarou	1	1

The scale of the estimated indexes, V_t, varied from region to region. Because price and NDVI indices were not constructed a priori to make regional information comparable, the estimated vulnerability indexes are not directly comparable from region to region. To address this problem, index estimates were standardized. The final estimates of a single-index of vulnerability to food insecurity were rescaled to run from 0 to 1, with 0 depicting the least vulnerable state and 1 depicting the most vulnerable state in the time period examined. These indices are presented in Figures 4.5.1 through 4.5.3.

4.5.2 The Single Index for each Region

This section provides an overview of vulnerability conditions for each region as they relate to the vulnerability indexes. Each summary is followed by the vulnerability mapping for the cercle (Figures 4.5.1 through 4.5.3) and the corresponding table of parameter estimates. Table 4.5 provides a summary of the single index turning points for

Table 4.5 Comparing the Single Index with the Reference Cycles

Region	Periods of Moderate Vulnerability	Periods of High Vulnerability	Key Turning Points in Vulnerability Index
Gao	January 1987 to June 1987 September 1987 to January 1988 November 1989 to February 1990 September 1992 January 1993 to February 1994 October 1995 to May 1996 September 1996 to January 1998	November 1986 to December 1986 February 1988 to May 1988 March 1990 to June 1990 June and July 1993 March 1994 to September 1995 June 1996 to August 1996 May and June 1997 October 1997	November 1986 March 1989 November 1992 May 1993
Mopti	January 1987 to July 1987 October 1989 January 1990 to May 1990 July 1991 October 1991 to March 1992 February 1993 December 1993 to May 1994 March 1995 September 1996 February 1997	November and December 1986 August 1987 to July 1988 June 1990 to October 19990 April 1992 to July 1992 April 1995 to August 1996 March 1997 to January 1998	May and June 1987 August 1989 July 1991 November 1993 January 1995 November 1996
Timbuktu	January 1988 to August 1988 March 1989 to August 1990 April 1991 July and August 1991 January and February 1992 June to August 1992 December 1992 to December 1993 January and February 1995 (some areas)	October 1986 to July 1987 June 1989 February 1990 and March 1990 May and June 1991 September 1991 to December 1991 March 1992 to May 1992 June 1994 to January 1998	May 1988 December 1988 August 1992 March 1995 April 1997

Gao, Mopti, and Timbuktu. If a turning point appeared in advance of moderate or highly vulnerable periods, this was viewed as a valuable feature of the index. Whether the level of the index distinguished among periods of low, moderate and high vulnerability was also a key feature upon which to evaluate the efficacy of the indexes.

Gao

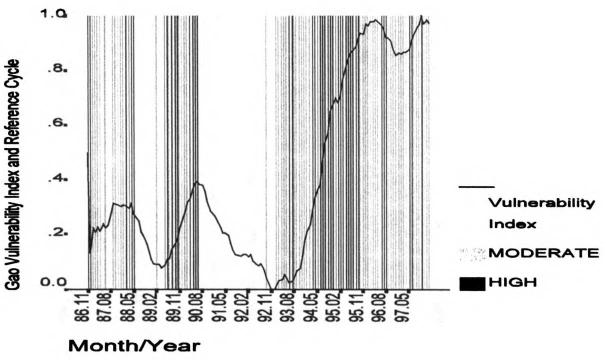
We turn to Figure 4.5.1 which maps the single index of vulnerability to food insecurity in Gao with the qualitative reference cycles constructed from the monthly SAP reports.

The vulnerability index for Gao demonstrates a sharp drop at the beginning of the period under study, October 1986. The initial drop in the index reflects the seasonal decline in prices at harvest time which was further depressed with the release of food aid in the cercle. There is a significant upturn in the vulnerability index at December 1986 which corresponds with the reports, this upturn continues through the harvest.

January 1998 is a period of increasing vulnerability with migration pressures and markets poorly stocked in cereals. February through May 1988 are declared periods of food insecurity in the cercle. Food aid deliveries are spaced out during this period and appear to mitigate further deterioration in conditions. The vulnerability index captures this as a continued increase from the turning point of October 1987.

The vulnerability index has another turning point in April 1989 which is confirmed as the onset of a vulnerable period in the qualitative reports. In May and June 1990, food

Figure 4.5.1 **Gao Vulnerability Index and Reference Cycle Mapping of Vulnerability to Food Insecurity November 1986 to January 1998**



aid distributions and wild cereals mitigate food security problems where a average harvest is expected. The vulnerability index reflects this as the local peak occurs in August 1990 and the decline corresponds to the qualitative assessments.

After August 1990, the index continues its decline. A food aid delivery in November 1992 serves to assist the most vulnerable. This occurs at the next turning point in the Gao vulnerability index, this upturn corresponds to conditions reported in the SAP assessments. In July, the United Nations High Commission on Refugees establishes a camp in Gao. This outside assistance may account for the slight downturn in the vulnerability as reflected in the index. There is another turning point in the vulnerability index in August 1993 which is confirmed when an expected poor harvest is realized and sharp increases in millet prices around the cercle reported in September and October such that there is an increase vulnerability to food insecurity throughout the rest of 1993.

The Gao vulnerability index shows a steep increase until January 1996. The index captures the effects of devaluation on millet prices and the increase in the adjusted NDVI during this period. The decline in vegetative cover may depict the disruptions to farming due to civil conflict and the deterioration of environmental conditions in the region. While there are continued downturns and turning points the relative level of the vulnerability index is much higher than for the rest of the year. This whole period in the sample is a time of high vulnerability in Gao cercle primarily due to the disruptions caused by civil conflicts and then with repatriation of displaced persons. The were high levels of disease in this period as well. The relative downturn in August 1996, that still reflects a high level of vulnerability could be related to food aid delivered the previous month which depressed millet prices and to the harvest when prices typically drop quite sharply in October and November.

Overall, we find the experimental vulnerability index for Gao to appropriately reflect the periods of vulnerability to food insecurity in the region. The index is composed of just two variable: millet price and an adjusted NDVI such that events, such as food aid deliveries with respect to millet prices, appear to be captured in the index. In terms of providing a mechanism to detect early onset of threats to food security, the index performs fairly with turning points generally one or two months in advance of problems as described in the monthly SAP reports.

Table 4. 5.1 Parameter Estimates for the Vulnerability Index, Gao (2,4)

Parameter	Parameter Estimate	Standard Errors
ϕ_1	1.9016	.0319
ϕ_2	-.9040	.0304
γ_1	-.04950	.0479
γ_{11}	-.03620	.0905
γ_{12}	.1023	.0518
ψ_{11}	.8021	.1936
ψ_{12}	-.0058	.2279
σ_1	.1346	.0168
γ_2	-.0679	.0153
γ_{21}	.5922	.2128
γ_{22}	-.5950	.9550
γ_{23}	-.1483	1.0097
γ_{24}	.2393	.3224
ψ_{21}	-1.1862	.615
ψ_{22}	-0.3518	.3650
σ_2	0.0088	.0309
Likelihood Value		69.49

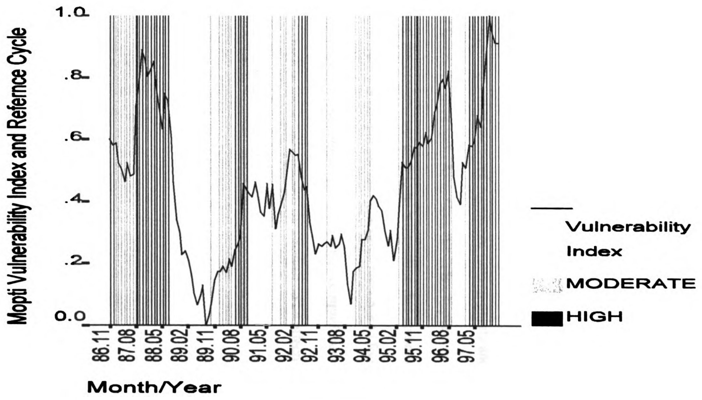
Mopti

The vulnerability index for Mopti Cercle (see Figure 4.5.2) consists of a larger number of dramatic turning points which indicate an increase in vulnerability at these points. At the beginning of the sample period, October 1986, the index starts at a relatively high level (0.6) and decreases at harvest reflecting the typical drop in millet prices at harvest. Beginning in May 1987 there is a slight upturn in the index reflecting an increase on demands for foods with an increase in migration to the area, the impact on prices is dampened with the food aid distributions. After the 1988 harvest, the vulnerability index continues its decline from very high levels to its nadir at October 1989. There is a sharp increase in prices in November and December but a good harvest replenishes household reserves. There is a corresponding turning point in the vulnerability index with an increase. The vulnerability conditions are moderate when compared to the period prior to August 1988 and this seems reflected in the index. Food aid deliveries arrive in June and July which appears as a brief plateau in the rising index.

In January 1991 there is a steep increase in prices and many areas under surveillance: Korientza, Sendegue, Fatoma, Konna, Soufouroulaye and Soye. This is reflected in the vulnerability index. An April food aid delivery appears as a decline in the vulnerability index which turns upward again right after the delivery. The vulnerability index has a distinctive turning point in August 1991 which provides a two month lead into a moderately vulnerable period that continues into August of 1992.

The situation stabilizes and improves until post-harvest of 1993 when poor harvests cause migration and several areas grow increasingly more vulnerable. This situation is

Figure 4.5.2 Mopti Vulnerability Index and Reference Cycle Mapping of Vulnerability to Food Insecurity November 1986 to January 1998



captured in the index with a turning point in August 1993, providing at least a month ahead indication of a change in conditions relative to the SAP reports. March of 1995 is the onset of a very vulnerable period with high disease and sharp price increases. This is depicted in the index with a turning point at least two months prior to the SAP assessments reporting a deterioration in food security conditions. As captured in the vulnerability index, food security begins to deteriorate in 1997 and problems persist for the rest of the sample period. Sharp price increases, disease, and weak household reserves characterize most of 1997 and January 1998.

Overall, the vulnerability index captured significant turning points and the severity of vulnerability to food insecurity in Mopti. As in Gao, the index appears to be capturing more than mean seasonal fluctuations but additional information that communicates the progression of conditions over the sample period. The price response to food aid deliveries is communicated through the index and when these deliveries are significant and made at regular intervals early enough in the hungry season, they appear to be effective in improving conditions without dramatic price effects.

Table 4.5.2 Parameter Estimates for the Vulnerability Index, Mopti (1,3)

Parameter	Parameter Estimate	Standard Errors
ϕ_1	1.6364	.1336
ϕ_2	-.6694	.1091
γ_1	-.1121	.07810
γ_{11}	.1721	.08551
ψ_{11}	1.2850	.1263
ψ_{12}	-.4019	.1219
σ_1	.0987	.0334
γ_2	.1203	.1603
γ_{21}	.0783	.0216
γ_{22}	.0640	.2110
γ_{23}	-.2258	.1596
ψ_{21}	.2465	.3148
ψ_{22}	.0309	.1499
σ_2	.5152	.2067
Likelihood Value		28.06

Timbuktu

The vulnerability index for Timbuktu in Figure 4.5.3 reveals several distinctive turning points and numerous minor turning points. A distinctive turning point occurs in February 1989 which is confirmed as an one month leading indicator to the reports of onset of poor conditions for food security as reported in March and persist through August of the same year when conditions stabilize with harvest.

The index leads the problems of high disease and prices noted in April 1992 as a cercle-wide phenomenon. A distinctive turning point in the index occurs in late 1992 as Nomad populations are at risk and deterioration in conditions persist as civil conflict persists into 1993 and 1994. Another turning point that foreshadows a sharp increase in vulnerability to food insecurity occurs at May 1994. A hard hungry season is expected for 1998, the vulnerability index has another turning point in December 1997 reflecting sharp price increase.

Overall, the vulnerability index offers some early warning for Timbuktu giving a month lead at several point in the sample period leading sharp increases in vulnerability by a month or more. The mid-1994 through the January 1998 is a period of marked increase in vulnerability relative to the rest of the sample period and is captured by the single-index. The adjusted NDVI tended to increase over the sample period and significantly contributes to the increase in the upward trend in the index.

Figure 4.5.3 Timbuktu Vulnerability Index and Reference Cycle Mapping of Vulnerability to Food Insecurity October 1986 to January 1998

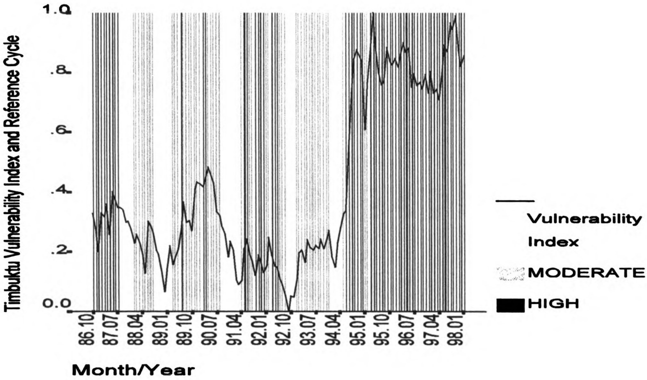


Table 4. 5.3 Parameter Estimates for the Vulnerability Index, Timbuktu (1,3)

Parameter	Parameter Estimate	Standard Errors
ϕ_1	1.1613	.02781
ϕ_2	-.1854	.2699
γ_1	.3637	.0946
γ_{11}	-.3110	.0951
ψ_{11}	1.3756	.3278
ψ_{12}	-.4564	.3019
σ_1	.0780	.0729
γ_2	.0476	.0524
γ_{21}	-.0144	.05400
γ_{22}	.0687	.0558
γ_{23}	.0784	.0572
ψ_{21}	.4186	.1536
ψ_{22}	-.0203	.1209
σ_2	.1776	.0321
Likelihood Value		52.15

4.6 Comparison of the Single Index with the Simple Index and Reference Cycles

Table 4.6 presents turning point summaries for the simple and single indexes as well as reference cycle highlights for each region. For Gao, Mopti, and Timbuktu we do find that the simple index provides more appropriate turning points with some lead time to the onset of vulnerability. In addition, the levels of the single indexes better correspond to the severity of food insecurity conditions as depicted in the reference cycles. Adjusted NDVI significantly enhances the early warning capacity of the single index over the simple index for most regions. This is not the case for Douentza, Tenenkou and Youvarou (all cercles in Mopti Region) which are primarily livestock trading economies (see Appendix Chapter 4). Detailed summaries follow.

Gao

Figure 4.6.1 presents a mapping of the single and simple indexes with the reference cycles for Gao. The single index capture the key turning points with one to three months lead time. However the simple index coincides with vulnerability conditions post-1995 without early warning features. The single index of vulnerability to food insecurity provides desirable features such as timely turning points and levels that reflect the severity of vulnerability conditions.

Mopti

The Mopti single index is less smooth than the single index (Figure 4.6.2). Both indexes perform better (in both levels and turning points) at the beginning and end of the sample period. The simple index captures general conditions in 1990 and 1992 but the levels do not match the relative severity of vulnerability conditions. Overall, the single

Table 4.6 Comparing the Single Index and the Simple Index with the Reference Cycles

Region	Periods of Moderate Vulnerability	Periods of High Vulnerability	Key Turning Points in Simple Millet Index	Key Turning Points in Vulnerability Index
Gao	January 1987 to June 1987 September 1987 to January 1988 November 1989 to February 1990 September 1992 January 1993 to February 1994 October 1995 to May 1996 September 1996 to January 1998	November 1986 to December 1986 February 1988 to May 1988 March 1990 to June 1990 June and July 1993 March 1994 to September 1995 June 1996 to August 1996 May and June 1997 October 1997	November 1997 May 1990 June 1993	November 1986 March 1989 November 1992 May 1993
Mopti	January 1987 to July 1987 October 1989 January 1990 to May 1990 July 1991 October 1991 to March 1992 February 1993 December 1993 to May 1994 March 1995 September 1996 February 1997	November and December 1986 August 1987 to July 1988 June 1990 to October 19990 April 1992 to July 1992 April 1995 to August 1996 March 1997 to January 1998	July 1987 April 1990 May 1993 August 1995	May and June 1987 August 1989 July 1991 November 1993 January 1995 November 1996
Timbuktu	January 1988 to August 1988 March 1989 to August 1990 April 1991 July and August 1991 January and February 1992 June to August 1992 December 1992 to December 1993 January and February 1995 (some areas)	October 1986 to July 1987 June 1989 February 1990 and March 1990 May and June 1991 September 1991 to December 1991 March 1992 to May 1992 June 1994 to January 1998	January 1987 January 1990 July 1993 January 1995	May 1988 December 1988 August 1992 March 1995 April 1997

Figure 4.6.1 **Gao Vulnerability Index, Simple Index, and Reference Cycle Mapping of Vulnerability to Food Insecurity November 1986 to January 1998**

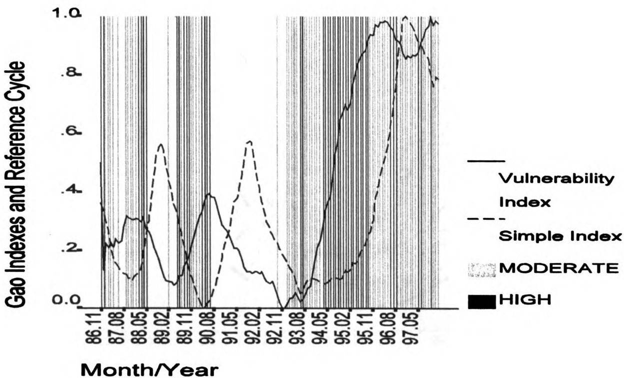
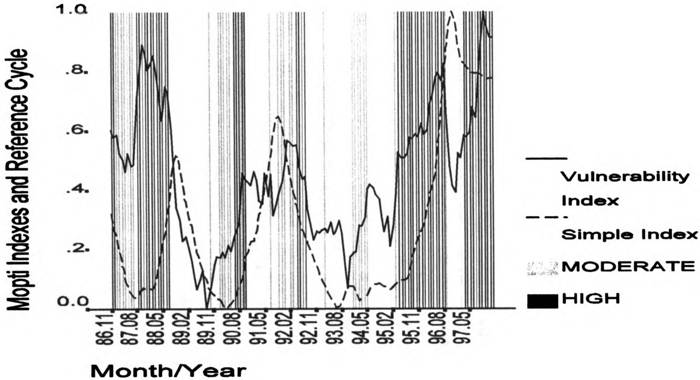


Figure 4.6.2 Mopti Vulnerability Index, Simple Index, and Reference Cycle Mapping of Vulnerability to Food Insecurity November 1986 to January 1998



index possesses key turning points that are appropriate for the early warning of the onset of vulnerable periods.

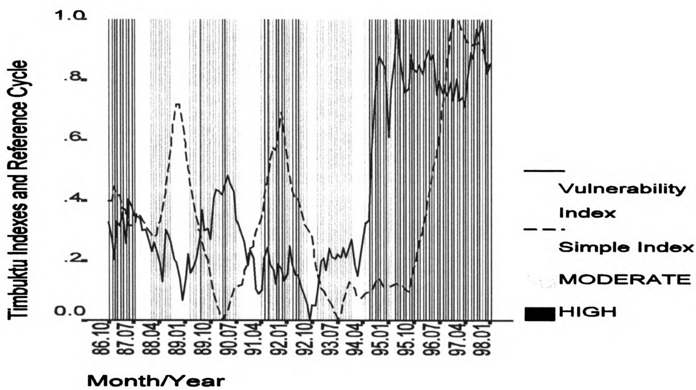
Timbuktu

The simple index for Timbuktu captures the high vulnerability to food insecurity in 1992 while the levels of the single index fails to do so (Figure 4.6.1). The single vulnerability index performs better than the simple index in 1989 and post-1995. Adjusted NDVI is especially important in depicting vulnerability conditions in the later part of the sample period. The upward trend in adjusted NDVI reflects the disruption in planting due to civil conflict as well as environmental degradation. Vulnerability to food insecurity is high post-1995 due to these factors and the single index performs better than the simple index over this period both predictively and descriptively.

From close study of these vulnerability mappings we find a visual and intuitive representation of the evolution of vulnerability in the eight regions under study. On the whole, the single vulnerability indexes provide information concerning the onset of vulnerable conditions with one to three month lead times. The characterization of moderate and high periods of vulnerability generally correspond to the index levels over the sample period.

Certainly, further research to include more indicator variables in the construction of the single indexes could lead to measures that are smoother with more distinct turning points. This parsimonious vulnerability index, incorporating just two variables, performed

Figure 4.6.3 Timbuktu Vulnerability Index, Simple Index, and Reference Cycle Mapping of Vulnerability to Food Insecurity October 1986 to January 1998



reasonably well for the eight regions in Mali. The single indexes along with the qualitative assessments provide tools to communicate the evolution of conditions related to food security in these regions as well as in forecasting conditions. This capacity may be a useful tool for analysts and decision makers. Policy implications for these vulnerability mappings are explored in concluding chapter.

Time Series Analysis of Famine Early Warning Systems in Mali

Volume II

By

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Chapter 5

Vulnerability to Food Insecurity and Regional Goat Market Integration in Mali

5.1 Introduction

Market Integration and Food Security Vulnerability

Research in market integration relies on the correlations between regional prices as indicating market integration. Such models have numerous shortcomings. For example, country-wide macroeconomic shocks such as devaluation or inflation, might overshadow more subtle price movements, possibly leading the analyst to strong yet spurious correlations and inferences.

This study explores regional price information as well as regional measures of vulnerability to create a structural model. This research incorporates vulnerability index for Mopti, developed earlier, whereby the level of vulnerability to food insecurity delineates the market integration regimes. A framework is developed for depicting the movements from one regime of market integration, for example one of a high level of integration, to the next. The regimes characterized in this study differentiate two differing states market integration that are triggered by a change in the level of vulnerability to food insecurity. We examine spatial market integration in goat markets in the region of Mopti to determine whether the markets perform differently in vulnerable periods than in food secure periods.

In this chapter we explore regime shifts in market integration as they relate to periods of vulnerability to food insecurity in Mali. Goat prices are monitored by FEWS and SAP because goats and other ruminants and larger animals are viewed as assets in agro-pastoral households. Prices of these animals tend to fluctuate with the climate of food security vulnerability. In vulnerable times, households tend to sell off animals even though grain-to livestock terms of trade are less favorable in order to secure food so to avert a short-term crisis. In addition, periods of food stress may foster the breakdown of arbitrage activities and increase transactions costs such that trade relationships deviate from their functioning during low stress periods. The innovation of this research is the use of structural information, the state of vulnerability to food insecurity, as the trigger variable for regime shifts.

5.2 Literature Review

5.2.1 Cointegration

The evaluation of market integration in spatially separated markets has generated a considerable amount of empirical research and debate. Most work has focused on the examination of price correlations to determine the extent to which shocks are transmitted among markets. As discussed ealier, it is important to first investigate the univariate characteristics of the price series in order to determine whether the univariate series are stationary or nonstationary. Once this is ascertained, appropriate econometric techniques can be employed since the treatment of stationary and nonstationary data are distinctly different. Many of the earlier works on market integration failed take this distinction into account.

More recently, the cointegration models of Engle and Granger (1987) have been widely used in studies of market integration to investigate long-run relationships between variables. Goodwin (1992) uses cointegration tests of Johansen (1988) and Johansen and Juselius (1990) to investigate the Law of One Price in international wheat markets. These approaches test the null hypothesis of no cointegration in that the residuals are tested for stationarity. In effect, the conclusions are based on the acceptance of an alternative hypothesis.

Fackler (1993), like Alderman (1989), performs the proper univariate investigations of the price series which leads them to use more appropriate time-series techniques. He notes that it is only meaningful to discuss long-run equilibrium between endogenous variables when the series are nonstationary. When a time-series is stationary, long-run restrictions are not appropriate because the series move about a constant mean. However, additional univariate investigations in the area of autoregressive conditional heteroskedasticity might enhance the empirical and theoretical work.

Some literature has attempted to address the issue of the degree to which markets are integrated. Timmer constructed an index of market connection, to be discussed further below. Heytens also used this notion in his applied work. However, these studies have been limited by their econometric approaches. In the Timmer and Heytens studies, the univariate characteristics were not fully investigated. Timmer's index of market connection relies on the assumption that prices follow AR(1) processes. Since it is most likely that prices are integrated (nonstationary), this leads to bias in the standard error estimates, and thus the index constructed with these estimates is of little value. The manner in which previous studies, including those employing techniques to treat nonstationary data, test for market integration does not allow for varying degrees of integration. The hypothesis that markets are integrated is either rejected or accepted. This dichotomy is very restrictive.

As many researchers have noted, transactions costs have been ignored in models of market integration . As Goodwin and Piggott (2000) point out, the primary mechanism ensuring integration is spatial trade and arbitrage. The structure and evolution of transactions costs can affect the structure and stability of price linkages of spatially separate markets. The role of transactions costs in regime shifts is considered in work on market integration by Baulch (1994), Spiller and Wood (1996), and others. Market integration has also been examined in a nonlinear framework though the use of threshold cointegration models (Obsfeld and Taylor, Goodwin and Grenes). Goodwin and Piggott (2000) employ a model of threshold cointegration to explore the role of transactions costs in inhibiting price adjustments which can affect tests of market integration. They evaluate price linkages among several local North Carolinian corn and soybean markets. Goodwin and Piggott's analysis employs nonlinear modeling techniques to account for regimes shifts within a neutral band to depict the effects of transactions costs on long-run equilibrium relationships. Threshold models characterize a regime switch as triggered by a transition variable (or variables) crossing some threshold value. This threshold parameter delineates alternative regimes. Hitherto, most tests for market integration express the long-run price adjustment as a linear phenomenon while threshold cointegration allows for alternative regimes to exist along with the long-run relationship.

Their results demonstrate that large shocks (shocks above some threshold) evoke a different response than do smaller shocks.

We examine the functioning of markets during times of food security vulnerability or famine and draws from the research incorporating threshold cointegration models. While most threshold models use the series under examination as the threshold variable, this research uses the vulnerability index as the trigger variable for regime shifts. The trigger variable here is taken to be exogenous. This may be a strong assumption but the distribution theory for a nonexogenous has yet to be developed. It is assumed that periods of high vulnerability to food insecurity could destabilize trading relationships by sharply increasing transactions costs or causing other disturbances to equilibrium price relationships. The fact that market A is a net seller of goats to market B in a non-stress period does not imply that this linkage would prevail in times of vulnerability.

In part of this research, we examine the functioning of goat markets in Mopti. Goats are an important asset to households in the region. As discussed in Chapter 4, during times of food insecurity a sell off of these assets is often employed as a strategy to mitigate hardship. Mopti Cercle, the regional capital, is the central market in the region. Djenne, Douentza, Tenenkou and Youvarou are peripheral markets for trade in the area (see Figure 2.1). We incorporate additional structural information and allow differential integration in times of stress using the vulnerability indicator developed in the first part of this study. We explore two regimes rather than developing a neutral band as in the work of Goodwin and Piggott (2000). In this chapter we present the univariate analysis of goat prices for Mopti. In the next section, the econometric framework for the threshold cointegration model is developed and empirical results presented.

5.2.2 Threshold Cointegration

Cointegration techniques have been widely used to model long-run relationships such as the relationship between consumption and income or the Permanent Income Hypothesis (Campbell, 1987), stock prices and dividends (Campbell and Shiller, 1987) as well as market integration (Alderman, 1989, Goodwin, 1990). The concept of cointegration was developed to depict the long-run equilibrium relationships between nonstationary variables (Granger, 1986 and Engle and Granger, 1987).

Systems of cointegrated variables can be characterized by an error correction model which captures the adjustment process under which the long-run equilibrium is maintained. Typically, this cointegration is viewed as linear in that the system tends to move toward this unique equilibrium state in every period. Models of threshold cointegration address the case when the movement toward equilibrium does not take place in every period (Balke and Fomby, 1997). Tong (1989) pioneered theoretical work in threshold time series models. Balke and Fomby (1997) note that an example might be the presence of fixed costs of adjustment that prevent economic agents from adjusting continuously. Only when the deviation from equilibrium exceeds some critical threshold do the benefits of adjustment exceed the cost and economic agents act to move the system back toward equilibrium. This example relates to many economic phenomenon; especially notable is the case of efficient financial markets in which the presence of transactions costs may create a band in which asset returns are free to diverge and in which arbitrage activities exist. This idea also relates to policy interventions in exchange rate management and commodity price interventions which are often characterized as discrete interventions. These discrete adjustments can be characterized using models of threshold cointegration.

There has been growth in the literature related to threshold cointegration and threshold autoregressive models in finance, economics and agricultural economics (Franses and van Dijk 2000, Hansen 1997 and 2000, Martens et al 1998, Potter 1995, Koop et al 1996, Goodwin and Piggott, 2000). Most research explores cases where the cointegrating relationship is inactive inside a given range and then becomes active once the system has gone too far out of equilibrium. For example, Goodwin and Piggott's work on market integration in corn and soybean markets characterize their model with a neutral band depicting transactions costs. Further, the threshold variable selected in the literature is the series, or residual series, under investigation. Threshold models where the series under investigation is the threshold as well are known as *Self-Exciting Threshold Autoregression models*, SETAR.

In this work, we examine market integration between goat markets in Mopti region exploring the long-run equilibrium price relationships in Mopti goat markets. Rather than viewing a neutral band, we model the process as deviations from an equilibrium relationship (market integration) such that the associated error corrections model responds to the deviations from the equilibrium relationship; the strength of the relationship depends on how far the variable is away from the equilibrium relationship. One could think of this as a controller trying to return the control variable to a certain level as opposed to allowing deviations to fluctuate within some range. The relationship is modeled as one where the cointegrating relationship between variables turns on and off. In addition, the threshold variable used in this investigation is the index of vulnerability to food insecurity for Mopti Cercle, the central market, developed in Chapter 4. We use this index of the central market as the benchmark for vulnerability to food insecurity in the region. The SETAR approach is also investigated.

Balke and Fomby hold that the conventional approach to testing for cointegration, the Engle-Granger approach developed for linear time series, is also capable of detecting threshold cointegration. Hansen (2001) has developed a new test for threshold cointegration but for this research we approach testing for cointegration with the conventional method which is most common and accepted in the literature. The first step then is to test for threshold cointegration is to test for cointegration with the Engle-Granger approach and then to determine whether there is threshold behavior present in the time series.

Typically, cointegrating relationships (for the case of two variables, y_t and x_t) can be depicted as

(5.1) $$y_t - \beta x_t = z_t \quad where \quad z_t = \rho z_{t-1} + \varepsilon_t$$

Such that

$|\rho| < 1$ implies cointegration

$|\rho|$ *near* 1 implies nonstationary, no cointegration

$|\rho| = 1$ implies the existence of a unit root, no cointegration.

As Hansen (1992) notes, the case where $|\rho| < 1$ is the linear case of cointegration as originally defined by Granger (1986). In the above representation, the cointegrating residuals are represented as z_t .

Next we consider nonlinear, threshold, behavior where various regimes may be present. In threshold cointegration the linear autoregressive structure is altered to reflect the delineation between regimes triggered by the threshold value c, such that

$$(5.2) \qquad \rho = \begin{cases} \rho^{(1)} & \text{if } |z_{t-1}| \leq c, \\ \rho^{(2)} & \text{if } |z_{t-1}| > c. \end{cases}$$

This formulation depicts a two regime AR(1) model with different means in each regime. Other representations allow for more complex state dependent dynamic behavior meaning that certain properties of the time series such as mean , variance, and/or autocorrelation, are different depending on the regime. We focus on this regime process as stochastic and build on the current literature to expand the framework to capture autoregressive models of higher orders. First we estimate the cointegration relationship and investigate the characteristics of the residuals from this cointegrating relationship.

5.3 Model Specification and Estimation

We begin by investigating the nature of the relationships between goat markets in the Mopti region. Mopti Cercle is characterized as the central market and surrounding markets of DJenne, Douentza, Tenenkou and Youvarou as peripheral markets. In the

Section 5.4.1 we explore the univariate characteristics retail goat price series for each market region and determine the series to be I(1) time series. Recall from Chapter 3, Douentza is a main livestock trading area whereas the other peripheral markets are more diverse in their trading activities. Based on these findings, threshold cointegration is used to explore relationships between goat prices between cercles in the Mopti region of Mali.

We proceed by building threshold autoregressive models (TAR) from the time series of residuals from the cointegrating relations. We treat the vulnerability index for Mopti as the threshold variable, q_t, and we construct the SETAR versions for comparison: the threshold variable may be a lagged value of the series itself or a lagged value for the vulnerability index. The TAR model assumes that a regime is determined by the value of the threshold variable relative to a threshold value. SETAR models treat the regime switching behavior as discrete, other models such as the Smooth Transition Autoregressive models (STAR) allow for a gradual transition from one regime to the next. The SETAR model can be approximated by the STAR model by adjusting for a smoothing parameter (Franses and van Dijk, 2000). In this research we focus on discrete regime transitions and leave the smooth transition models for further research. Specifically, the model we will explore considers two regimes, when the threshold variable is the Mopti vulnerability index we refer to these regimes as one of low vulnerability (Regime 1) and one of high vulnerability (Regime 2). The model is expressed as:

$$(5.3) \qquad y_t = \begin{cases} \varphi_{0,1} + \varphi_{1,1} y_{t-1} + \dots + \varphi_{p,1} y_{t-p} + \epsilon_t & \text{if } q_{t-i} \leq c, \\ \varphi_{0,2} + \varphi_{1,2} y_{t-1} + \dots + \varphi_{p,2} y_{t-p} + \epsilon_t & \text{if } q_{t-i} > c. \end{cases}$$

where i= 1,2,3,4. We estimate AR(p) models for a variety of nonlinear cases and select candidates based on an adjusted AIC criterion. One consideration in this research is that higher order dynamics (p>1) may be appropriate for the models under investigation. We assume, however, that the order of the autoregression is the same for each regime in a region, but that the order can differ from region to region. Tong (1990) defines an alternative AIC for a two- regime SETAR model as the sum of the two AICs for the AR(p) models in the two regimes, we use a version that assumes the lag order is the same for each region:

(5.4) $$AIC\,(p) = n_1 \ln \hat{\sigma}_1^2 + n_2 \ln \hat{\sigma}_2^2 + 4(p + 1)$$

where n_1 and n_2 are the number of observations in regime 1 and regime 2, respectively; and

$\hat{\sigma}_1^2$ and $\hat{\sigma}_2^2$ are the variance of the residuals for regime1 and regime 2, respectively. Even though ε_t is assumed to have the same variance across regimes, the estimates can differ.

The estimation of the two regime SETAR model involves sequential conditional least squares estimation of the parameters of interest which are

$\phi_{i,j}\ ,\ i = 0\ ,\ 1\ ,\ .....\ ,\ p\quad ,\ j = 1\ ,\ 2\ ;\ c\ ,\ \sigma^2$. Under the additional assumption of normally distributed innovations, the resulting estimates are equivalent to maximum likelihood estimates (Franses and van Dijk 2000). Parameter estimates $\hat{\phi}_{i,j}(\,c\,)$ are conditional on the threshold value. The corresponding residuals are denoted as $\hat{\varepsilon}_t(\,c\,) = y_t - \hat{\phi}(\,c\,)'\,x_t(\,c\,)$

where $\phi_j = (\,\phi_{0,j}\ ,\ \phi_{1,j},\ ....\ \phi_{p,j}\,)'$ j= 1,2 and $\phi = (\,\phi_1\ ,\ \phi_2\,)'$ with

$x_t = (1, y_{t-1}, \ldots, y_{t-p})'$. The variance is expressed as $\hat{\sigma}^2 = \frac{1}{n} \Sigma_{t=1}^{n} \hat{\varepsilon}_t(c)^2$.

The least squares estimate of c can be obtained by minimizing this residual variance, that is

(5.5) $$\hat{c} = argmin_{c \in C} \; \hat{\sigma}^2(c)$$

where C denotes the set of all possible threshold values. The final estimates of the autoregressive parameters are given by $\hat{\phi} = \hat{\phi}(\hat{c})$, while the residual variance is estimated as $\hat{\sigma} = \hat{\sigma}^2(\hat{c})$ (Franses and van Dijk 2000).

Direct search is used to solve the minimization problem in (7.6). Hansen (1997) derives a limiting distribution for threshold estimates that is free of nuisance parameters apart from a scale parameter. The estimates of the autoregressive parameters are consistent and asymptotically normal.

In constructing confidence intervals for c, Hansen (1997) suggest an approach that relies on the inversion of the likelihood ratio test-statistic to test the hypothesis that the threshold is equal to some specific value c_0, given by

(5.6) $$LR(c_0) = n \frac{(\hat{\sigma}^2(c_0) - \hat{\sigma}^2(\hat{c}))}{\hat{\sigma}^2}.$$

where the $100 * \alpha$ percentile of the asymptotic distribution of the LR-statistic, see Hansen (1997) for the percentiles for various values of α. The $100 * \alpha\%$ confidence interval for the threshold is given by the set $\hat{C}_\alpha$ consisting of those values of c for which the null hypothesis is rejected at significance level α. The set $\hat{C}_\alpha$ provides a valid confidence region since the probability that the true threshold value is contained in $\hat{C}_{\alpha}$ approaches α as the sample size becomes large (Franses and van Dijk 2000).

In the empirical analysis we also provide the asymptotic 95% confidence interval for the parameter. The estimates of the autoregressive parameters ϕ_1 and ϕ_2 are asymptotically normally distributed. For example, the asympototic 95% confidence interval for each parameter in Regime 1 is constructed as

$(\hat{\phi}_{1,p} - 1.96\hat{\sigma}_{1,p}\ ,\ \hat{\phi}_{1,p} + 1.96\hat{\sigma}_{1,p})$ where p is the lag order.

To account for proper asymptotic behavior a positive trimming percentage, the percentage of the observations to trim for the beginning and the end of the sample, is required (Hansen, 1992). The literature suggests a trimming percentage of 15%, this level is a rule of thumb figure rather than driven by rigorous investigation. The sample sizes used in this study are sufficiently small (n=135) such that a trimming percentage of 5% is selected in order to retain the maximum number of observations while meeting the appropriate restrictions.

An important question to answer in constructing regime switching models is whether the additional regime adds to explaining the dynamic behavior of y_t relative to the linear AR model. We must construct the linear AR(p) model and compare it to our two regime AR(p) models. Neglected heteroscedasticity may lead to spurious rejection of the null hypothesis of nonlinearity. Granger and Terasvirta (1993) and Franses and van Dijk suggest using specification tests developed by Wooldridge (1990, 1991) to create more robust linearity tests. Hansen (1997) outlines procedures to compute a heteroskedasticity-consistent (HCC) variant of the LM-type test-statistic against a SETAR alternative. After estimating the SETAR models with the threshold variable as the series and the alternative threshold of the Mopti vulnerability index, v_t ,this HCC test of linearity against the SETAR alternative is conducted for each of the candidate models.

In dealing with nonlinear models, traditional impulse response functions (TIRF) fail to capture the complex dynamics developed with threshold models. TIRFs are history independent, symmetric such that both negative and positive shocks provoke the similar responses in magnitude in a system and the linear nature creates a proportional response to an impulse. Nonlinear models require careful consideration in developing a framework for investigating the persistence of shocks to the system. For nonlinear models, impulse response functions are history dependent, asymmetric, and shocks are not proportional in response to an impulse. Many researchers have used generalized impulse response functions (GIRF) to explore the effect of shocks to SETAR models (Potter 1995, Koop et al 1996, Goodwin and Piggott 2001). The GIRF is a function of the shock and histories which are realizations of random variables. In the GIRF, the expectations of y_{t+h} are conditioned on the history and/or the shock to the system. In this study, the exogenous threshold variable, the Mopti vulnerability index, creates some additional and complex challenges in constructing the generalized impulse response functions which are beyond the scope of this research. Future research will explore the nonlinear impulse response functions for the models developed in this chapter.

5.4 Data and Preliminary Results

5.4.1 Univariate Analysis of Goat Prices

The first step in empirical analysis is the investigation of the univariate charactistics of the retail goat prices for each cercle. Descriptive statistics are presented in Table 5.1. Graphs of the series are presented in Figure 5.1 to Figure 5.5. Based on the ADF tests as outlined in Chapter 4, the retail price of goats appear to be nonstationary in each cercle (see Table .2). The null hypothesis of the presence of a unit root is not rejected. Similar tests were conducted on the first differences of the retail goat price series were found to be stationary ruling out integration of an order greater than one. Having established these characteristics, appropriate tests for cointegration between retail goat prices in Mopti and each cercle are conducted with results presented in the next section.

Table 5.1 Descriptive Statistics for Retail Goat Prices

Cercle	T	Min	Max	Mean	σ^2	Trend t_1= Predeval t_2= Postdeval	S.E.
Mopti	135	3,000	15,550	7,472.78	9,145,065	t_1= -54.65*** t_2= 76.97***	1711.61
DJenne	135	2,500	12,900	6,281.74	5,504,399	t_1= -36.15*** t_2= 72.92***	1393.50
Douentza	135	2,000	15,000	6,128.04	7,030,163	t_1= -49.86*** t_2= 59.06***	1654.42
Tenenkou	135	3,375	12,500	6,731.11	5,056,069	t_1= -31.87*** t_2= 62.84***	1483.79
Youvarou	135	2,420	9,875	5,497.99	3,262,388	t_1= -21.38*** t_2= 51.15***	1341.64

*, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.
Predeval and Postdeval refer to pre-devaluation and post-devaluation, respectively
S.E: refers to standard error of the regression

Table 5.2 **Results from Augmented Dickey-Fuller Test of the Null Hypothesis of Non-Stationarity for Goat Prices in Mopti Region**

Number of Lags	Mopti		DJenne		Douentza		Tenenkou		Youvarou	
	ADF	Root Value	ADF	Root Value	ADF	Root Value	ADF	Root Value	ADF	Root Value
2	-2.64	-.108	-2.04	-.102	-2.59	-.132	-2.56	-.139	-2.80	-.184
4	-2.29	-.0978	-2.07	-.108	-1.86	-.092	-2.28	-.131	-2.14	-.144
8	-2.39	-.110	-1.85	-.101	-1.76	-.0934	-1.90	-.118	-2.43	-.171
10	-1.97	-.0935	-1.88	-.106	-1.82	-.0985	-2.71	-.167	-2.43	-.178
12	-1.72	-.0837	-2.13	-.121	-1.76	-.0989	-2.48	-.165	-2.17	-.170

*, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

Figure 5.1 Mopti: Retail Goat Price

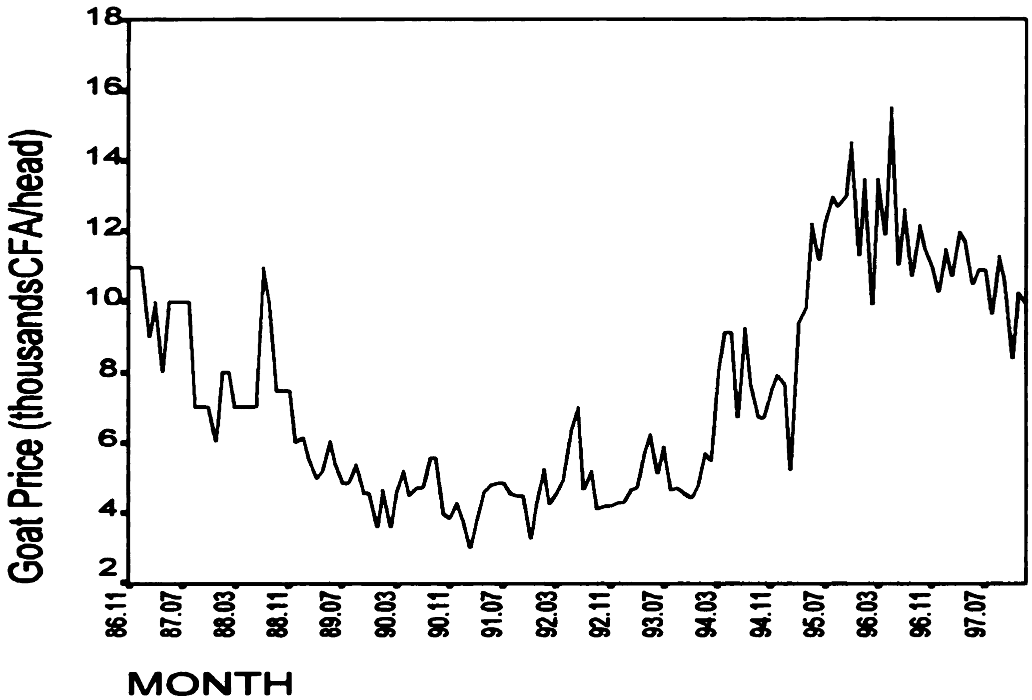


Figure 5.2 DJenne: Retail Goat Price

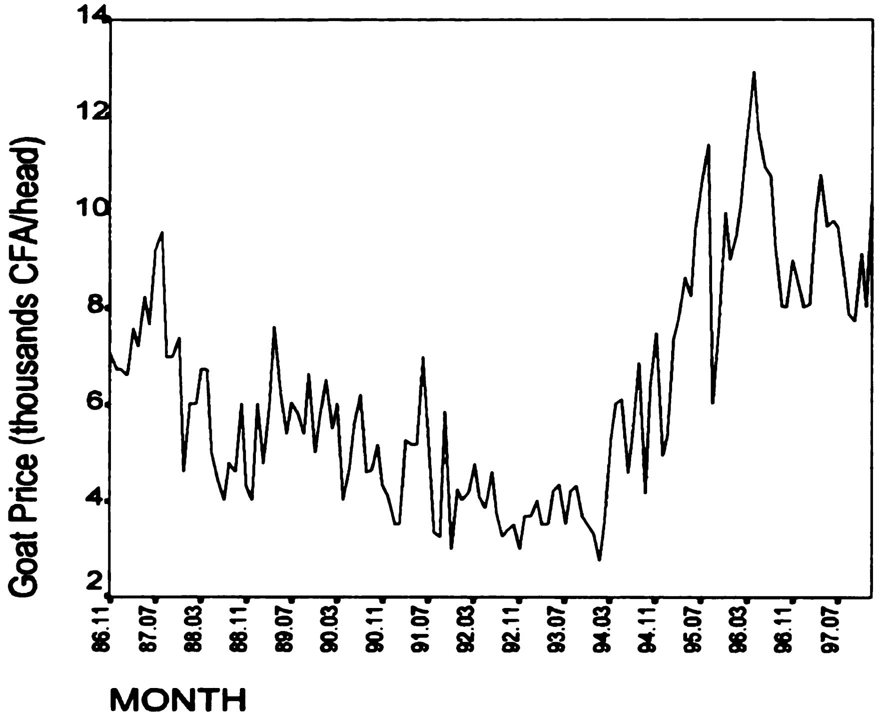


Figure 5.3 Douentza: Retail Goat Price

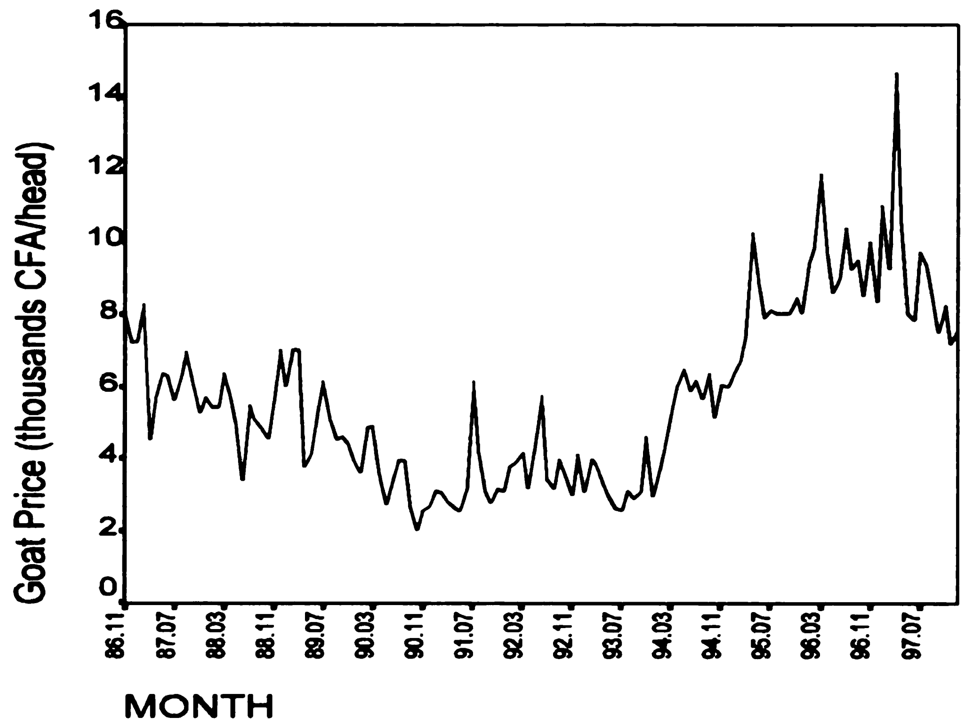


Figure 5.4 Tenenkou: Retail Goat Price

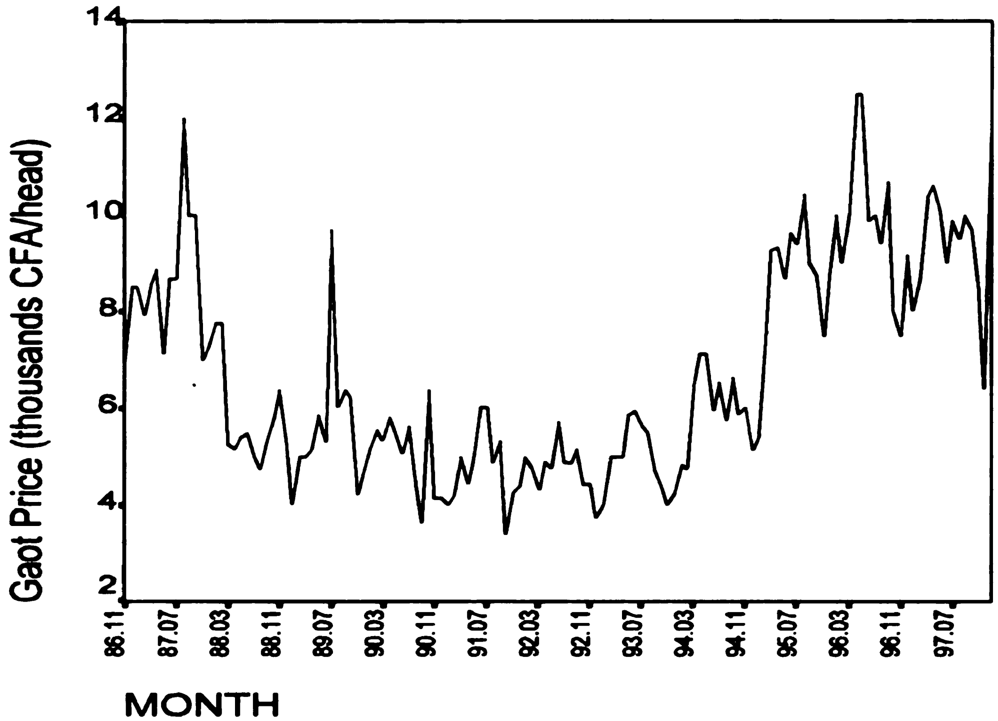
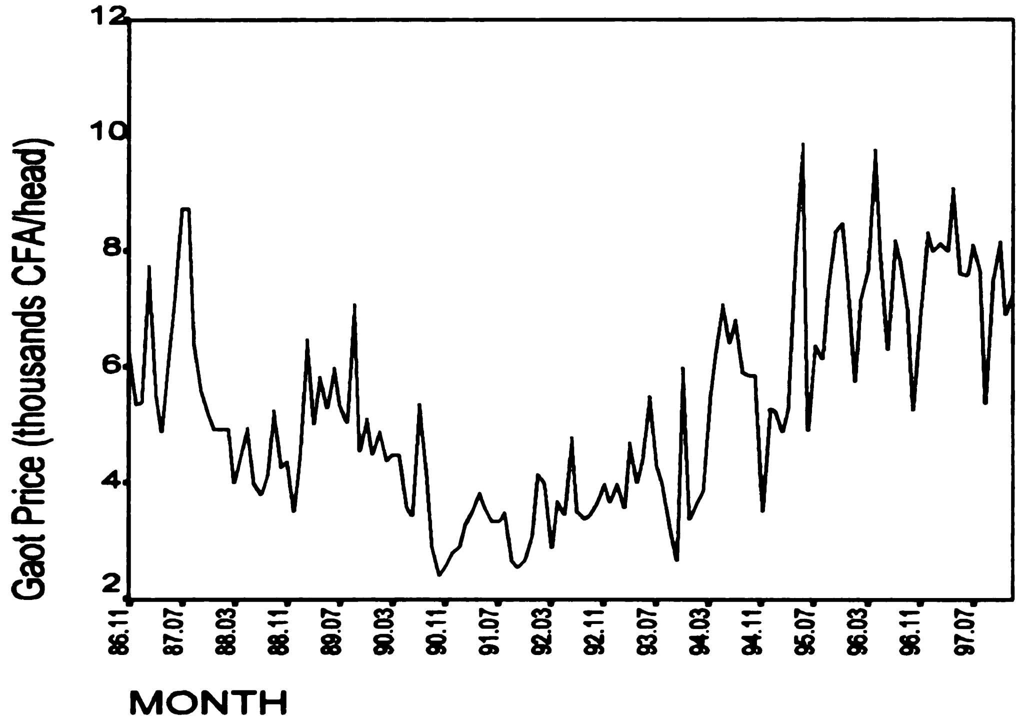


Figure 5.5 Youvarou: Retail Goat Price



Empirical Analysis

5.4.2 Cointegration Tests of Retail Goat Prices in Mopti Region

Four goat market interactions are examined in Mopti: Mopti-DJenne, Mopti-Douentza, Mopti-Tenenkou, and Mopti-Youvarou. We apply Engle and Granger's two step method for testing cointegration and first perform OLS on:

$$(5.7) \quad P_t^{Mopti} = \alpha + \beta P_t^i + \varepsilon_t$$

where P_t^{Mopti} represents the retail goat price for Mopti Cercle, the central market and the retail goat price for the peripheral markets is depicted by P_t^i in each cointegrating regression. The results are presented in Table 5.3.

We then conduct three procedures for testing cointegration: the Johansen maximum eigenvalue and trace tests (Johansen ,1988), the Hansen L_c test (Hansen, 1992) , and the Phillips-Ouliaris P_z test (Phillips and Ouliaris, 1990). The results are reported in Table 5.4. The maximum eigenvalue test has as its null hypothesis that ther are r+1 cointegrating vectors with an alternative hypothesis that there are r cointegrating vectors.

The trace test has as its null hypothesis that there are r cointegrating vectors. We find that the results of these Johansen tests provide evidence of one cointegrating vector for all four regions under investigation. The trace tests for Mopti-Djenne and Mopti-Tenenkou for the test of r=0 do not reject the null hypothesis of no cointegrating vectors. Johansen and Juselius (1990) suggest that the maximum eigenvalue test may be more reliable than the trace test. The maximum eigenvalues tests supports the existence of one cointegrating vector for the two regions. Therefore, we find support for the existence of one cointegration vector in Mopti-DJenne and Mopti-Youvarou.

The Hansen L_c test, originally developed to test parameter stability, provides a test of the null hypothesis of cointegration, a hypothesis which is not rejected for all regions. The L_c is asymptotically robust to heteroskedasticity; its variance matrix is exactly the central component in the heteroskedasticity-robust covariance matrix of White (White 1980, Hansen 1992). The Phillips-Ouliaris P_Z test, tests the null hypothesis of no cointegration, this null hypothesis is rejected for all regions.

To examine the Law of One Price we conduct an LR test where the null hypothesis that $\alpha = 0$ and $\beta = 1$. The results are reported in Table 5.4. The null hypothesis is rejected for all regions. The null hypothesis implies that transactions cost are proportional and invariant with respect to price. This rules out risk premia and other factors as Goodwin and Piggott (2000) note. They further remark that the rejection of the null in these tests is not surprising and should not be taken as evidence against integration. These results are consistent with the results in the following section. In particular, threshold effects would not be consistent with the Law of One Price. With a threshold model, each regime has characteristics distinct from other regimes. Thus, these regimes could depict differences in transactions costs and risk premia which are clearly in violation of the Law of One Price.

Table 5.3 Results from Cointegration Regression Goat Prices between Mopti Markets

$P_t^{Mopti} = \alpha + \beta P_t^i + \varepsilon_t$ (i=Peripheral Markets: DJenne, Douentza, Tenenkou, Youvarou)

Markets	α	β	R^2
Mopti-DJenne	.960 (.443)	1.041 (.066)	.650
Mopti-Douentza	1.491 (.363)	1.040 (.058)	.707
Mopti-Tenenkou	.007 (.486)	1.103 (.069)	.660
Mopti-Youvarou	.502 (.517)	1.310 (.092)	.604

Standard errors for parameter estimates are in parentheses

Table 5.4 Cointegration Testing Results

Markets	Test	Test Statistic
Mopti-DJenne	Max Eigen Value Test: r=0	12.17**
	Trace Test: r=0	11.36
	Max Eigen Value and Trace Test: r=1	0.0875
	Hansen L_c Statistic	0.2887
	P_Z Test	110.77**
	LR Test of α= 0 and β=1	31.22***
Mopti-Douentza	Max Eigen Value Test: r=0	23.26**
	Trace Test: r=0	22.06**
	Max Eigen Value and Trace Test: r=1	1.210
	Hansen L_c Statistic	0.2260
	P_Z Test	123.72**
	LR Test of α= 0 and β=1	74.08***
Mopti-Tenenkou	Max Eigen Value Test: r=0	24.62**
	Trace Test: r=0	24.27**
	Max Eigen Value and Trace Test: r=1	0.3562
	Hansen L_c Statistic	0.4549
	P_Z Test	129.81**
	LR Test of α= 0 and β=1	13.84***
Mopti-Youvarou	Max Eigen Value Test: r=0	14.48**
	Trace Test: r=0	13.89
	Max Eigen Value and Trace Test: r=1	0.5931
	Hansen L_c Statistic	0.1452
	P_Z Test	131.63**
	LR Test of α= 0 and β=1	92.11***

*, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.
The maximum Eigenvalue and Trace tests are Johansen cointegration tests critical values are drawn from Maddala and Im (2000). The L_c test is a test with the null of cointegration from Hansen (1992). The P_z is the Phillips-Ouliaris (1990) cointegration test with the the null hypothesis of no cointegration.

Based on these results, we go on to investigate whether or not there is evidence of nonlinearities in the cointegrating relationships. Hansen's approach is revisited in constructing confidence intervals for threshold parameters in the TAR framework.

Figures 5.6 through 5.9 provide a graphs of the residuals from the cointegrating regressions along with the Mopti vulnerability index.

Figure 5.6 Mopti Vulnerability Index and residuals from Cointegrating Regression, Mopti and DJenne Retail Goat Prices

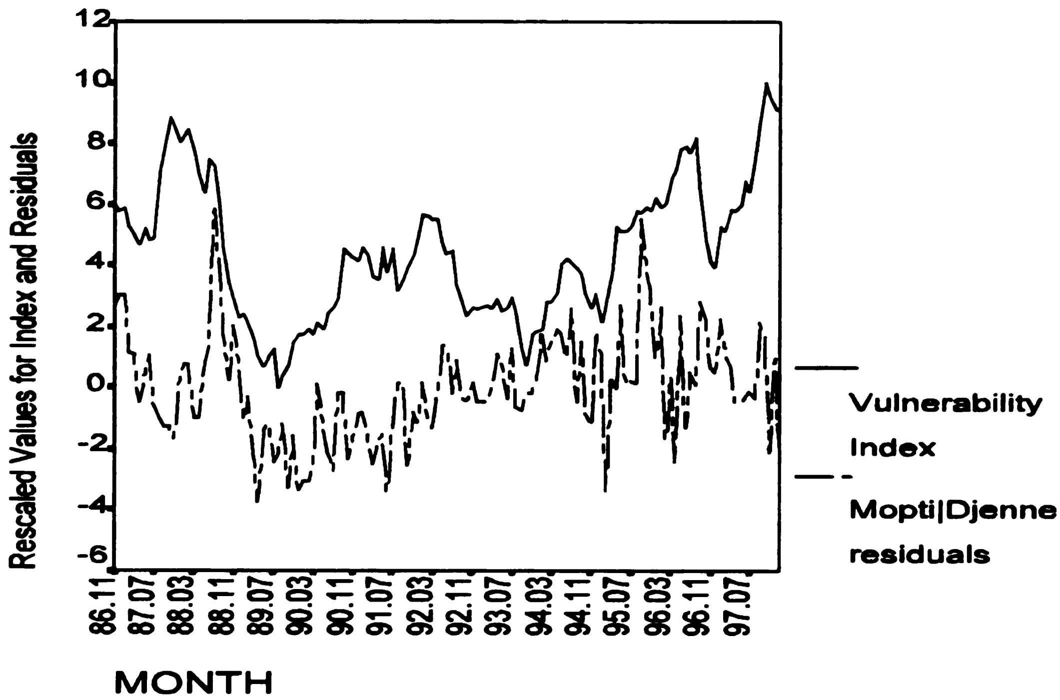


Figure 5.7 Mopti Vulnerability Index and residuals from Cointegrating Regression, Mopti and Douentza Retail Goat Prices

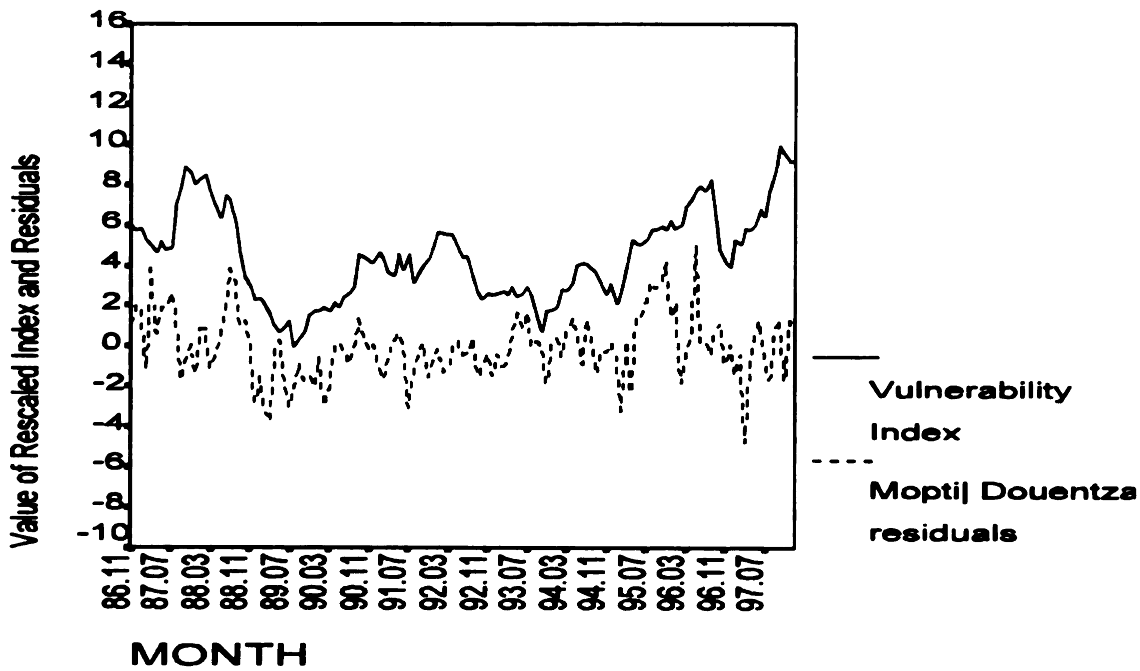


Figure 5.8 Mopti Vulnerability Index and residuals from Cointegrating Regression, Mopti and Tenenkou Retail Goat Prices

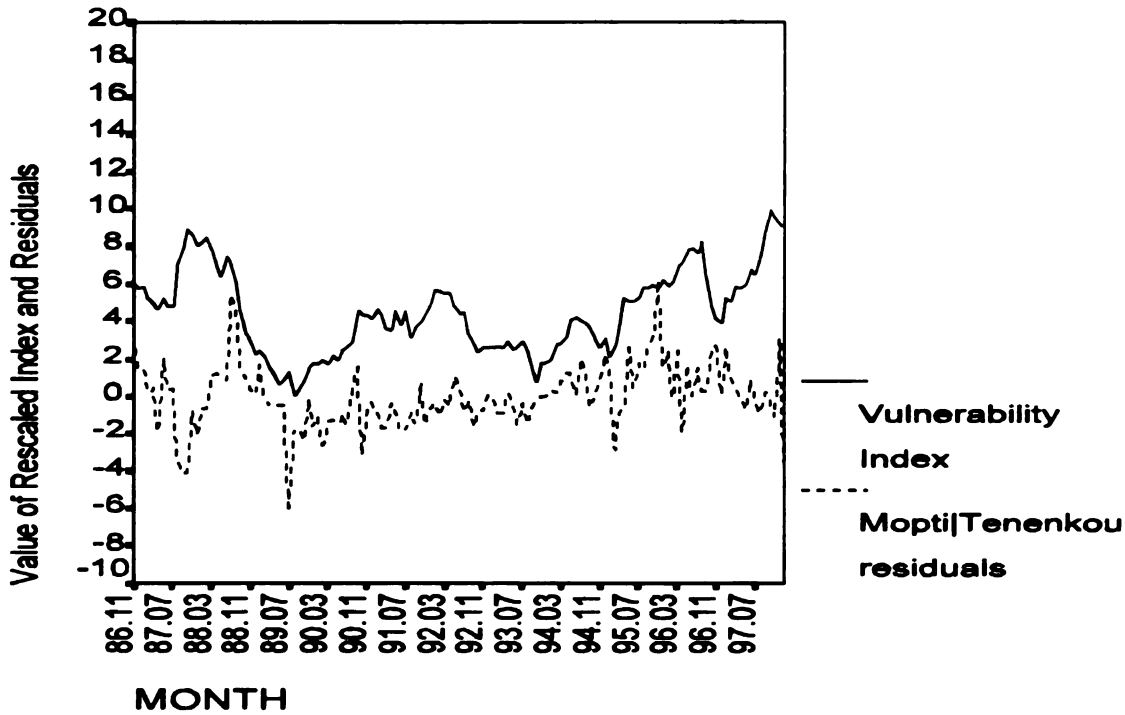


Figure 5.8 Mopti Vulnerability Index and residuals from Cointegrating Regression, Mopti and Tenenkou Retail Goat Prices

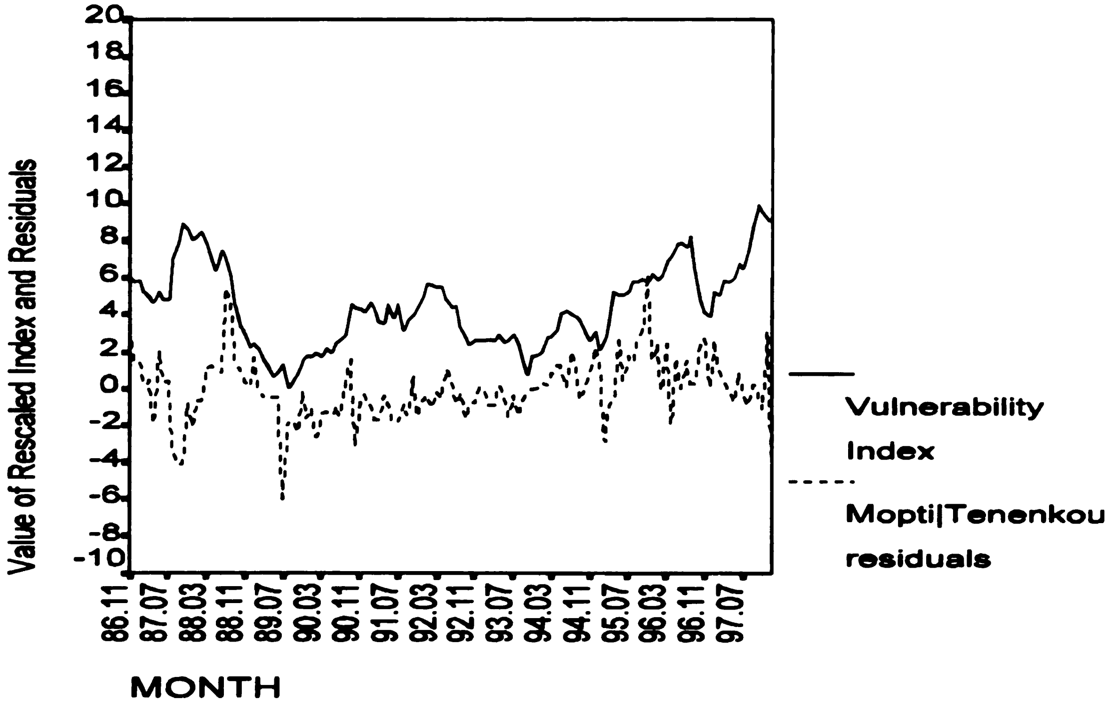
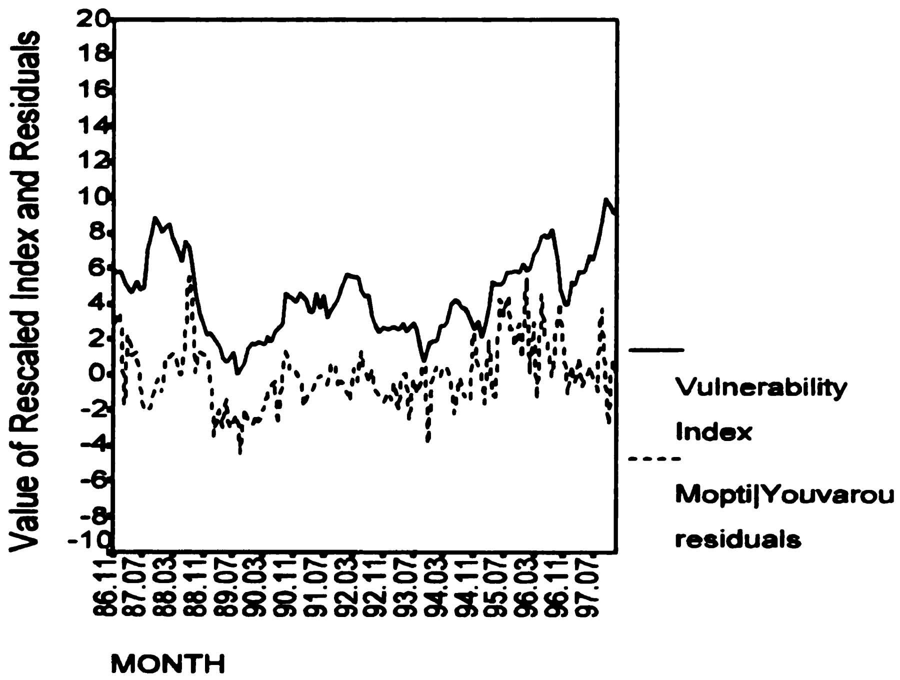


Figure 5.9 Mopti Vulnerability Index and residuals from Cointegrating Regression, Mopti and Youvarou Retail Goat Prices



5.5 Empirical Results

In the first part of this section we present the empirical results from estimation of the threshold cointegration models for the four market relationships in the Region of Mopti. The second part provides a broader discussion of this investigation into regimes shifts in Mopti goat markets.

5.5.1 Empirical Results

Mopti-DJenne

Tables 5.5 through 5.7 present the results of model estimation of threshold cointegration models for the goat markets in DJenne and Mopti. We found the AIC criterion (Table 5.5) to suggest the best model as one where the threshold variable is the vulnerability index lagged two periods, v_{t-2}, and an AR(3) structure. The HCC test results in Table 5.6 suggests that the null of no threshold effect, a linear alternative, is strongly rejected. The estimates of the model parameters are found in Table 5.7. The value of the threshold level was estimated as 4.87 such that a regime of low vulnerability is defined as occurring where $v_{t-2} < 4.87$; and a regime of high vulnerability to food insecurity occurs above this threshold value. As the threshold variable, the vulnerability index is lagged two periods implying that the regime shift is triggered in time t by the vulnerability conditions two periods prior. The AR(3) model is stationary in both regimes. The constant terms in the regimes are of opposite sign. This suggests that possibly the transactions costs or risk premiums in the two regimes differ. One would expect the transportation costs between markets to increase in vulnerable periods. Further, this also suggests a tendency of retail goat prices in the central market to be relatively higher in periods of high vulnerability and lower in periods of low vulnerability. This result is consistent with the value of the asset diminishing in periods of crisis as households sell off their goats and other assets in order to mitigate food security crisis in the short run.

Table 5.5 ***AIC values for SETAR models for cointegrating relationship between Mopti and DJenne Goat Prices***

Threshold Variable	*p (lag length for AR)*					
	0	1	2	3	4	5
y_{t-1}	117.99	110.56	110.14	113.84	111.34	116.06
y_{t-2}	121.33	98.76	109.48	113.84	111.84	110.58
y_{t-3}	137.09	106.36	100.03	110.02	98.86	101.86
y_{t-4}	119.21	97.04	103.80	107.50	104.41	102.12
v_{t-1}	127.10	104.96	105.61	98.25	100.22	104.48
v_{t-2}	128.19	107.99	108.26	94.85	97.23	103.11
v_{t-3}	135.27	108.73	108.15	99.15	97.98	102.89
v_{t-4}	131.33	108.96	110.60	102.82	103.37	107.86

Table 5.6 ***p-values for HCC test of linearity against a SETAR alternative for the cointegrating relationship between Mopti and DJenne Goat Prices***

Threshold Variable	*p* (lag order)					
	0	1	2	3	4	5
y_{t-1}	0.000	0.430	0.472	0.056	0.134	0.142
y_{t-2}	0.000	0.021	0.155	0.291	0.650	0.459
y_{t-3}	0.002	0.022	0.013	0.024	0.014	0.014
y_{t-4}	0.000	0.001	0.003	0.014	0.000	0.000
v_{t-1}	0.000	0.004	0.053	0.023	0.035	0.048
v_{t-2}	0.000	0.006	0.098	0.004	0.002	0.006
v_{t-3}	0.000	0.132	0.505	0.005	0.004	0.009
v_{t-4}	0.001	0.035	0.350	0.092	0.062	0.013

5.7 SETAR estimates for the cointegrating relationship between Mopti and DJenne Goat Prices

		Confidence Intervals (95%)			
		Asymptotic		LR Statistic	
Variable	**Estimate**	**Low**	**High**	**Low**	**High**
Regime1 $v_{t-2} \leq \hat{c}$ (80 obs.)					
Constant	-0.294	-0.572	-0.016	-0.575	-0.007
y_{t-1}	0.336	0.150	0.522	0.136	0.495
y_{t-2}	0.008	-0.213	0.229	-0.189	0.229
y_{t-3}	0.342	0.121	0.563	0.115	0.599
Regime 2 $v_{t-2} > \hat{c}$ (50 obs.)					
Constant	0.449	0.004	0.894	-0.0179	0.944
y_{t-1}	0.362	0.121	0.603	0.146	0.581
y_{t-2}	0.291	0.058	0.582	0.0769	0.547
y_{t-3}	-0.390	-0.645	-0.135	-0.678	-0.140
Threshold	**4.87**			4.57	5.74

Mopti-Douentza

Tables 5.8 through 5.10.1 to 5.10.3 present the results of model estimation of threshold cointegration models for the goat markets in Douentza and Mopti. We found the AIC criterion (Table 5.8) to suggest the best model as one where the threshold variable is the residual series itself (with an AR(0) structure) along with two other models where vulnerability index lagged three or four periods, v_{t-3} and v_{t-4}, and an AR(1) structure are compelling candidates as well. The HCC test results in Table 5.9 suggests that the null of no threshold effect, a linear alternative, is strongly rejected for all three of these models. The estimates of the model parameters are found in Tables 5.10.1 to 5.10.3. For the first candidate (Table 5.10.1), the threshold variable was selected as y_{t-1} and the structure of the model in each regime was just a constant term, this is a pure SETAR model: the threshold variable is the series itself. The sign of the constant term in the model for the low vulnerability regime, Regime 1, is negative; while that in the high vulnerability regime, Regime 2, is positive. The reasoning outlined for Mopti-DJenne is consistent for the three models presented for Mopti-Douentza. It is easy to envision the regime switching behavior in this framework. A discrete jump from one value (the constant term in each regime) to the next is triggered by the value of the series in the previous period.

The model candidates that present the threshold variable as the lagged vulnerability index are now examined (Tables 5.10.2 and 5.10.3). The value of the threshold level was estimated as 4.88 such that a regime of low vulnerability is defined as occurring where $v_{t-4} < 4.88$; ,$v_{t-3} < 4.88$; and a regime of high vulnerability to food insecurity occurs above this threshold value. The models for each regime are AR(1), stationary, with parameter estimates for the autoregressive terms very similar among regimes. As in the case of DJenne, the constant terms in the regimes are of opposite sign. This suggests that possibly the transactions costs or risk premiums in the two regimes differ. One would expect the transportation costs between markets to increase in vulnerable periods. Similarly, the sell off of asserts as vulnerability to food insecurity could be taking place. Recall that Douentza is the most active trading partner in livestock with the central market, Mopti, of the regions studies in this research. The results from this investigation seem to suggest that there are threshold effects but that the adjustment process is similar in each regime. The level of the vulnerability index lagged three or four periods is providing the information concerning the regime shift in time t. This may indicate that this information could be useful in detecting opportunities for intervention that could stabilize this asset market in order to deter household from selling off their wealth in times of crisis.

Table 5.8 ***AIC values for SETAR models for cointegrating relationship between Mopti and Douentza Goat Prices***

Threshold Variable	*p* (lag length for AR)					
	0	1	2	3	4	5
y_{t-1}	85.44	88.30	93.63	97.80	106.40	112.85
y_{t-2}	101.05	88.92	94.22	99.98	105.87	112.18
y_{t-3}	117.43	97.72	102.32	107.53	106.80	113.15
y_{t-4}	116.83	97.05	92.56	100.04	104.84	103.49
v_{t-1}	105.15	90.22	94.30	99.93	96.86	103.01
v_{t-2}	100.89	90.27	93.45	99.54	103.95	109.02
v_{t-3}	100.41	88.29	97.58	102.87	101.94	107.48
v_{t-4}	98.813	88.67	94.13	99.96	105.56	110.48

Table 5.9 ***p-values for HCC test of linearity against a SETAR alternative for the cointegrating relationship between Mopti and Douentza Goat Prices***

Threshold Variable	*p* (lag length for AR)					
	0	1	2	3	4	5
y_{t-1}	0.000	0.014	0.084	0.087	0.178	0.238
y_{t-2}	0.000	0.012	0.131	0.242	0.483	0.639
y_{t-3}	0.016	0.713	0.991	0.975	0.500	0.399
y_{t-4}	0.283	0.771	0.619	0.107	0.181	0.135
v_{t-1}	0.000	0.007	0.045	0.086	0.177	0.247
v_{t-2}	0.001	0.013	0.042	0.142	0.277	0.339
v_{t-3}	0.000	0.059	0.126	0.315	0.533	0.507
v_{t-4}	0.000	0.001	0 023	0.094	0.179	0.301

5.10.1 SETAR estimates for the cointegrating relationship between Mopti and Douentza Goat Prices

		Confidence Intervals (95%)			
		Asymptotic		LR Statistic	
Variable	**Estimate**	**Low**	**High**	**Low**	**High**
Regime1 $y_{t-1} \leq \hat{c}$ (83 obs.)					
Constant	-0.675	-0.942	-0.408	-0.900	-0.400
Regime 2 $y_{t-1} > \hat{c}$ (47 obs.)					
Constant	1.020	0.570	1.470	0.580	1.49
Threshold	**0.305**			0.238	0.437

5.10.2 SETAR estimates for the cointegrating relationship between Mopti and Douentza Goat Prices

		Confidence Intervals (95%)			
		Asymptotic		LR Statistic	
Variable	**Estimate**	**Low**	**High**	**Low**	**High**
Regime1 $v_{t-3} \leq \hat{c}$ (81 obs.)					
Constant	-0.374	-0.648	0.100	-1.99	0.178
y_{t-1}	0.332	0.116	0.548	-0.469	0.690
Regime 2 $v_{t-3} > \hat{c}$ (49 obs.)					
Constant	0.449	0.002	0.896	-0.897	1.061
y_{t-1}	0.391	0.175	0.607	-1.00	0.618
Threshold	**4.88**			1.05	8.24

5.10.3 SETAR estimates for the cointegrating relationship between Mopti and Douentza Goat Prices

		Confidence Intervals (95%)			
		Asymptotic		LR Statistic	
Variable	**Estimate**	**Low**	**High**	**Low**	**High**
Regime1 $v_{t-4} \leq \hat{c}$ (81 obs.)					
Constant	-0.438	-0.750	-0.126	-0.723	-0.0816
y_{t-1}	0.329	0.098	0.560	0.131	0.598
Regime 2 $v_{t-4} > \hat{c}$ (49 obs.)					
Constant	0.592	0.228	0.956	0.176	0.899
y_{t-1}	0.331	0.138	0.524	0.141	0.521
Threshold	**4.88**			4.30	5.98

Mopti-Tenenkou

Tables 5.11 through 5.13 present the results of model estimation of threshold cointegration models for the goat markets in Tenenkou and Mopti. We found the AIC criterion (Table 5.11) to suggest the best model as one where the threshold variable is the vulnerability index lagged two periods, v_{t-1} , and an AR(3) structure. The HCC test results in Table 5.12 suggests that the null of no threshold effect, a linear alternative, is strongly rejected. The estimates of the model parameters are found in Table 5.13. The value of the threshold level was estimated as 5.09 such that a regime of low vulnerability is defined as occurring where $v_{t-1} < 5.09$; and a regime of high vulnerability to food insecurity occurs above this threshold value. The constant terms in the regimes are of opposite sign. This suggest that possibly the transactions costs or risk premiums in the two regimes differ. One would expect the transportation costs between markets to increase in vulnerable periods.

Recall that Tenenkou is a relatively wealthier area than Djenne, Douentza, and Youvarou. There are other economic activities in the region beyond trade in goats and other livestock. This may provide more resilence in vulnerable periods than in other regions such that households are less prone to selling off their assets until later in crisis periods. Perhaps this is the reflected in the higher value of the level of the threshold variable that triggers regime shifts and the shorter lag on the variable itself.

Table 5.11 *AIC values for SETAR models for cointegrating relationship between Mopti and Tenenkou Goat Prices*

Threshold Variable	*p* (lag length of AR)					
	0	1	2	3	4	5
y_{t-1}	124.19	119.06	113.61	122.05	122.14	113.01
y_{t-2}	127.14	119.61	120.86	127.11	123.80	106.93
y_{t-3}	132.38	114.91	111.43	117.02	121.15	119.56
y_{t-4}	128.05	113.91	114.38	112.79	121.89	128.19
v_{t-1}	129.07	111.38	106.69	107.30	113.92	125.75
v_{t-2}	129.46	121.26	112.43	118.18	119.32	107.98
v_{t-3}	127.41	115.12	113.67	116.53	117.58	119.34
v_{t-4}	130.60	114.51	111.42	119.66	122.41	118.59

Table 5.12 *p-values for HCC test of linearity against a SETAR alternative for the cointegrating relationship between Mopti and Tenenkou Goat Prices*

Threshold Variable	***p* (lag length of AR)**					
	0	1	2	3	4	5
y_{t-1}	0.000	0.842	0.982	0.689	0.860	0.850
y_{t-2}	0.000	0.029	0.726	0.925	0.994	0.483
y_{t-3}	0.000	0.255	0.830	0.427	0.647	0.971
y_{t-4}	0.000	0.037	0.572	0.140	0.275	0.411
v_{t-1}	0.000	0.141	0.060	0.001	0.008	0.011
v_{t-2}	0.002	0.163	0.426	0.024	0.086	0.051
v_{t-3}	0.000	0.087	0.093	0.026	0.111	0.023
v_{t-4}	0.000	0.046	0.132	0.034	0.094	0.029

5.13 SETAR estimates for the cointegrating relationship between Mopti and Tenenkou Goat Prices

		Confidence Intervals (95%)			
		Asymptotic		**LR Statistic**	
Variable	**Estimate**	**Low**	**High**	**Low**	**High**
Regime1 $v_{t-1} \leq \hat{c}$ (83 obs.)					
Constant	-0.265	-0.532	0.002	-0.583	-0.0043
y_{t-1}	0.299	0.166	0.432	0.156	0.441
y_{t-2}	0.042	-0.087	0.171	-0.114	0.163
y_{t-3}	0.174	0.035	0.313	-0.021	0.332
Regime 2 $v_{t-1} > \hat{c}$ (47 obs.)					
Constant	0.360	-0.132	0.852	-0.116	0.774
y_{t-1}	0.316	-0.105	0.636	-0.0532	0.670
y_{t-2}	0.557	0.296	0.818	0.310	0.776
y_{t-3}	-0.240	-0.491	0.011	-0.451	0.420
Threshold	**5.09**			4.41	8.52

Mopti-Youvarou

Tables 5.14 through 5.16 present the results of model estimation of threshold cointegration models for the goat markets in Youvarou and Mopti. We found the AIC criterion (Table 5.14) to suggest the best model as one where the threshold variable is the vulnerability index lagged two periods, v_{t-3}, and an AR(1) structure. The HCC test results in Table 5.15 suggests that the null of no threshold effect, a linear alternative, is strongly rejected. The estimates of the model parameters are found in Table 5.16. The value of the threshold level was estimated as 5.25 such that a regime of low vulnerability is defined as occurring where $v_{t-3} < 5.25$; and a regime of high vulnerability to food insecurity occurs above this threshold value. The constant terms in the regimes are of opposite sign. This suggests that possibly the transactions costs or risk premiums in the two regimes differ. One would expect the transportation costs between markets to increase in vulnerable periods. However, Youvarou may experience especially low trading volume in highly vulnerable periods relative to the other areas which may account for the larger differential between the estimates of the constant terms in each regime.

Table 5.14 ***AIC values for SETAR models for cointegrating relationship between Mopti and Youvarou Goat Prices***

Threshold Variable	*p (lag length of AR)*					
	0	1	2	3	4	5
y_{t-1}	136.24	136.49	120.60	124.76	127.66	131.35
y_{t-2}	147.52	124.16	125.27	129.45	130.05	134.73
y_{t-3}	143.07	125.60	119.77	131.05	133.39	138.76
y_{t-4}	141.00	119.76	118.64	123.33	126.89	133.66
v_{t-1}	133.50	123.93	115.24	123.68	127.41	131.65
v_{t-2}	127.05	118.96	120.92	114.23	121.95	126.77
v_{t-3}	109.94	105.97	107.75	113.04	113.05	116.44
v_{t-4}	122.57	116.19	118.65	123.14	119.25	120.42

Table 5.15 ***p-values for HCC test of linearity against a SETAR alternative for the cointegrating relationship between Mopti and Youvarou Goat Prices***

Threshold Variable	*p (lag length of AR)*					
	0	1	2	3	4	5
y_{t-1}	0.000	0.354	0.152	0.034	0.080	0.016
y_{t-2}	0.000	0.011	0.194	0.431	0.521	0.335
y_{t-3}	0.000	0.002	0.028	0.326	0.877	0.699
y_{t-4}	0.000	0.041	0.185	0.317	0.333	0.346
v_{t-1}	0.000	0.000	0.014	0.026	0.167	0.165
v_{t-2}	0.000	0.000	0.010	0.013	0.078	0.118
v_{t-3}	0.000	0.000	0.001	0.002	0.004	0.001
v_{t-4}	0.000	0.000	0.012	0.008	0.002	0.011

5.16 SETAR estimates for the cointegrating relationship between Mopti and Youvarou Goat Prices

		Confidence Intervals (95%)			
		Asymptotic		LR Statistic	
Variable	**Estimate**	**Low**	**High**	**Low**	**High**
Regime1 $v_{t-3} \leq \hat{c}$ (86 obs.)					
Constant	-0.442	-0.754	-0.130	-0.841	-0.158
y_{t-1}	0.489	0.273	0.705	0.193	0.675
Regime 2 $v_{t-3} > \hat{c}$ (44 obs.)					
Constant	1.145	0.518	1.772	0.455	1.70
y_{t-1}	0.089	-0.160	0.338	-0.160	0.403
Threshold	**5.25**			4.83	5.27

5.5.2 Implications of Threshold Cointegration Results and Market Integration in Mopti Region

Overall, there is strong evidence of threshold effects in the cointegrating relationships for goat prices in each Mopti goat market investigated in this study. The level of the vulnerability index that delineates the two regimes is near 5 (on a scale from 0 to 10, which is scaled up by a factor of 10 from those developed in Chapter 4) or higher which supports the intuition behind the vulnerability index. The consistent and significant difference between the two regimes appears to be the estimate of the constant term for each region which is negative in the low vulnerability regime and positive in the high vulnerability regime. This suggests that the difference may be capturing the disparity in transactions costs in the two regimes. In addition, the negative constant term suggests that the retail goat price in Mopti, the central market, tends to be lower in periods of lower vulnerability to food insecurity than in periods of high vulnerability. This implies that if goats are viewed as an asset, their value is diminished in periods of high vulnerability relative to periods of low vulnerability, which is consistent with the behavior of selling off assets to mitigate food insecurity. Further, the results may reflect low trading volumes or in thin markets at times of high vulnerability. The structure of the regime shift depicts a discrete jump. The sale of assets such as goats may unfold in such a manner that desperate sellers are forced to sell off more than is desired at sharply lower prices due to their low bargaining power. Once under a regime of high vulnerability to food insecurity, the Mopti markets could be characterized as 'lumpy asset markets'; this appears to be supported by this empirical investigation.

The use of an external threshold variable, the vulnerability index, adds a structural interpretation to this modeling of market integration. Traditional cointegration techniques would suggest that the there is a single regime and that there is a long run equilibrium relationship that prevails in each period. However, after viewing the relationship as nonlinear we find that a more compelling narrative unfolds that is consistent with economic theory. The existence of threshold effects explains why the Law of One Price fails to hold in light of evidence of cointegration. Cointegration required that transactions costs are bounded. The evidence, in particular the stationary expressions for the AR(p) models in each regime for each region, suggests that transactions costs are bounded but differ in the each vulnerability regime. The transition from one level of market integration to another is a jump triggered by the level of vulnerability. Future research might examine a smoother transition from one regime to the next.

Chapter 6
Conclusions and Policy Recommendations

6.1 Conclusions

Information empowers consumers, farmers, businesses, traders, policy makers, and investors when it is transformed into knowledge which is useful to constituents. This investigation builds on the work done by researchers at SIM, SAP, and other information systems as well as through cooperative efforts at universities and government agencies. This dissertation contributes to the knowledge base by exploring the development and application of measures of vulnerability to food insecurity, drawing from current and past research of FEWS and SAP in Mali. This research creates a reference cycle and a single index of vulnerability to food insecurity, incorporating both qualitative and quantitative indicators of food insecurity. In addition, a framework is developed to incorporate these indexes in the analysis of market integration. Specifically, the research outcomes include: 1) construction of a food security vulnerability index and evaluation of its effectiveness in depicting the state of vulnerability to food insecurity for regions in Mali using NDVI and price data; 2) employment of robust econometric tests for market integration which are structural in nature and; 3) use of the vulnerability indicators in the construction of models of market integration to assess the impact of vulnerability on the degree and stability of market integration between regions.

6.1.1 The Single Index of Vulnerability to Food Insecurity

In the first part of the dissertation, indexes that capture the unobservable state of vulnerability to food insecurity were developed for eight regions in Mali: Gao, Mopti, Timbuktu, Segou, Djenne, Douentza, Tenenkou and Youvarou. These indexes were individually referenced to the qualitative information on food security conditions available in monthly reports by SAP. These qualitative vulnerability conditions include sharp increases in prices, low levels of food stuffs in the market, civil unrest, pest infestation, poor harvests and high levels of disease. The estimated indexes were displayed graphically along with these qualitative indicators to provide a visual representation of the pattern of vulnerability to food insecurity by region. The resulting indexes were not comparable across regions but provided an overview on a region by region basis. We found that the estimated vulnerability indexes captured the key turning points of vulnerability to food insecurity in the eight regions. These turning points, anchored in the index, typically occurred two to three months in advance of reports of conditions of moderate vulnerability in regions. In addition, the turning points were followed by moderate and then highly vulnerable conditions, in many cases. When food aid delivered in periods of moderate vulnerability mitigated worsening conditions, in general. The vulnerability mappings developed in the first part of this research provide a tool for detecting patterns of food security conditions and holds some potential as a tool in policy analysis.

While the spread and functioning of early warning systems in Africa is considered by many a success story in development, there persists a disconnect in early warning of vulnerability to food insecurity and response measures (Von Braun et al, 2000, Buchanan and Davies 1995, FEWS, 1998). One issue is that the information gathered and communicated to decision makers fails to evoke interventions or response to crisis because it can be perceived as subjective and viewed as less than conclusive. This research explores this aspect by providing a reproducible method for combining the early warning indicators which are relied upon by early warning analysts. The vulnerability indexes developed here provide a mechanism for assessing current vulnerability conditions in a dynamic framework, one can compare the severity of conditions within historical periods.

In this research, qualitative information from monthly SAP bulletins was used to construct reference cycles of vulnerability to food insecurity for eight regions in Mali. These assessments were used to characterize periods as: low, moderate, and high vulnerability. Compiling information in this manner provided a means by which to compare the qualitative information with the quanitative information in the form of vulnerability mappings. First, a key vulnerability indicator, millet prices, was transformed into smoothed millet price indexes for each region. This simple index served as a benchmark for evaluating the effectiveness of developing a more sophisticated index (composed of NDVI and millet prices), the single index of vulnerability to food insecurity.

Turning points in the indexes were compared to the reference cycles. If a turning point appeared in advance of moderate or highly vulnerable periods, this was viewed as a valuable feature of the index. Whether the level of the index distinguished among periods of low, moderate and high vulnerability was also a key feature upon which to evaluate the efficacy of the indexes.

Overall, we found the single index approach to capture the more dramatic shifts in vulnerability to food insecurity in Gao, Mopti, and Timbuktu. These turning shifts were confirmed by the reference cycles. The single index proved superior to the simple smoothed millet price index in the three regions providing early warning of vulnerability with one to three months lead times.

NDVI appears to have added significant value to the vulnerability index especially in regions where the trend in NDVI depicted a decline in crop greenness, this was the case in Gao, Timbuktu as well as Segou (see the appendix for Chapter 4). The simple index out-performed the more sophisticated index in regions dominated by livestock trading (Tenenkou and Youvarou).

6.1.2 Regime Shifts in Market Integration

The second part of the dissertation investigated the stability of markets with respect to the level of vulnerability to food insecurity. The goat markets in Mopti and surrounding cercles were investigated in terms of market integration. Departures from integration as revealed through price relationships in the region are assumed to stem from spatial arbitrage and transactions costs conditions. We examined the goat market in Mopti with Mopti cercle as the central market and Douentza, Djenne, Tenenkou and Youvarou (all cercles within the Mopti region) as peripheral markets. The goat markets were selected in order to explore the behavior in an important asset market (goats) during food secure and food insecure periods. As described in Chapter 4, a coping strategy to mitigate insecurity in its later stages is to sell off assets to purchase food. One would suspect that this behavior would be revealed in the price relationships between markets for goats in a region.

The vulnerability index for the central market was used as a threshold or indicator variable when exploring the stability of the spatial goat price relationships. This is an important innovation because it provides a structural approach to explaining the regime shifts. The vulnerability index serves as a structural trigger, depicting the state of vulnerability to food insecurity, that derives from economic logic and intuition rather that just being interpreted as a statistical phenomenon. We found that the cointegrating relationship between the goat market (reflected through goat prices) in Mopti and its surrounding regions exhibited nonlinearities that suggest the asset market performs differently under periods of vulnerability to food insecurity and more stable periods. Further, the Mopti vulnerability index served as an appropriate threshold variable such that regime shifts occurred at threshold values denoting a period of heightened vulnerability to food insecurity in all cases. The difference in the behavior of markets is attributable to a shift in transactions costs, a risk premium, spatial arbitrage and/or the implementation of coping strategies that includes the sell off of goats. The desperate sellers are trading under less that favorable conditions which may force them to sell more goats than desired at a low value just to insure that trade takes place. This could explain the discrete regime shift.

6.2 Policy Recommendations

"... the balance of short term and long term needs to be addressed as concern for people first is appropriate not only on ethical grounds, but also in terms of sound economics: appropriate relief represents a basic investment in human development"

(Von Braun et al 2000)

There has been an increasing tendency in the 1980's and 1990's on the part of international donors and African governments to focus on short term solutions rather than long term development. International organizations and the United States spent more on short term relief and peacekeeping operations than on development programs in the early 1990's (von Braun et al, 2000). By diminishing the focus on development orientation, the conditions that perpetuate vulnerability to food insecurity remain and are exacerbated. The ability of individuals and households to endure severe conditions and rebound afterward is diminished when faced with these circumstances without mechanisms to preserve their asset base and livelihoods.

Together, the qualitative and quantitative indexes capture the evolution of food security in the examined regions. This depiction may assist in policy analysis with regards to the development and targeting of strategies to ensure food security. In this new millennium, the challenge facing policy makers and donors is to develop an 'optimal policy mix that combines short and long term strategies (relief and development) in mutually reinforcing ways ' (Von Braun et al 2000). While this inquiry does not aim to define the 'optimal' policy mix, thinking about this research in its context as a tool with potential to assist decision makers in this quest may be helpful.

How does this research contribute to the development of such an optimal policy mix? By adding a method for exploring the process of vulnerability, providing a mapping of qualitative and quantitative measures to provide a dynamic presentation of vulnerability conditions. The resulting representations can highlight patterns. This capacity could contribute as a tool in developing a framework for public intervention that encompasses two dimensions: the *type* of policies and programs to implement and the *timing* of the implementation of these actions. The vulnerability mappings developed here provide a tool for exploring these dimensions on a region by region basis.

This research develops a framework for depicting the movements and adjustments from one regime of market integration, for example one of a high level of integration, to the next. The implications for early warning and response are clear with respect to targeting vulnerable areas and building on existing linkages to effectively respond in troubled locations. With the proper information flows, times of crisis have the potential to present entrepreneurial opportunities which could spill over to new economic activity in the region long after the initial period has passed. Thus, SAP would expand its ability to serve in a variety of capacities, including as a tool in regional planning and development.

The exploration of market integration in goat markets offers a tool to investigate the role of asset transfers and credit programs in the preservation of livelihoods. The vulnerability index for the central market serves as an indicator in turning points or regime shifts in the asset market, the market for goats. There is a point at which households choose to sell off their livestock and this typically follows a persistent deterioration in their most liquid assets. A sell off of livestock represents the relinquishing of their long term ability to maintain food security. There is a need in the early stages of a decline in food security of vulnerable households to intervene with short term and long term programs such as employment generation and credit programs to preserve livelihoods or to expand the choice set of vulnerable individuals. The methods developed in the second part of the dissertation can assist analysts in assessing the level of market integration and information flows and structuring institutional initiatives that promote food security and poverty alleviation.

Through augmenting analytical approaches, SAP and FEWS could also work more effectively and creatively with other existing and emerging information systems. The goal of developing a decentralized market information system is to "foster an efficient, timely, reliable, and donor-independent agricultural and food marketing system in Mali and strengthen the capacity of private and public sectors to use the resulting market information effectively to promote agribusiness growth and food security." (Dembélé and Staatz, 1999) SAP and external information systems are key parts of this vision and important partners in improving information flows as well as coordination of early warning activities and analysis in the region.

This research develops new methods for analyzing data currently archived and collected by existing famine early warning systems. Exploring new methods for examining this information and developing complementary tools for depicting vulnerability to food insecurity could shed light on the evolution of the processes that detract from secure livelihoods for individuals in many regions in Africa. It is hoped that this research will make such a contribution to early warning capacities and assist policy makers in constructing effective policy portfolios that combine relief activities and development oriented interventions.

6.3 Future Research

Future research could include the expansion of the number of indicators in the construction of the vulnerability indexes. Prices of other commodities, indicators of civil unrest, and other agroclimatic indicators could serve to create smoother vulnerability indexes with more well defined turning points. Other modeling approaches that address seasonality and other periodicities in the single-index model could also be explored. In addition, the development of techniques to model generalized impulse response functions that explore the dynamics of threshold models where the threshold variable is exogenous. This would contribute to better understanding of these models especially in the context of regime shifts in market integration.

APPENDIX CHAPTER THREE

A3.1 Regional Descriptions: Segou, DJenne, Douentza, Tenenkou, Youvarou

Segou

Segou is located along the Niger River about 240 km from Bamako. The Office du Niger, the organization promoting rice production in West Africa, is headquartered in Segou. Rainfall in the area averages 600 mm annually. Segou, along with Sikasso, is a major surplus producing region in cereals. SAP began to monitor this cercle in 1988.

DJenne

Located to the southwest of Mopti, DJenne is one of the oldest settled areas of West Africa. DJenne connects to Mopti by the Bani River. Annual rainfall is approximately 500 mm. DJenne was in its prime in the fourteenth and fifteenth centuries when it was a region profiting from trans-Saharan trade and inhabitants enjoyed high living standards. The Grand Mosquee of DJenne is a landmark of this picturesque area. Economic activity centers on trade in livestock and cereals.

Douentza

Douentza cercle lies east of Mopti Cercle and shares a borders with Timbuktu to its north. Douentza's average annual rainfall is about 450mm. According to Davies (1996), the importance of monitoring the region is that it is the frontier between transhumant pastorialism and millet cultivation. The regions agro-pastoral producers are some of the most vulnerable in agroecological terms. Recurrent drought have undermined livelihood security and is representative of other marginal areas for this reason. The main transport route, the paved road from Bamako to Gao, runs through Douentza. While trade has expanded little economic growth is evident in the cercle. Douentza is a main transit zone for Sahelian livestock moving to southern markets despite policy impediments devaluation of currency. Douentza has historically served as the first refuge of people from the northern areas in search of pasture and water.

Tenenkou

Tenenkou lies southwest of Mopti Cercle, north of DJenne and south of Youvarou and receives an average annual rainfall of 450mm. Tenenkou is a comparatively wealthy zone in the region, it attracts rural to rural migrants in search of paid work during the rice harvest and in fishing camps. Most transhumant pastoralists who rely on the Delta pastures travel through this cercle.

Youvarou

Youvarou is a microcosm of the Inner Niger Delta and the surrounding drylands. With average annual rainfall of 250 mm and the lakes areas of Debo and Walado, Youvarou Cercle is home to millet cultivation, agro-pastoralism, agro-fishing, transhumant fishing and transhumant pastoralism. Youvarou lies northwest of Mopti Cercle.

A3.2 Reference Cycle Mappings

In this section we present reference cycle summaries. Table A3.1 provides a summary of moderate and vulnerable periods for each region. Figures A3.2.1 through A3.2.5 present a graphical representation of these reference cycles.

Table A3.1 Summary Classifications for Reference Cycles

Region	Periods of Moderate Vulnerability	Periods of High Vulnerability
Segou	April 1988 to July 1988 November and December 1989 September and October 1990 January 1991 to March 1991 July and October 1991 January to July 1992 January to April 1993 March and April 1995	August to December 1992 May 1993 to October 1994 May 1995 to October 1995 April to December 1997
DJenne	January 1987 to June 1987 February and March 1989 November and December 1989 April 1992 to September 1992 February 1993 September 1993 to June 1994 May 1995 to August 1995 March and April 1997	November and December 1986 July 1987 to August 1988 February 1990 to June 1991 November and December 1992 September 1995 to July 1996 October 1997 to January 1998
Douentza	August 1989 January and February 1990 September to December 1990 October 1991 to May 1992 January 1993 to July 1993 March to June 1994 February 1995 to September 1995	November 1986 to September 1988 March to August 1990 January to September 1991 October 1995 to January 1998
Tenenkou	February to July 1987 January and February 1988 January to April 1989 January to July 1990 February and March 1992 November 1992 to February 1993 August 1993 to October 1993 February 1994 to July 1994 February to April 1995 September 1996 to April 1997	October 1986 to January 1987 August 1987 to December 1987 March to August 1988 October and November 1989 April 1990 March 1991 to May 1992 May 1995 to August 1996 May 1997 to January 1998
Youvarou	January 1987 to June 1987 August 1989 to August 1990 February to August 1992 May to September 1993 February to June 1994 March to August 1995 October 1996 to April 1997 October 1997 to January 1998	October to December 1986 July 1987 to September 1988 September 1990 to July1991 September 1995 to September 1996 May 1997 to September 1997

Segou

Segou tends to be a far more food secure cercle relative to the other cercles in this study. Overall, we find the reference cycle mapping (Figure A3.2.1) depicts a gradual increase in vulnerability in Segou over the sample period, April 1988 through April 1998. Through late 1989, the main concern in the cercle rests with the refugee populations, otherwise food security is reported as good.

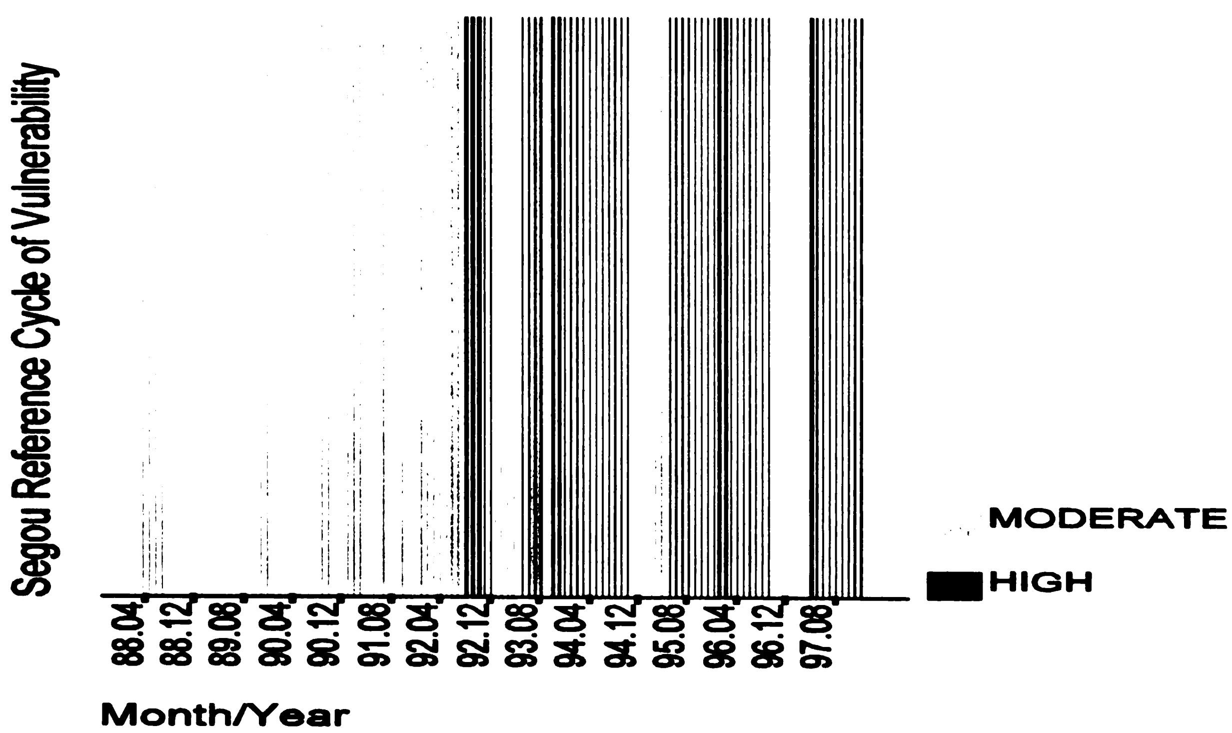
A sharp price increase in October and the problems for six villages which are abandoned in search of food due to pest damage are reported. Food aid is delivered to the most vulnerable areas in December 1989. Food security stabilizes or improves throughout 1990. By April 1991 there is an epidemic of measles and steep price increases until harvest. There are pressures of migration from areas suffering from civil unrest which causes a pressures on food security. There are problems reported in the SAP assessments in 1992 where a continued increase in vulnerability conditions is noted: Migration pressures, price increases, disruption in trading in livestock with producers in Mopti Region, disease outbreaks and reports of weak household reserves. It is important to note that this period shows the first assessments of household reserves as "weak"in Segou for this sample. Conditions of moderate vulnerability persist throughout 1994 with sharp increases in prices and disease outbreaks as well as low quantities of cereals in the markets in July 1994. Food security improves post-harvest as captured.

From March through May there are outbreaks of measles and meningitis. In June there is an increase in prices reported as well as poor rains. Conditions deteriorate with low levels of cereals in the markets as well as even higher prices and the spread of disease.

The harvest is fair to poor and there is a cholera outbreak in November and December 1995. In 1996, SAP reports household resources as weak for much of the year and disease outbreaks persist. By August 1996 conditions appear at their worst for the year; in household reconstitute reserves with fonio and harvest. Food aid is delivered in February and July. Overall, conditions seem to improve post harvest.

While disease persists into 1997, food security conditions appear stable until July when the SAP assessments report household reserves as weak in the cercle. There are food aid deliveries in August and September which, along with a good harvest, appear to improve food security overall.

Figure A3.2.1 Segou Reference Cycle Mapping of Vulnerability to Food Insecurity April 1988 to January 1998



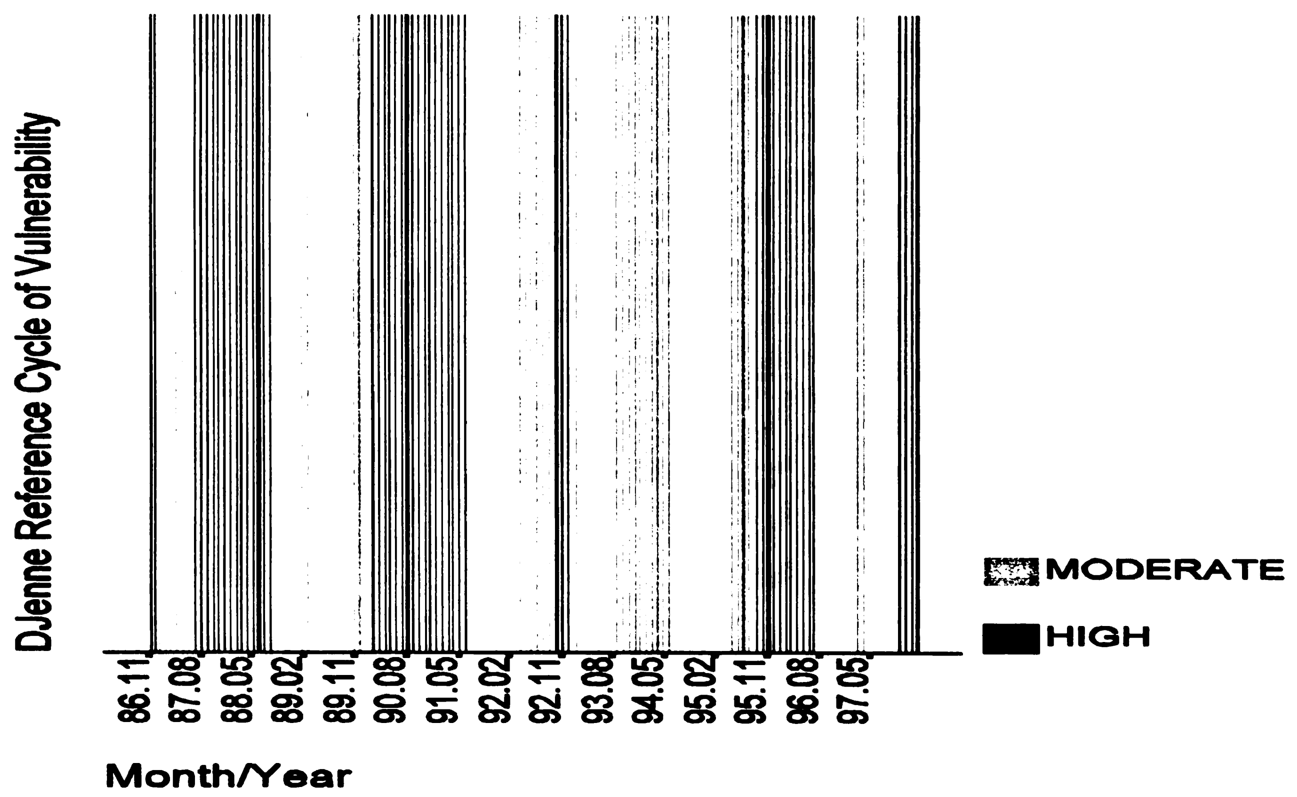
DJenne

The reference cycle mapping for Djenne is presented in Figure A3.2.2. Significant levels of food aid are delivered from October through December 1986 that may contribute to mitigating weak HHRting point. Moderate to high vulnerability persists through to harvest of 1988. Conditions improve providing stability for food security after the harvest.

Late 1989 is a period of high vulnerability due to a rise in prices and the poor harvest. These conditions contribute to the decline in food security for households for 1990 and 1991. Over this period, there are severe measles outbreaks in the cercle, dramatic price increases, low quantities of cereals marketed, and many areas that are declared at risk. A good harvest is realized which serves to reconstitute household stocks. However, migration pressures due to civil conflicts (fishermen from the North are relocation in Djenne, for example) and environmental challenges disrupts food security somewhat. Moderate vulnerability occurs in the later part of 1992. In September 1993 there is an onset of more vulnerable conditions throughout the cercle. 1994 proves to be a year with price increases and the spread of meningitis as well as deaths due to measles. Food aid in May, June and July appear to mitigate further decline we find conditions improves post-harvest.

In late 1995 vulnerability increases in the Cercle due to a poor harvest and increases in migration in search of food. Prices increase throughout the cercle with Konio in the North particularly vulnerable. Food aid deliveries in May and June improve conditions although major problems in Konio persist. There are moderate vulnerability conditions in 1997: irregular migration, price increases and a poor harvest create problems for households from October into January 1998, the end of the sample period.

Figure A3.1.2 DJenne Reference Cycle Mapping of Vulnerability to Food Insecurity November 1986 to January 1998



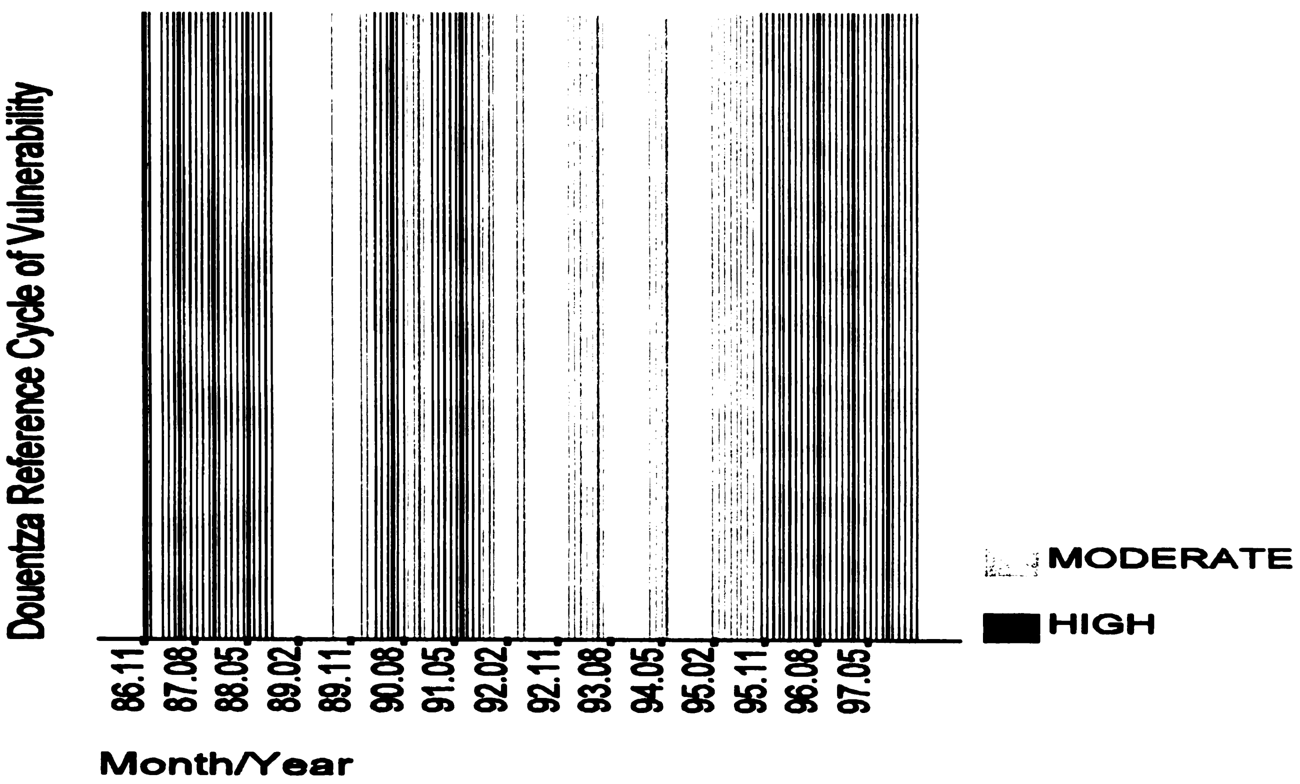
Douentza

The reference cycle mapping created for Douentza presented graphically in Figure A3.2.3. There are conditions of high vulnerability to food insecurity throughout 1987 and 1988 with a major jump at harvest time in 1987. The years poor harvest created a very difficult hungry season in 1988 with household reserves exhausted by April 1988. Migration from Timbuktu and elsewhere along with high food prices and the consumption of famine foods characterize this period. July and August 1988 are the height of the severity of problems in the cercle according to the SAP summaries. Consistent food aid throughout the period keeps a crisis from setting in. By September 1988 conditions improve throughout the Douentza cercle with a good agricultural outlook and a subsequent good harvest of millet.

In 1989, food security conditions are satisfactory in the cercle with Mondoro and a few other areas having some problems in August. With a poor agricultural outlook. The SAP reports show the cercle at risk from August through September 1989. This vulnerability persists and increases over 1990 especially in the North with HHR weak in the cercle and some areas declared as in high risk. Food aid deliveries proceed in March, June and July which help to mitigate crisis in the most vulnerable regions. By August the region shows some improvement in food security conditions which continues through early 1991. Some areas are still at risk while others are under surveillance. In early 1991, conditions in the cercle are reported to include some migrations in search of food and areas at risk. The food security conditions improve after harvest although some arrondissments are under surveillance. The index continues to decline and this corresponds to a satisfactory food security situation in the cercle as reported by SAP. A poor harvest in 1992 sets the stage for conditions of vulnerability in the cercle. The North is particularly vulnerable during 1993 with regions declared DA by mid-year. Food aid delivered in April, June, September and October serves to assist the most vulnerable and to keep prices from sharply increasing. There is some migration out of Douentza cercle due to poor conditions. Household reserves are noted as weak as of October. An average to poor harvest in the cercle further threatens food security. Throughout 1994, the northern areas continue to be at risk and the entire cercle is reported as vulnerable to food insecurity. There are some problems with disease outbreaks and an expected poor harvest. Food aid is delivered in April and July.

In 1996 vulnerability persists with sharp price increases, disease outbreaks, weak household reserves; these conditions worsen over the course of the year. Food aid deliveries from April through September help the most vulnerable in the cercle. Conditions deteriorate throughout 1997 and are exacerbated by an influx of refugees.

Figure A3.2.3 Douentza Reference Cycle Mapping of Vulnerability to Food Insecurity November 1986 to January 1998

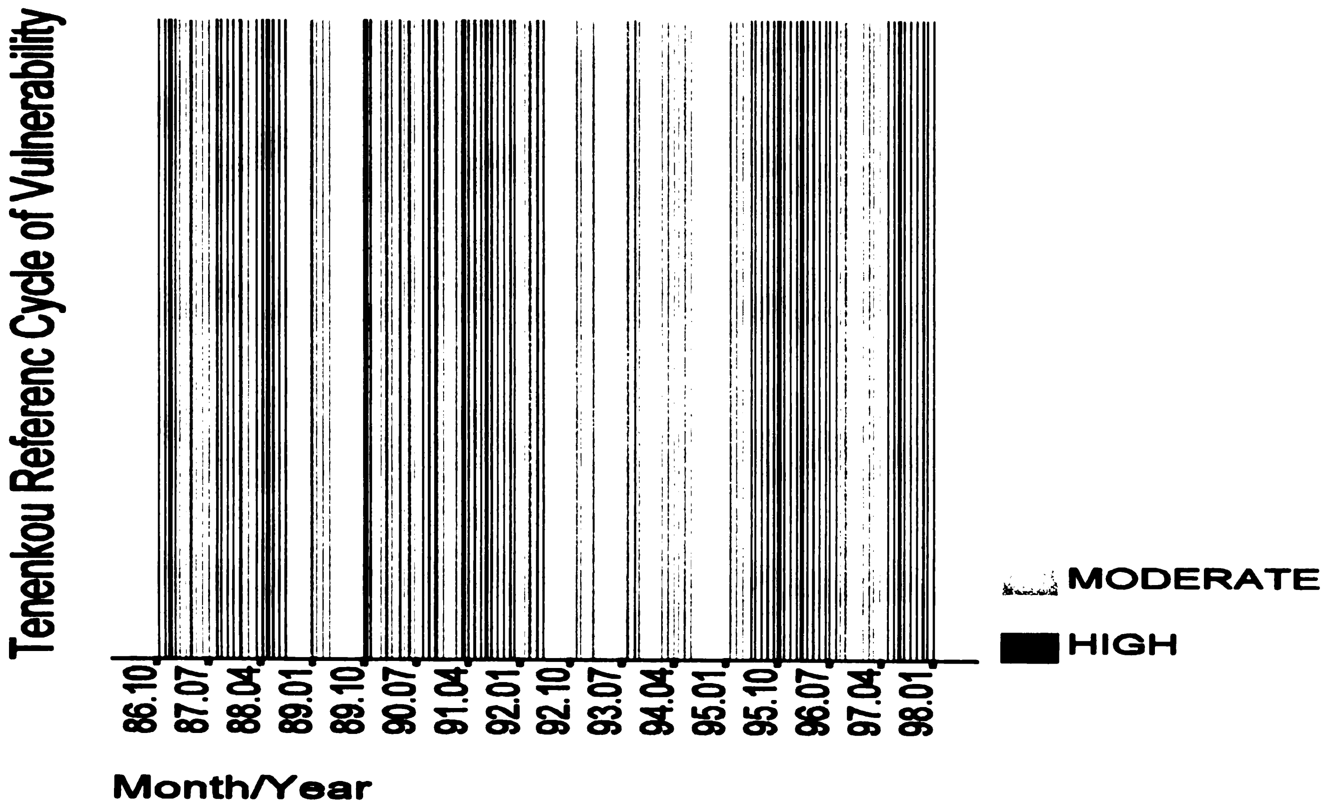


Tenenkou

The period begins with the regions in the North as at risk with the South under surveillance. This situation persists into 1987 and worsens by year's end. There is food aid delivered in large quantity throughout the period. There is a sharp increase in prices by September 1988 and weak household reserves for the rest of the year. Vulnerability increases throughout 1988 with many areas with household reserves exhausted by May and access and cost of cereals prohibitive by June. The agricultural outlook is excellent as reported by SAP and the harvest reconstitutes household reserves such that 1989 is a year of satisfactory food security with some price increases. The poor harvest of 1989 pushes up prices and there is a noted decline in cereals in the market. These conditions of high vulnerability are captured in the reference cycle mapping (Figure A3.2.4).

Vulnerability persists in 1990 with out-migration in search of food in some areas. Conditions stabilize in November and December but overall the cercle is still vulnerable. In 1991 there is heavy population movements due to insecurity and the entire cercle appears to be vulnerable throughout the year. Dioura is a trouble area in 1992 but appears to be an isolated problem. There is some irregular migration in November and December of 1992 as well as the spread of measles. Conditions of insecurity and irregular migration persist into 1993 when by September hoarding of cereals is reported. By September 1994 conditions improve with a good harvest. In early 1995, there are high vulnerability conditions which correspond to a high level of disease among livestock, a key income source in the region. There is also a high level of cholera and measles reported as well an influx of refugees. These conditions along with a poor harvest create conditions of high vulnerability in the cercle until harvest. However, by May of 1997 vulnerability to food insecurity increases as SAP reports indicate weak household resource levels and high disease. Poor rains and a poor harvest in 1997 cause continued vulnerability in the cercle as well as irregular migration and price increases. Food aid is localized around Dioura although needed throughout the cercle.

Figure A3.2.4 Tenenkou Reference Cycle Mapping of Vulnerability to Food Insecurity October 1986 to January 1998

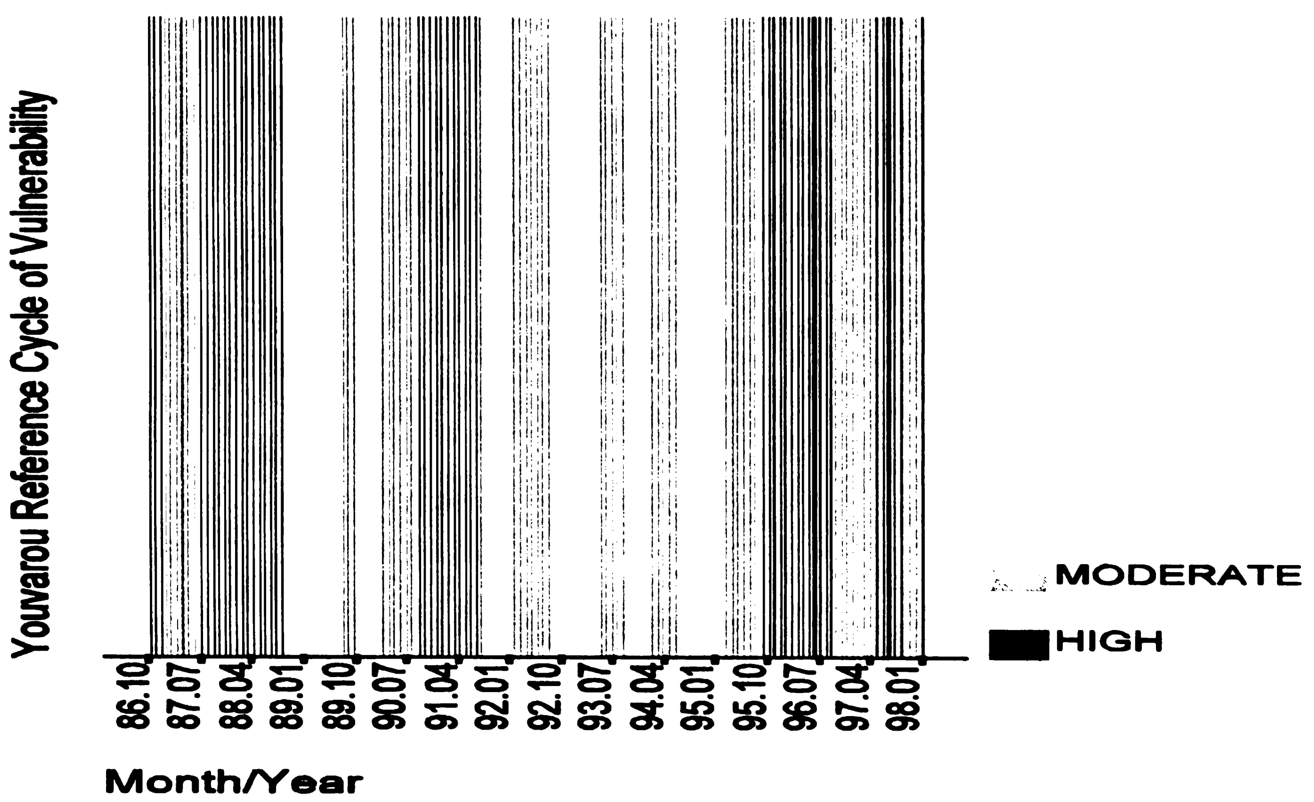


Youvarou

The reference cycle mapping constructed for Youvarou (Figure A3.2.5) has classifications similar to the Tenenkou reference cycle with the exception of the end of the sample period. Food aid distributions and general conditions in 1986 and 1987 are quite similar. Conditions improve after August 1988 due to from the effect of food aid deliveries and a good harvest that serves to reconstitute household reserves. By August 1989 there is a shortage of staples in the market, price increases and the consumption of famine foods to fill gaps. Moderate vulnerability prevails until April of 1990 when a low level of cereals in markets is reported as well as a low number of traders. The entire cercle is under watch at year's end. Vulnerability persists until September 1991 with a good harvest. Conditions are more stable for food security in 1992 except for problems that are localized to Ambiri and Sah. Regular food aid in 1992 assists the most vulnerable.

Beginning in May 1993, there are moderate vulnerability in the cercle with progressively increasing prices, measles outbreaks, and low levels of millet in markets by August. In February of 1994 significant problems are observed with respect to price increases and the availability of cereals in the market. Repatriation of refugees in 1995, the spread of cholera, and nomads returning with weak resources create vulnerable conditions in the cercle. A poor harvest perpetrates vulnerability into 1996. In October/November 1996 there is an improvement in food security when a good harvest ensues. By April 1997 conditions reflect moderate to high vulnerability for the rest of 1997, the end of the sample period.

Figure A3.2.5 Youvarou Reference Cycle Mapping of Vulnerability to Food Insecurity October 1986 to January 1998



A3.3: Tables A3.4 through A3.8: Vulnerability Assessments by Region
(Segou, Djenne, Douentza,Tenenkou, Youvarou)

Reference cycles, depicted as shaded areas in Figures A3.2.1 through A3.2.5 in Chapter 3, were constructed from the monthly SAP reports and are reported in this appendix. Table A3.2 is reprinted here to facilitate interpretation of the summaries.

Table A3.2 Characteristics of Reference Periods for Vulnerability Assessments

1.	**General qualitative assessment of vulnerability in food security summary**
2.	**DEL: Some economic difficulties (as presented in Table 2.6)** **DES: Severe economic difficulties** **DA: Food Deficit** **CA: Food Crisis** **FA: Famine**
3.	**Household reserves reported as "weak"**
4.	**Food aid authorized**
5.	**Sharp increase in staple prices reported**
6.	**Low level of staples in market reported**
7.	**Disease outbreaks classified as epidemics (meningitis, cholera and/or measles)**
8.	**Consumption of wild cereals reported**
9.	**High level of migration into the cercle reported**
10.	**Civil conflicts reported**

Note: HHR refers to 'household reserves' in Tables A3.4 through A3.8
FFW refers to 'Food for Work Program"

Table A3.4 Vulnerability Assessments for Segou based on SAP Reports

Year	Vulnerability Assessment based on SAP Reports
1988	April and May: overall ok some potential problems from displaced persons June: Pockets of problems May through August: Food aid HHR improve with food aid June: Some vulnerability for refugees August: positive ag outlook, refugee population still problems August through November: Situation for refugee population "precarious" Situation for cercle good overall
1989	January through December: Overall, HHR good except for refugee population September: some pest damage to crops October: Sharp price increases in some areas, FOOD Aid for some November: General price increases, 6 villages abandoned which were hard hit by pest damage December: Food aid to most vulnerable areas
1990	Food security good overall September through November: some areas vulnerable due to pest damage to crops
1991	April through June: Epidemic of measles under control by July June and July: Price jumps for staples generally Good rainfall August: price increases for millet and sorghum but good Ag outlook September: Reports good overall with average harvest expected
1992	January: Some areas under surveillance, increase in migration (due to civil conflict) and prices increase February: In Tenenkou SAP report, note a decline in buyers from Segou and Nonio due to insecurity Price increases March: Price increases but cereals in market to meet demand June and July: increase in measles outbreak August and September: Price increases and continued spread of measles Food security improving overall October: HHR weak

1993	January, June and September: Food aid and Food for Work May through August: Marked price increases in some areas October: High increase in rice prices November: Measles outbreak, poor rice harvest in many areas
1994	March through May: Meningitis outbreak during hungry season July: High level of disease, Sharp price increases with low quantities in markets
1995	March through May: Measles and meningitis outbreaks June: Increase in Millet Prices, poor rains August: Decline in cereals in market, increase in disease, sharp increase in prices in general September: HHR weak Cholera outbreak in November and December Ag outlook: Fair
1996	January and February: Disease outbreaks HHR: Weak May through September...improvements with harvests June: HHR weak, price increases, low quantities in markets,, high disease July: Continued spread of measles, price increases, low rainfall, HHR weak August: HHR weak, disease declines, outmigration to Burkina Faso October: HHR reconstituted with harvest, average ag outlook February, July: Food aid
1997	April: high level of measles and meningitis May: disease continues to spread, HHR weak for migrants July: HHR weak, high level of disease August: Disease declines, FOOD AID , HHR are weak to average September: HHR weak, Food Aid to Boron October: Ag outlook good, prices decline but nonhabitual migration in some outlying areas
1998	January: HHR improve with harvests Generally, positive reports

Source: SAP

Table A3.5 Vulnerability Assessments for DJenne based on SAP Reports

Year	Vulnerability Assessment based on SAP Reports
1986	October through December: vulnerable Food aid delivered =>improved HHR
1987	January and February: No major problems reported March: Noted vulnerability in some areas May: Disease outbreaks reported and problems with rats June: Measles spread July: Some price increases in cercle August through October: Sharp price increases with poor rains November: HHR poor in many areas January through June: somewhat vulnerable=> food aid deliveries July through December: vulnerable or food insecure food aid deliveries
1988	January: Increasing vulnerability with increased migration HHR weak, Rice harvest poor to average February through May : Vulnerable, HHR weak, poor pastures, migration March: HHR weak, abnormal migration in search of water and pastues June through August: Highly Vulnerable June: Price of millet increases dramatically, absence of wild cereals Population movements in search of food July: FOOD AID, creation of nutrition centers, low quantities in markets HHR weak August: still problems but more cereals in markets September through October: Ag outlook good/decline in vulnerability Improvements with folio and rice harvest
1989	February: increase in migration to the area March: Slight increase in prices November and December: sharp increase in prices Overall, low vulnerability due to good harvest

1990	February and March: Measles outbreak with prices variable April: Sharp increase in measles and meningitis, slight increase in prices in cercle May: Price increases June and July: Sharp price increases and pests throughout cercle September and October...some vulnerable areas noted, Low quantities in markets with sharp price increases Most of cercle under surveillance November and December: areas under watch (poor rice harvest impedes reconstitution of HHR)
1991	January through June: Increasing vulnerability with markets poorly stocked with cereals July through August: Ag outlook good decreasing vulnerability October: Migration pressures due to civil conflicts elsewhere and those displaced due to environmental challenges November: Increase in migration of fishers relocating due to conflicts in North Some bird and pest damage to rice crops December: Price increases reported but full reports not submitted
1992	April through September: Gradual increase in vulnerability with poor Ag Outlook HHR: fair to weak as year progresses April: Measles outbreak September through December: HHR weak
1993	February: fishing outlook poor September through December: Increasing vulnerability in isolated areas HHR compromised due to poor harvest

1994	January through May : Vulnerable...HHR weak Meningitis outbreak, many villages at risk Price increases May and June: Food aid June: Deaths due to measles, HHR weak in Djenne and Sofara July: Improvement in HHR with food aid but Djenne and Sofara DA, Price increases for millet and sorghum August through December: decreasing vulnerability noted with good ag outlook
1995	May and June: Sharp increase in cereal prices in Jenne and Konio Disease outbreaks July: Food aid and increase in disease August: cholera, measles and Food aid September: decline in disease but increase in millet prices November and December: Konio at risk, measels, low level of cereals in markets Irregular migrations due to food insecurity
1996	January through July: Konio at risk Noted: cholera and measles outbreaks Price increases throughout cercle, HHR weak May and June: Food aid August through December: Problems for Konio anticipated
1997	March: Food aid, Konio still vulnerable July through December: HHR: fair with increasing vulnerability noted October through December: DEL Konio Irregular migration continues poor Ag Outlook, overall HHR weak Migrant workers with poor resources in search of work
1998	January: Poor harvest => HHR not reconstituted fully : vulnerable

Source: SAP

Table A3.6 Vulnerability Assessments for Douentza based on SAP Reports

Year	Vulnerability Assessment based on SAP Reports
1986	October through December: vulnerable with HHR@ 3 months October and November: Food aid
1987	January through June: Food aid January through June: At risk to at high risk throughout cercle February: Migration from Timbuktu March NGO study finds 7.3% children malnourished May: Consumption of famine foods noted,migration May through October: increasing vulnerability, poor ag outlook November and December: Food aid authorized due to poor harvest
1988	January through June: Increasing vulnerability. HHR notably weak ....entire cercle at risk January and February: Increase in migration in search of food February, April, June and July: Food aid April: HHR exhausted July and August: Height of severity of problems throughout region (general assessment) September: Improvement of HHR and general conditions Good ag outlook and subsequent harvest =>decreasing vulnerability
1989	January through July : stable August: Some areas vulnerable...Mondoro reports decrease in number of meals per day September: Food aid August through December: Poor ag outlook, at risk
1990	January through June: Increasing vulnerability especially in North, HHR weak March through July: Boni, Mondoro, Hombori and N'Gouma high risk March, June and July: Food aid distributions. HHR better with Fonio consumption August: some decrease in prices with food aid distributions October through December: Improvement by October but some areas still at risk and others under surveillance

1991	January through May: N'Gouma, Mondoro vulnerable with Mondoro declared at risk. Food aid and consumption of wild cereals serves to mitigate severe problems April through September: Food aid October and November: HHR improve with secondary crop harvests Ag outlook good with some areas under watch Some village to village migration in search of food December: Douentza Central and N'Gouma under surveillance
1992	March: Problems in 'Gouma, Douentza Central, Hombori (localized DES) May: Measles outbreak September: HHR improve with fonio sauvage October through December: Poor harvest... HHR fair overall but some areas vulnerable localized
1993	January through June: increasing vulnerability in the North. January through July: DA in the Northeast (April "precarious") April, June, September and October: Food aid October through December: Mondoro DA HHR weak in Mondoro and Hombori Some migration to Burkina Faso and Cote d'Ivoire Ag outlook average to poor in some areas
1994	January through April: Mondoro and Hombori at risk January through June increasing vulnerability January through April: Wild cereals/famine foods fill gaps April through July: Food aid distributions Good harvest
1995	January through June: stable February through April: Meningitis outbreak April and July: Food aid April through September: Problems in N'Gouma July: poor harvest expected, recession ag outlook good

1996	Off season crops: good April, June, July and September: Food aid Sharp price increases February through June: Meningitis and measles outbreaks April through September: weak HHR November and December: Prices increasing, meningitis spreads
1997	January and September: Food aid February through December: HHR weak with poor harvest following the previous season July: Influx of refugees
1998	January: vulnerable

Source: SAP

Table A3.7 Vulnerability Assessments for Tenenkou based on SAP Reports

Year	Vulnerability Assessment based on SAP Reports
1986	North at Risk. October through December: Food aid distributions HHR: 6-9 months in South 3-5/1-2 months available in North
1987	January through June: Food aid January through June: Vulnerable...migration from smaller villages Ag outlook: good w/ prices decreasing in July August through December: Several areas weak- Dioura and Diafarabe Ag outlook poor with prices increasing HHR weak Increasing vulnerability through December...Food aid authorized
1988	January: Dioura and Diafarabe at risk March through August: increasing vulnerability with HHR exhausted in most areas by May March, June and July: Food aid June: Access and cost of cereals prohibitive September: excellent Ag outlook
1989	Generally food secure throughout the year with steady price increases Potential problem: poor harvest and poor outlook for recession ag October: decline in quantities in market with sharp price increases November: Prices volatile in region several areas under surveillance
1990	January and February: Dioura under surveillance Outmigration to increase HHR April: Price increases May and June: Food aid authorized July: Food aid distributions end August and September: Sharp price increases June and July: Pest infestations October: Low quantities in markets, very high prices, slight improvement in HHR November and December: Conditions stabilize

1991	January: HHR reconstituted with rice harvest March and April: flood zone areas at risk Several areas with HHR weak May through July: Price increases sharp June and July: Some vulnerable areas: famine foods and secondary crops fill gaps February through September: Dioura at risk ("in crisis"in July) May, August and September: Food aid distributed October: Good harvests expected Vaccination program suspended due to civil unrest in region November and December: Dioura under surveillance Heavy population movement with insecurity
1992	January through June: Dioura is problem whole year (preharvest) Millet price increases Problems in Kotia March: Ambiri(DEL) and Diafarabe Measles April: spread of measles, villages abandoned in Dioura Ag outlook: fair....HHR improve with harvest...some measles cases reported November and December: irregular migration
1993	February: Some problems with irregular migration May: Food aid September: uncertain with ag outlook due to inconsistent rainfall Hoarding reported August through October: HHR: fair to weak with some improvements with harvests
1994	February: Diafarbe problems June and July: Price increases noted for Millet Diondiori and Diafarabe (DE) Chicken pox outbreak September through December: HHR stable and subsequently reconstituted from harvest

1995	February ,March and April: migrants return with poor resources High disease levels among livestock May through December: cholera and measles outbreaks June: large number of refugees in Dioura April/July/August: Food aid to Dioura and Tenenkou September: inmigration continues November and December: Increase in disease related deaths (cholera) Sharp price increases Irregular migration continues Ag outlook: fair to poor...
1996	February through July: HHR: weak......disease outbreaks throughout cercle February through June: Dioura at risk June: Food for Work Ag outlook: Good except Dioura with restocking of HHR high level of disease cases throughout year
1997	January through April: HHR: fair....meningitis and measles outbreaks May through September: HHR weak and disease persists June, September and October: Food aid mostly distributed around Dioura Ag outlook fair to poor with poor rainfall October: Price increases Irregular migration HHR weak
1998	January: At risk with weak HHR rainfed crops and rice: poor harvests

Source: SAP

Table A3.8 Vulnerability Assessments for Youvarou based on SAP Reports

Year	Vulnerability Assessment based on SAP Reports
1986	October through December: HHR weak Sah and Ambiri especially vulnerable Food aid distributions
1987	Northeast: High vulnerability for entire year January through June: Food aid Poor rains increase vulnerability June: Consumption of famine foods reported July thorugh December: "precarious situation in cercle"
1988	February: Increased migration to area March through August: Food security crisis January, February, June and September: Food aid May: HHR exhausted. August: HHR improvements as food aid distributed Good rains ...good Ag outlook...HHR improve post harvest
1989	Stable August: shortage of staple in markets, consumption of secondary crops fills gaps Ag outlook: Average to poor HHR improve with harvest including rice
1990	Overall stable. March through May: Problems in Sah April and May: Decline in availability of staples in markets Low number of traders noted September through December: Poor rains=>poor harvest some areas under watch
1991	South: stable local rice fills gaps January through May: North- at risk... precarious by April February and April through July: Food aid distributions which are noted as slow to arrive...end in July September through December: HHR Improvements with secondary crops then harvest

1992	January: rice more successful than other crops February through August: vulnerable..."precarious"in Sah and Ambiri May/June/July/August: food aid August: Fonio sauvage September: improvements in food security with secondary crops HHR and food security improves with harvest (good) HHR improve except in Sah
1993	Food security: "good"beginning of year May-September: steady price increase throughout year Measles outbreaks By August and September low quantity of millet in markets Enough rice in market but price increases August: Food aid in Ambiri August: PPIV sells rice during hungry season Ag outlook fair October: increase HHR with fonio and millet
1994	February: Sharp increase in price of staple cereals in Ambiri and Youvarou May and June: Decline in availability of cereals in market HHR stable overall Good rains and good harvest improve HHR PPIV sells stock and enhances food security
1995	March: Return of nomads with weak HHR April and July: Food aid distribution July through December: Cholera outbreak September: Return of refugees from Mauritania to Gathi-Loumo Poor rains=> poor ag outlook including for rice
1996	January through September: Low levels of cereals in markets disease outbreaks May and June: Food aid to Sah Ag outlook: good to poor in cercle with rice harvest expected to be fair
1997	HHR: weak and continue to decline throughout year May through September: Markets poorly supplied with cereals October: HHR insufficient Poor ag outlook, rice outlook also poor
1998	January: Vulnerable with weak HHR Sharp price increases

Source: SAP

A3.4 Comparing the Smoothed Millet Price Index to the Reference Cycles

A simple index (exponentially smooth millet prices) was constructed for each of the regions. Table A3.5 summarizes turning points of the simple index and periods of moderate and high vulnerability to food insecurity. Figures A3.4.1 through A3.4.5 provide a mapping of the reference cycles with the simple index for each region. For the areas of Tenenkou and Youvarou we found fairly good matching of turning points to moderate and high periods of vulnerability. For DJenne and Douentza, turning points coincide with reference cycles, such that they are more descriptive rather than predictive. The Segou simple index failed to cature the onset or the severity of vulnerability conditions. These results, as well as the results for Gao, Mopti and Timbuktu simple indexes, suggest that millet prices do tend to coincide with vulnerable periods. These strong descriptive contributions are harnessed in the development of a more sophisticated vulnerability index in Chapter 4.

Table A3.5 Comparing the Smoothed Millet Price Index and the Reference Cycles

Region	Periods of Moderate Vulnerability	Periods of High Vulnerability	Key Turning Points in Simple Millet Index
Segou	April 1988 to July 1988 November and December 1989 September and October 1990 January 1991 to March 1991 July and October 1991 January to July 1992 January to April 1993 March and April 1995	August to December 1992 May 1993 to October 1994 May 1995 to October 1995 April to December 1997	February 1990 July 1993 June 1995
DJenne	January 1987 to June 1987 February and March 1989 November and December 1989 April 1992 to September 1992 February 1993 September 1993 to June 1994 May 1995 to August 1995 March and April 1997	November and December 1986 July 1987 to August 1988 February 1990 to June 1991 November and December 1992 September 1995 to July 1996 October 1997 to January 1998	August 1987 March 1990 June 1995
Douentza	August 1989 January and February 1990 September to December 1990 October 1991 to May 1992 January 1993 to July 1993 March to June 1994 February 1995 to September 1995	November 1986 to September 1988 March to August 1990 January to September 1991 October 1995 to January 1998	November 1987 April 1990 March 1995

Region	Periods of Moderate Vulnerability	Periods of High Vulnerability	Key Turning Points in Simple Millet Index
Tenenkou	February to July 1987 January and February 1988 January to April 1989 January to July 1990 February and March 1992 November 1992 to February 1993 August 1993 to October 1993 February 1994 to July 1994 February to April 1995 September 1996 to April 1997	October 1986 to January 1987 August 1987 to December 1987 March to August 1988 October and November 1989 April 1990 March 1991 to May 1992 May 1995 to August 1996 May 1997 to January 1998	August 1987 February 1990 May 1993 July 1995 January 1998
Youvarou	January 1987 to June 1987 August 1989 to August 1990 February to August 1992 May to September 1993 February to June 1994 March to August 1995 October 1996 to April 1997 October 1997 to January 1998	October to December 1986 July 1987 to September 1988 September 1990 to July1991 September 1995 to September 1996 May 1997 to September 1997	June 1987 January 1990 March 1993 March 1995

Figure A3.4.1 Segou Simple Index and Reference Cycle Mapping of Vulnerability to Food Insecurity April 1988 to January 1998

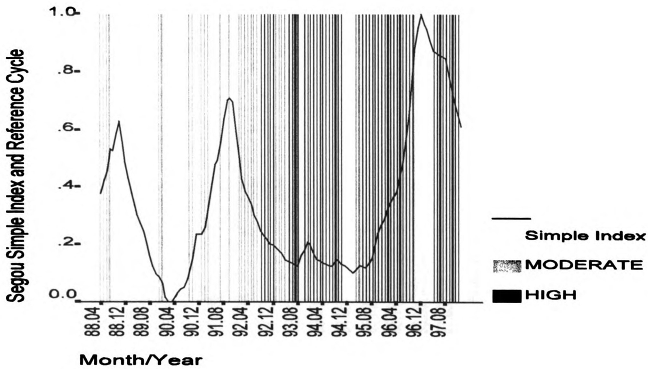


Figure A3.4.2 DJenne Simple Index and Reference Cycle Mapping of Vulnerability to Food Insecurity November 1986 to January 1998

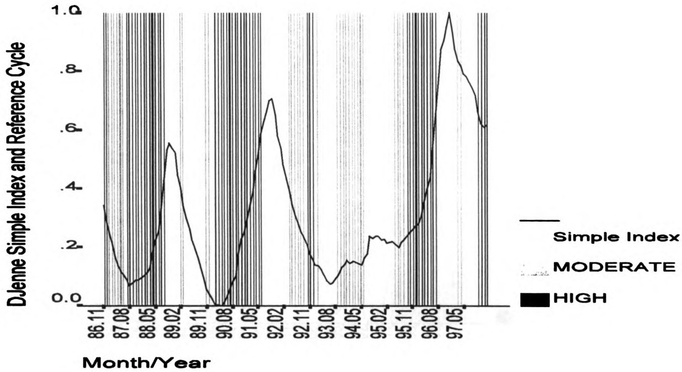


Figure A3.4.3 Douentza Simple Index and Reference Cycle Mapping of Vulnerability to Food Insecurity November 1986 to January 1998

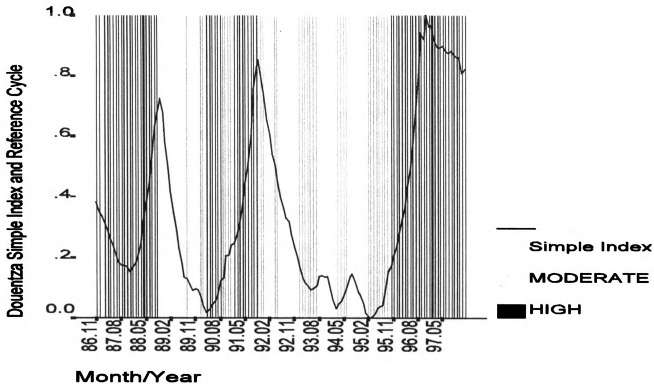


Figure A3.4.4 Tenenkou Simple Index and Reference Cycle Mapping of Vulnerability to Food Insecurity October 1986 to January 1998

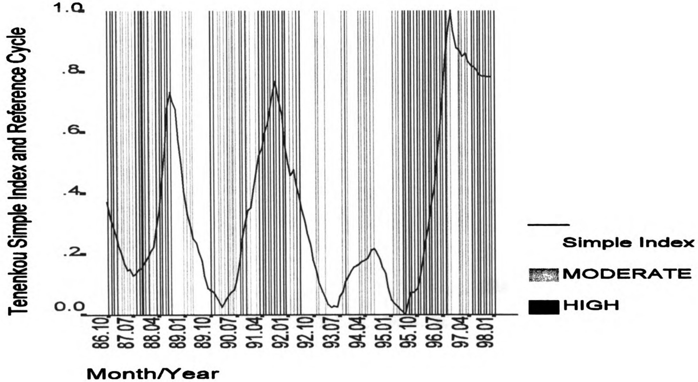
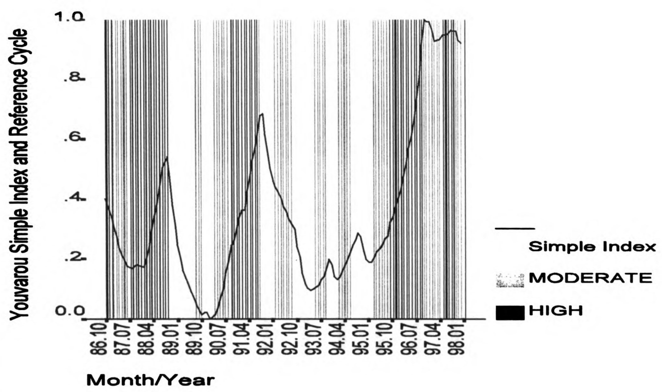


Figure A3.4.5 Youvarou Simple Index and Reference Cycle Mapping of Vulnerability to Food Insecurity October 1986 to January 1998



APPENDIX CHAPTER FOUR

A4.1 The single-index model of the U.S. business cycle

This section presents the single-index model of the state of the economy as it is developed in Kim and Nelson (1999) and Stock and Watson (1991), both of which were based on the early work of Sargent and Sims (1977). In Chapters 4 and 5, the dynamic structure of the single-index model of vulnerability to food insecurity based on the characteristics of the Malian data is fully developed for each cercle and builds from the model presented here. Let X_t denote a k x 1 vector of the log of macroeconomic time-series which are hypothesized to move contemporaneously with economic conditions. These variables consist of four coincident variables used in the construction of the coincident index: industrial production, personal income less transfer payments, manufacturing and trade sales, and employees on nonagricultural payrolls. As developed in Stock and Watson (1991) and Kim and Nelson (1998), in the single-index model Y_{it} consists of two stochastic components: the common unobserved scalar time-series variable, or "index", C_t , and a k-dimensional component that represents idiosyncratic movements in the series and measurement error, e_{it}. In keeping with the Stock and Watson (1991) formulation, both idiosyncratic components, $\hat{D}_i$, and the unobserved index are modeled as having linear structures and C_t is assumed to appear contemporaneously in each variable. The model is written as:

(A4.1) $Y_{it} = \hat{D}_i + \gamma_i C_t + e_{it}$, $\quad i = 1,2,3,4$

(A4.2) $C_t = \hat{\delta} + \phi_1 C_{t-1} + \phi_2 C_{t-2} + w_t$, (A4.3) $e_{it} = \psi_{i1} e_{i,t-1} \psi_{i2} e_{i,t-2} + \epsilon_{it},$

ϵ_{it} ~i.i.d.$N(0,\sigma_i^2)$, $i = 1, 2, 3, 4$

w_t ~i.i.d.$N(0,\sigma_w^2)$

Stock and Watson select a second order autoregressive structure for the index and the measurement without any justification. Idiosyncratic components, D_i, are assumed to be time-invariant (intercepts), and the unobserved component enters each equation in (1) with different weights, contemporaneously. Many macroeconomic are found to possess stochastic trends and these stochastic trends could be captured by C_t . Thus, by this construction, each element of Y_{it} would have this trend in common. We would then need to consider whether the series were cointegrated of order (1,1) (Engle and Granger (1987)). Stock and Watson (1991) found that they could not reject the null hypothesis that these series, Y_{it} , possess a unit root. Further they note that without compelling evidence of cointegration this model can be reformulated to look at comovements among first differences of the coincident variables at frequencies other than zero in order to extract estimates of C_t. Harvey, Fernandez-Macho, and Stock (1987) explore unobserved components models with cointegrated variables.

Thus, Stock and Watson reformulate the system (A4.1) through (A4.3) in terms of growth rates (first differences) of the variables:

(A4.4) $\Delta Y_{it} = D_i + \gamma_i \Delta C_t + e_{it}, \qquad i= 1,2,3,4$

(A4.5) $(\Delta C_t - \delta) = \phi_1(\Delta C_{t-1} - \delta) + \phi_2(\Delta C_{t-2} - \delta) + w_t,$

(A4.6) $e_{it} = \psi_{i1} e_{i,t-1} + \psi_{i2} e_{i,t-2} + \epsilon_{it},$

ϵ_{it} ~i.i.d.$N(0,\sigma_i^2)$, i = 1, 2, 3, 4

w_t ~i.i.d.$N(0,\sigma_w^2)$

The inclusion of a non-zero idiosyncratic term allows for different drifts for ΔY_{it}. ΔC_t Is the common component and σ_ω^2 is set equal to 1 in order to normalize the common component. The polynomials, are assumed to have roots outside the unit circle. For convenience in presentation of the model, henceforth, they will both be defined as second order (as in Stock and Watson (1991)).

The next step in building this model is to develop sufficient identifying restrictions on the model in order to estimate unknown parameters and to extract estimates of ΔC_t. Sargent and Sims (1977) and Stock and Watson (1991) note that the main identifying assumption in the model expresses the fundamental notion that the comovements of the time series are driven by a single source, ΔC_t. This implies that $(e_{1t}, e_{2t}, \ldots, \Delta C_t)$ are mutually uncorrelated at all leads and lags. However, individual series may be autocorrelated. This restriction essentially means that dependence on the single-index accounts for all the observed cross-relations among the coincident indicators. It is important to note that the above specification results in the parameters D_i and δ not being separately identified in the first sample moment of the ith indicator ΔY_{it}. From (A4.4) we see that the first population moment for the ith indicator, ΔY_{it}, consists of two parameters:

(A4.7) $E(\Delta Y_{it}) = D_i + \gamma_i \delta$

Stock and Watson (1991) suggest writing the model in the form of deviations from means in order to solve the identification problem in MLE. This concentrates $D_i + \gamma_i \delta$ out of the likelihood function:

Model in Deviation from Means [Kim and Nelson (1999)]

(A4.8) $\Delta y_{it} = \gamma_i \Delta c_t + e_{it}, \qquad i = 1,2,3,4$

(A4.9) $(\Delta C_t - \delta) = \phi_1(\Delta C_{t-1} - \delta) + \phi_2(\Delta C_{t-2} - \delta) + w_t,$

(A4.10) $e_{it} = \psi_{i1} e_{i,t-1} \psi_{i2} e_{i,t-2} + \epsilon_{it},$

where $\Delta y_{it} = \Delta Y_{it} - E(\Delta Y_{it})$ and $\Delta c_t = \Delta C_t - \delta$.

ϵ_{it} ~i.i.d.$N(0, \sigma_i^2)$, $i = 1, 2, 3, 4$

w_t ~i.i.d.$N(0, \sigma_w^2)$

After this reformulation, the model is written in state-space form after which the Kalman filter is used for maximum likelihood estimation of the model based on prediction error decomposition and for inferences on Δc_t.

A4.1.2 State-Space Representation of Single-Index Model

A state-space representation of the single-index model from (A4.8) through (A4.10) is:

Measurement Equation

$$
\begin{bmatrix} \Delta y_{1t} \\ \Delta y_{2t} \\ \Delta y_{3t} \\ \Delta y_{4t} \end{bmatrix}
=
\begin{bmatrix}
\gamma_1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\gamma_2 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
\gamma_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
\gamma_{40} & \gamma_{41} & \gamma_{42} & \gamma_{43} & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0
\end{bmatrix}
\begin{bmatrix} \Delta c_t \\ \Delta c_{t-1} \\ \Delta c_{t-2} \\ \Delta c_{t-3} \\ e_{1t} \\ e_{1,t-1} \\ e_{2t} \\ e_{2,t-1} \\ e_{3t} \\ e_{3,t-1} \\ e_{4t} \\ e_{4,t-1} \end{bmatrix}
$$

$(y_t = H_t \beta_t + e_t),$

Transition Equation

$$\begin{bmatrix} \Delta c_t \\ \Delta c_{t-1} \\ \Delta c_{t-2} \\ \Delta c_{t-3} \\ e_{1,t} \\ e_{1,t-1} \\ e_{2,t} \\ e_{2,t-1} \\ e_{3,t} \\ e_{3,t-1} \\ e_{4,t} \\ e_{4,t-1} \end{bmatrix} = \begin{bmatrix} \phi_1 & \phi_2 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & 0 & 0 & \psi_{11} & \psi_{12} & \cdots & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdots & \psi_{41} & \psi_{42} \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 1 & 0 \end{bmatrix} \begin{bmatrix} \Delta c_{t-1} \\ \Delta c_{t-2} \\ \Delta c_{t-3} \\ \Delta c_{t-4} \\ e_{1,t-1} \\ e_{1,t-2} \\ e_{2,t-1} \\ e_{2,t-2} \\ e_{3,t-1} \\ e_{3,t-2} \\ e_{4,t-1} \\ e_{4,t-2} \end{bmatrix} + \begin{bmatrix} w_t \\ 0 \\ 0 \\ 0 \\ \epsilon_{1t} \\ 0 \\ \epsilon_{2t} \\ 0 \\ \epsilon_{3t} \\ 0 \\ \epsilon_{4t} \\ 0 \end{bmatrix}$$

$(\beta_t = F\beta_{t-1} + v_t)$

From this representation, estimates for the model parameters can be derived using maximum likelihood estimation based on prediction error decomposition. With these estimates, the Kalman filter is used to estimate the state vector conditional on information up to time t. We find the (1,1) element of the state vector is $\Delta c_{t|t}$.

A4.2 The construction of the leading index

The index depicting the unobserved state is derived from the single-index model is the minimum mean square error estimator of C_t constructed using data on the coincident variables through time t. We denote this as $C_{t|t}$. A further identifying assumption is that the estimate of the mean growth rate for C_t can be expressed as a weighted average of the observed indicators. The weights are retrieved from the Kalman filter matrices (Stock and Watson (1991) and Kim and Nelson (1999).

Given $\Delta c_{t|t}$, t = 1, 2, ..., T, we need to estimate δ to construct the new index, $C_{t|t}$. This follows from the expression

(A4.11) $$C_{t|t} = C_{t|t-1} + \Delta C_{t|t} + \delta$$

If all the parameters of the model (A4.8) through (A4.10) are known and we apply the Kalman filter we can obtain $C_{t|t}$. The relationship between $C_{t|t}$ and the observed variables, $\Delta Y_t = [\Delta Y_{1t}\ \Delta Y_{2t}\ \Delta Y_{3t}\ \Delta Y_{4t}]'$ can be expressed as

(A4.12) $$\Delta C_{t|t} = W(L)\Delta Y_t$$

where *W(L)* is a polynomial lag operator that relates the transformed vulnerability index to current and past values of the observed variables. We find:

(A4.13) $$E[\Delta C_{t|t}] = E[W(L)\Delta Y_t]$$

We retrieve the mean of the unobserved variables since

(A4.14) $\delta = W(1)E(\Delta Y)$ and

(A4.15) $\hat{\delta} = W(1)\Delta\overline{C}$.

Once W(1) is identified, δ is estimated given $\Delta\overline{Y}$. Kim and Nelson (1999) note that the relationship between $\Delta c_{t|t}$ and Δy_t can also be expressed as

(A4.16) $\Delta c_{t|t} = W(L)\Delta y_t$,

which suggests that we can retrieve *W(1)* from the model expressed as deviation from means (A4.8) through (A4.10). Stock and Watson (1991) identify *W(1)* from the last recursion of the Kalman filter applied to the state-space model written as a deviation from means. Kim and Nelson (1999) present the following interpretation of this process.

We retrieve several products from the Kalman filter recursion applied to the state-space model expressed in deviation from means, in particular we have,

(A4.17) $\beta_{t|t} = \beta_{t|t-1} + K_t\eta_{t|t-1}$,

(A4.18) $\beta_{t|t} = \beta_{t|t-1} + K_t(\Delta y_t - K_t H\beta_{t|t-1})$,

(A4.19) $\beta_{t|t} = F\beta_{t-1|t-1} + K_t\Delta y_t - K_t H\beta_{t|t-1}$,

(A4.20) $\beta_{t|t} = F\beta_{t-1|t-1} + K_t\Delta y_t - K_t H\beta_{t-1|t-1}$,

(A4.21) $\beta_{t|t} = (I - K_t H)F\beta_{t-1|t-1} + K_t\Delta y_t$

The Kalman gain, K_t , approaches the steady state Kalman gain, K, as $t \to \infty$,given a stationary transition equation (Harvey (1989) and Stock and Watson (1991)) . For a set of parameter estimates of the model, one applies the Kalman filter to the model in deviation from means. The Kalman gain at the last iteration, K_T, is the steady state Kalman gain. One will note that this convergence of K_t for $t = 1, 2, ..., T$ to the steady state is fairly quick. By this we have $\beta_{t|t} = \beta_{t-1|t-1}$ and $K_t = K$, and from equation (A4.19) we have:

$$(A4.22) \qquad \beta_{t|t} = (I - (I - KH)FL)^{-1}K\Delta y_t$$

where L is the lag operator. As noted previously, the (1,1) element of $\beta_{t|t}$ is $\Delta c_{t|t}$, $W(L)$ is given by the (1,1) element of $(I - (I\ KH)FL)^{-1}K$. Therefore, $W(1)$ in equation (A4.15) is given by the (1,1) element of $(I - (I\ KH)F)^{-1}K$.

A4.3 Empirical results of the Stock and Watson model

Stock and Watson (1991) compared their index to the existing index of coincident indicators published by the U.S. Department of Commerce. They found a high level of correlation between the two series. They also found that the standard deviation of the existing index far exceed their version due to the construction of the weights for each index: the commerce index weights sum to 1.8 but those for $\Delta C_{t|t}$ sum to 1 by construction. In order to present the two indexes on one graph for a meaningful comparison, Stock and Watson scaled their version to be comparable to the DOC version.

Kim and Nelson (1999) revisit this development of a single index by updating the sample period to January 1960 through January 1995 and by incorporating the possibility that employment is not coincident but lagging other variables. Kim and Nelson also adjust their index to be comparable with the DOC index. They found that treating employment as a lagging indicator did not enhance model performance. Both Stock and Watson and Kim and Nelson found their indexes to reveal higher growth in the 1970's and lower growth in the 1980's that the DOC index. Overall, both alternative indexes were found to be strikingly similar to the DOC index especially at business cycle frequencies. Presumably, Koopmans would be pleased by these developments in business cycle research as the theoretical foundations used in their development certainly address his concerns as a pioneer in this work.

A 4.4 Univariate Analysis: Segou, DJenne, Douentza, Tenenkou and Youvarou

Table A4.1 Descriptive Statistics for Retail Millet Prices

Cercle	T	Min	Max	Mean	σ^2	Trend t_1= Predeval t_2=Postdeval	S.E.
Segou	118	25	175	72.98	911.45	t_1= -.0059 t_2= .7830***	27.42
DJenne	135	28	193	73.52	1242.84	t_1= .0374 t_2= 1.051***	32.18
Douentza	135	46	190	87.71	982.60	t_1=.0420 t_2= 1.028***	27.99
Tenenkou	135	35	180	75.80	969.91	t_1= .0692 t_2= .9870***	28.49
Youvarou	135	25	225	102.15	1557.31	t_1=.0713 t_2= 1.771***	31.18

*, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.
Predeval and Postdeval refer to pre-devaluation and post-devaluation, respectively
S.E: refers to standard error of the regression

Table A4.2 Descriptive Statistics for Adjusted NDVI

Cercle	T	Min	Max	Mean	σ^2
Segou	118	-47.00	43.00	-0.3220	380.10
DJenne	135	-58.10	71.90	-1.1081	472.25
Douentza	135	-48.40	78.00	-1.3718	345.93
Tenenkou	135	-73.30	80.00	-2.0378	594.50
Youvarou	135	-54.70	78.60	-2.8459	436.89

Table A 4.3 Critical Values for Augmented Dickey-Fuller and Perron Unit Root Tests

Level of significance	ADF	Perron Intercept Shift	Perron Trend Shift	Perron Intercept and Trend Shift
1%	-3.96	-4.42	-4.51	-4.75
5%	-3.41	-3.80	-3.85	-4.18
10%	-3.13	-3.51	-3.57	-3.86

The results for the ADF unit root tests for the adjusted NDVI rejected the null hypotheses of the existence of unit roots. However, the test results for millet prices were ambiguous. There is evidence of stationarity for each price series (the null hypotheses of unit roots were rejected) with both the ADF and Perron tests, except for the Djenne millet price series. For Djenne, the ADF provided strong evidence that leads to the rejection of the null hypothesis of presence of a unit root in the series. Since the single index model accounts for idiosyncratic aspects for each indicator, the level of the millet price series is selected as the indicator variable as well as the level of the adjusted NDVI.

Table 4.4.1 Segou Results from Augmented Dickey-Fuller and Perron Tests of the Null Hypothesis of Non-Stationarity with and without a Structural Shift at Devaluation

Number of Lags	Adjusted NDVI (ADF)		Retail Millet Price Assumes no structural break (ADF)		Retail Millet Price Assuming Structural Break (Intercept Shift) (Perron)		Retail Millet Price Assuming Structural Break Trend Shift (Perron)		Retail Millet Price Assuming Structural Break (Intercept & Trend Shift) (Perron)	
	ADF	Root Value	ADF	Root Value	Critical Value	Root Value	Critical Value	Root Value	Critical Value	Root Value
2	-5.80***	-.761	-3.72**	-.206	-3.71*	-.377	-3.59*	-.400	-3.78	-.406
4	-4.77***	-.814	-3.54**	-206	-3.52*	-.393	-3.23	-.416	-3.52	-.426
8	-5.12***	-.819	-2.73	-.176	-2.70	-.363	-2.82	-.435	-3.77	-.452
10	-4.55***	-.827	-2.52	-.175	-2.46	-.354	-2.76	-.464	-2.90	-.478
12	-3.74**	-.829	-3.29*	-.242	-3.24	-.495	-3.72*	-.576	-3.97*	-.712

*, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

Figure 4.4.1 Segou: Retail Millet Price

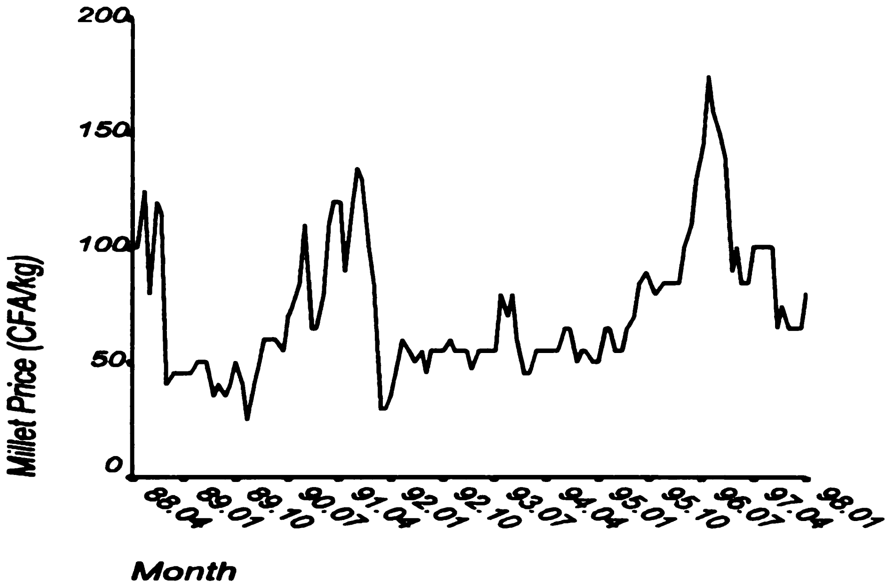


Figure 4.4.2 Segou: Adjusted NDVI

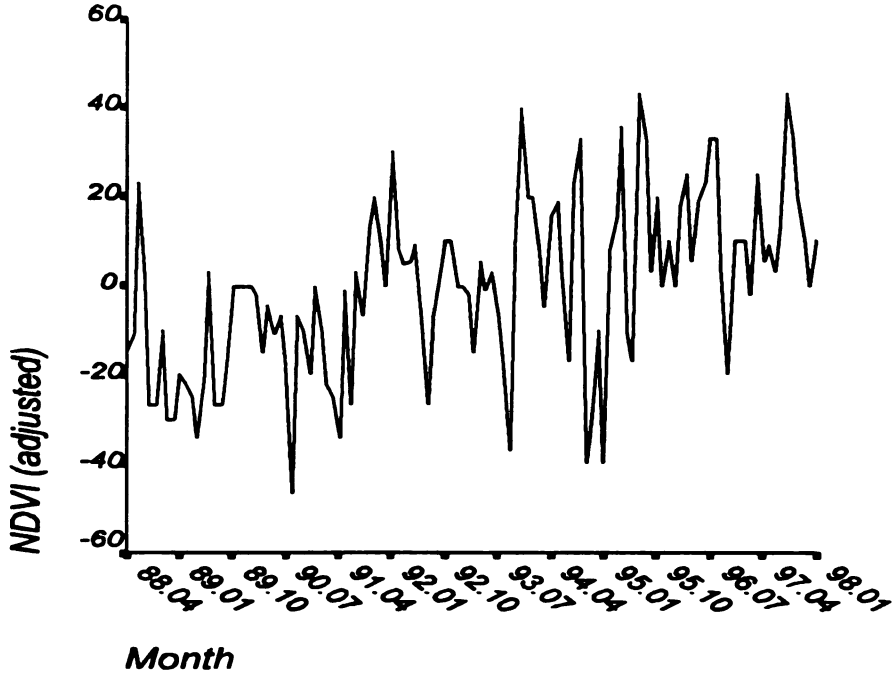


Table 4.5.1 DJenne Results from Augmented Dickey-Fuller Test of the Null Hypothesis of Non-Stationarity

Number of Lags	Adjusted NDVI (ADF)		Retail Millet Price Assumes no structural break (ADF)	
	ADF	Root Value	ADF	Root Value
2	-5.98***	-.513	-3.43**	-.151
4	-5.21***	-.521	-4.16***	-.198
8	-4.24***	.663	-3.46**	-.207
10	-3.27*	-.549	-3.62**	-.237
12	-3.45**	-.617	-3.79**	-.278

*, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

Figure 4.5.1 DJenne: Retail Millet Price

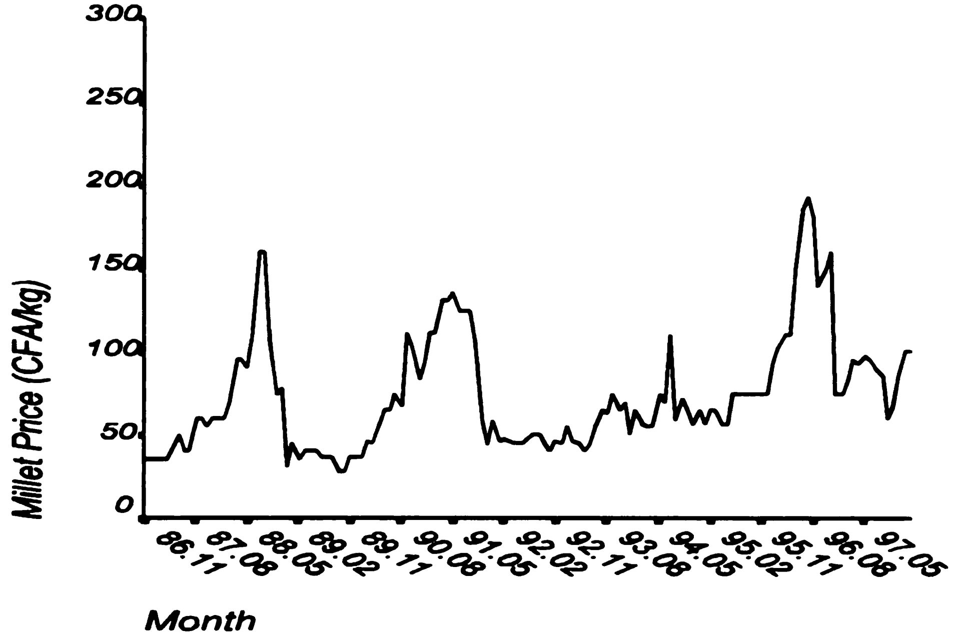


Figure 4.5.2 DJenne: Adjusted NDVI

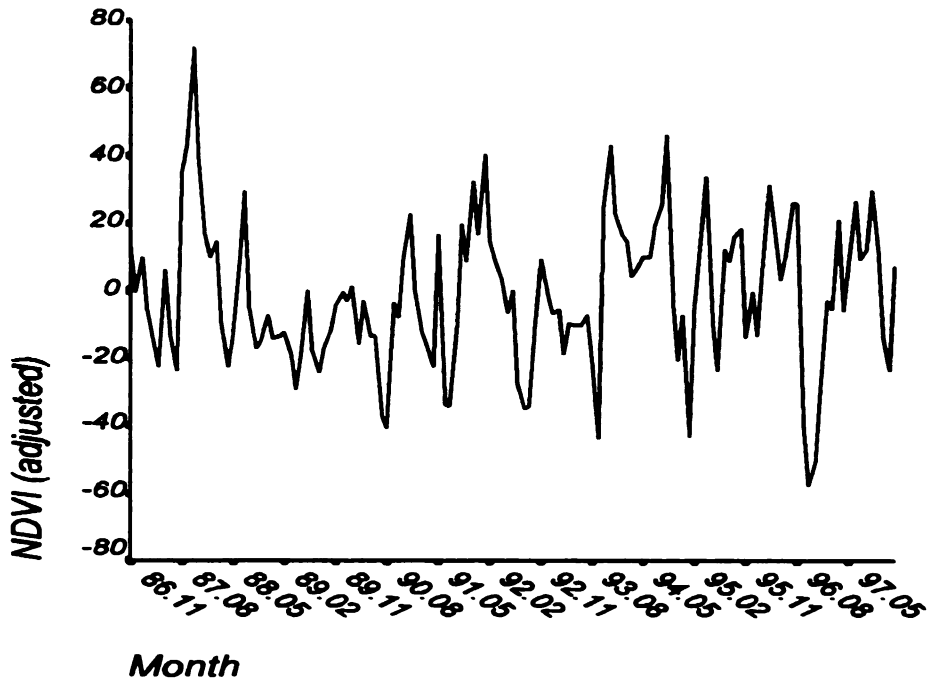


Table 4.6.1 Douentza Results from Augmented Dickey-Fuller and Perron Tests of the Null Hypothesis of Non-Stationarity with and without a Structural Shift at Devaluation

Number of Lags	Adjusted NDVI (ADF)		Retail Millet Price Assumes no structural break (ADF)		Retail Millet Price Assuming Structural Break (Intercept Shift) (Perron)		Retail Millet Price Assuming Structural Break Trend Shift (Perron)		Retail Millet Price Assuming Structural Break (Intercept & Trend Shift) (Perron)	
	ADF	Root Value	ADF	Root Value	Critical Value	Root Value	Critical Value	Root Value	Critical Value	Root Value
2	-4.62***	-.440	-3.89**	-.184	-3.74*	-.325	-3.99**	-.379	-3.90*	-.379
4	-4.19***	-.472	-3.85**	-.203	-3.45	-.303	-3.97**	-.426	-3.87*	-.428
8	-3.76**	-.488	-2.79	-.177	-2.68	-.287	-3.31	-.447	-3.16	-.448
10	-3.24*	-.469	-2.78	-.189	-2.41	-.312	-3.46	-.508	-3.32	-.519
12	-2.59	-.418	-3.13*	-.220	-2.76	-.361	-3.97**	-.621	-3.93*	-.672

*, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

Figure 4.6.1 Douentza: Retail Millet Price

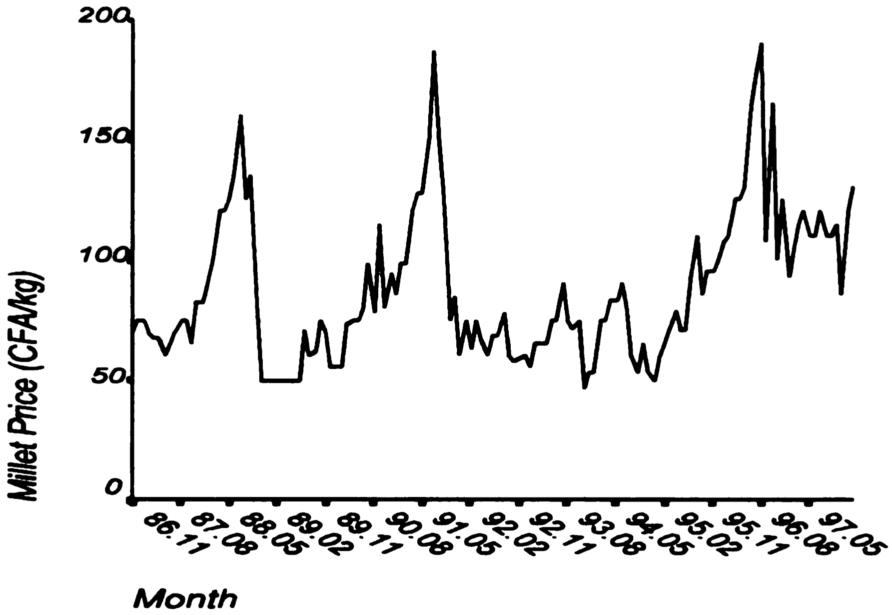


Figure 4.6.2 Douentza: Adjusted NDVI

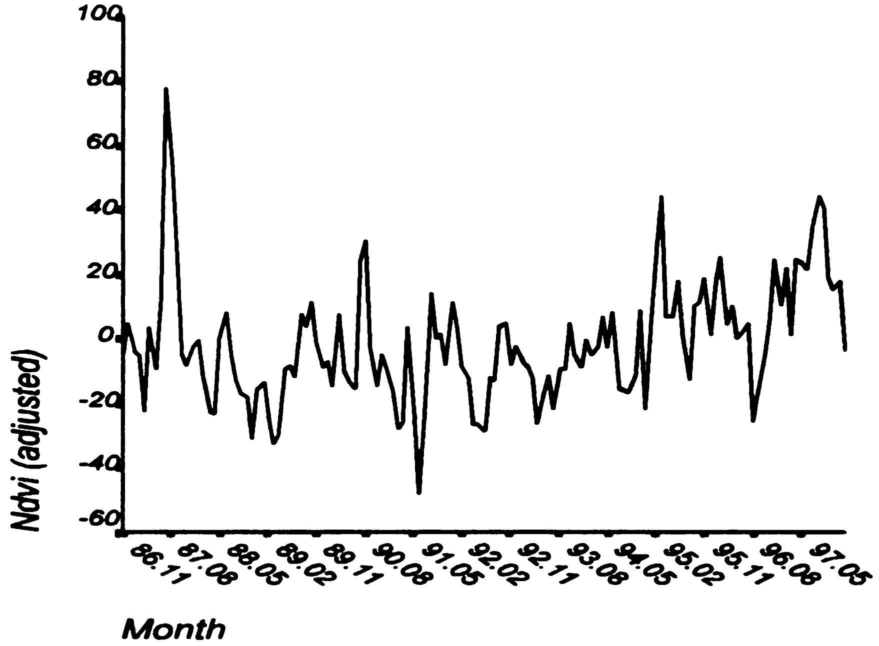


Table 4.7.1 Tenenkou Results from Augmented Dickey-Fuller and Perron Tests of the Null Hypothesis of Non-Stationarity with and without a Structural Shift at Devaluation

Number of Lags	Adjusted NDVI (ADF)		Retail Millet Price Assumes no structural break (ADF)		Retail Millet Price Assuming Structural Break (Intercept Shift) (Perron)		Retail Millet Price Assuming Structural Break Trend Shift (Perron)		Retail Millet Price Assuming Structural Break (Intercept & Trend Shift) (Perron)	
	ADF	Root Value	ADF	Root Value	Critical Value	Root Value	Critical Value	Root Value	Critical Value	Root Value
2	-5.69***	-.488	-3.94**	-.183	-3.00	-.352	-3.88**	-.389	-4.91**	-.421
4	-5.02***	-.518	-3.36*	-.174	-3.17	-.356	-3.44	-.387	-3.69	-.421
8	-3.88**	-.532	-3.03	-.187	-2.99	-.365	-3.41	-.472	-3.48	-.512
10	-3.67**	-.540	-3.39*	-.224	-3.34	-.439	-3.94**	-.591	-4.07*	-.667
12	-4.50***	-.723	-3.13*	-.229	-3.06	-.449	-3.78*	-.646	-3.95	-.740

*, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

Figure 4.7.1 Tenenkou: Retail Millet Price

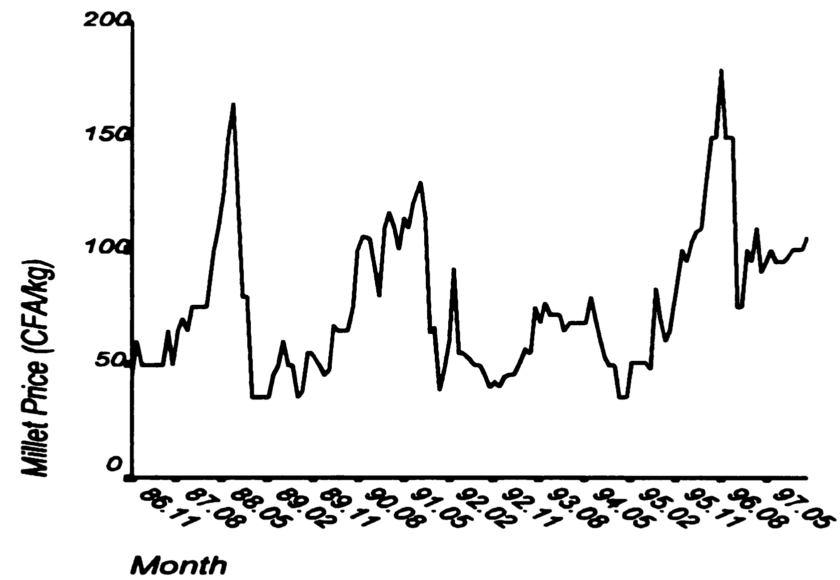


Figure 4.7.2 Tenenkou: Adjusted NDVI

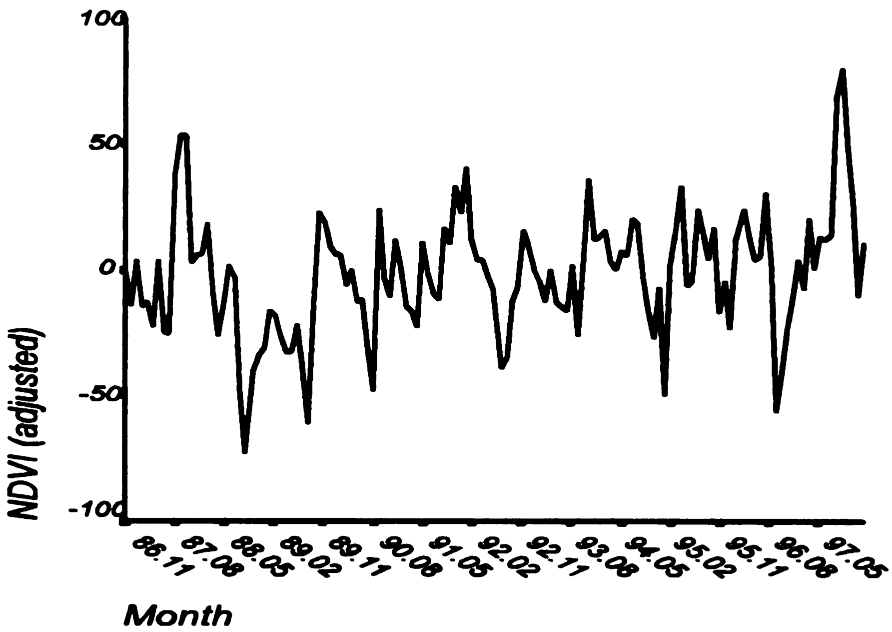


Table 4.8.1 Youvarou Results from Augmented Dickey-Fuller and Perron Tests of the Null Hypothesis of Non-Stationarity with and without a Structural Shift at Devaluation

Number of Lags	Adjusted NDVI (ADF)		Retail Millet Price Assumes no structural break (ADF)		Retail Millet Price Assuming Structural Break (Intercept Shift) (Perron)		Retail Millet Price Assuming Structural Break Trend Shift (Perron)		Retail Millet Price Assuming Structural Break (Intercept & Trend Shift) (Perron)	
	ADF	Root Value	ADF	Root Value	Critical Value	Root Value	Critical Value	Root Value	Critical Value	Root Value
2	-4.98***	-.406	-3.56**	-.160	-3.38	-.354	-3.86**	-.343	-3.78	-.451
4	-4.11***	-.388	-3.35*	-.166	-2.88	-.331	-3.44	-.323	-3.33	-.496
8	-3.03	-.350	-2.69	-.157	-2.39	-.316	-3.11	-.312	-2.96	-.491
10	-3.31*	-.382	-2.37	-.148	-2.17	-.306	-2.95	-.302	-2.76	-.507
12	-3.77**	-.473	-2.96	-.192	-2.73	-.406	-3.80*	-.370	-3.78	-.758

*, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.

Figure 4.8.1 Youvarou: Retail Millet Price

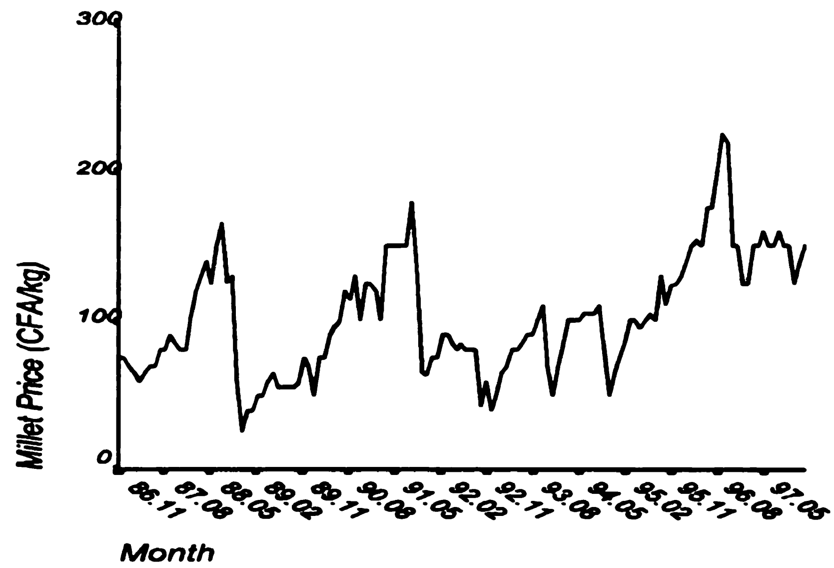
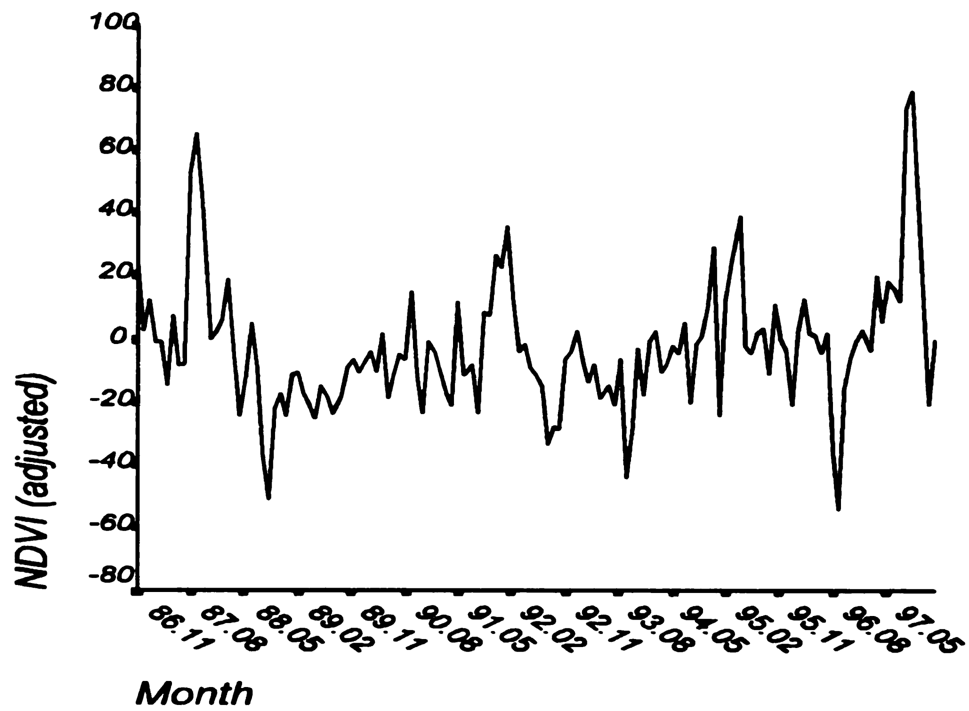


Figure 4.8.2 Youvarou: Adjusted NDVI



A4.4 The single Index of Vulnerability to Food Insecurity

Table A4.5 provides a summary of turning points as they relate to the reference cycles developed in Chapter 3.

Segou

Segou tends to be a far more food secure cercle relative to the other cercles in this study. Overall, we find the vulnerability index in Figure A4.41 depicting a gradual increase in vulnerability in Segou over the sample period, April 1988 through April 1998. There are some distinct turning points throughout the sample period which opens with a relatively high level for the vulnerability index which falls toward the beginning of 1988's hungry season. The index shows a general decline until it reaches its nadir in late 1989. The main concern in the cercle rests with the refugee populations, otherwise food security is reported as good.

The turning point in September 1989 foreshadows sharp price increase in October and the problems for six villages which are abandoned in search of food due to pest damage. The index shows an upturn in late 1991 which leads the problems reported in the SAP assessments in 1992 where a continued increase in vulnerability conditions is noted. Food security improves post-harvest as captured in Segou's vulnerability index.

The next turning point occurs in February 1995, from March through May there are outbreaks of measles and meningitis. The vulnerability index continues its upward climb and appears to capture these conditions of vulnerability to food insecurity. Overall, conditions seem to improve post-harvest 1996 and this is reflected in the index. The index appears to level off in August 1997 which corresponds to a good harvest.

The vulnerability index constructed for Segou appears to capture significant turning points with a month or two lead time to when the SAP assessments indicate problems. The single-index appears to capture the consistent increase in vulnerability in Segou after 1992 when household resources are noted as weakest in the period under investigation and when the adjusted NDVI has relatively higher volatility.

Figure A4.4.1 Segou Vulnerability Index and Reference Cycle Mapping of Vulnerability to Food Insecurity April 1988 to January 1998

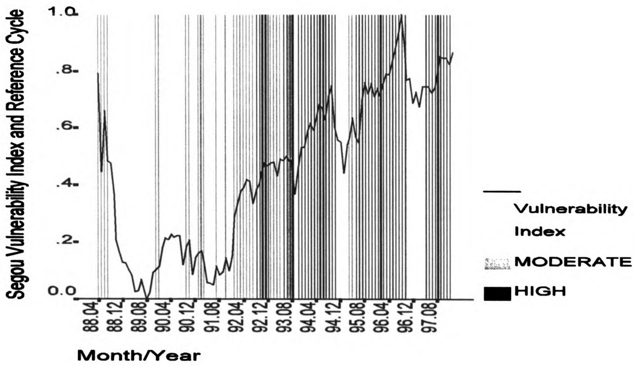


Table A4.4.1 Parameter Estimates for the Vulnerability Index, Segou (1,2)

Parameter	Parameter Estimate	Standard Errors
ϕ_1	1.7599	.2371
ϕ_2	-.7646	.2364
γ_1	-.4720	.0945
γ_{11}	.4887	.0851
ψ_{11}	1.4716	.2703
ψ_{12}	-.5414	.1989
σ_1	.0235	.0509
γ_2	.0884	.0801
γ_{21}	-.1683	.1317
γ_{22}	.1023	.0820
ψ_{21}	.3586	.1043
ψ_{22}	-.0321	.0187
σ_2	.6774	.0918
Likelihood Value		-22.68

DJenne

The vulnerability index for Djenne (see Figure A4.4.2) has as its nadir the beginning of the sample period. We note that the series that underlie the index, millet prices and the adjusted NDVI both have their lowest values in November 1986. Significant levels of food aid are delivered from October through December 1986 that may contribute to this low starting point. There is a sharp increase in the index that persists through to harvest of 1988 which depict an progression in the level of vulnerability to food insecurity.

The turning point of March 1989 depicts the upcoming rise in prices and the poor harvest which contributes to the decline in food security for households for 1990 and 1991. The DJenne vulnerability index shows a steep increase over this period during which there are severe measles outbreaks in the cercle, dramatic price increases, low quantities of cereals marketed, and many areas that are declared at risk. An index turning point occurs in December 1991 foreshadowing moderate vulnerability in the later part of 1992. The next turning point of July 1993 appears ahead of the September onset of more vulnerable conditions throughout the cercle.

The next major turning point in the vulnerability index appears in late 1995 and is an early indication of a poor harvest and increases in migration in search of food. Prices increase throughout the cercle with Konio in the North particularly vulnerable. Food aid deliveries in May and June improve conditions although major problems in Konio persist. Here the index seems to overstate vulnerability conditions when compared to the SAP assessments. The index captures the moderate vulnerability conditions in 1997 irregular migration, price increases and a poor harvest create problems for households from October into January 1998, the end of the sample period.

Overall, the DJenne vulnerability index captures the major turning points in threats to food security over the sample period. It seems to overstate the severity of conditions in 1996 which may be a result of the entire Mopti region experiencing a poor harvest in 1995/96 thus creating very high prices for millet in the region.

Figure A4.4.2 DJenne Vulnerability Index and Reference Cycle Mapping of Vulnerability to Food Insecurity November 1986 to January 1998

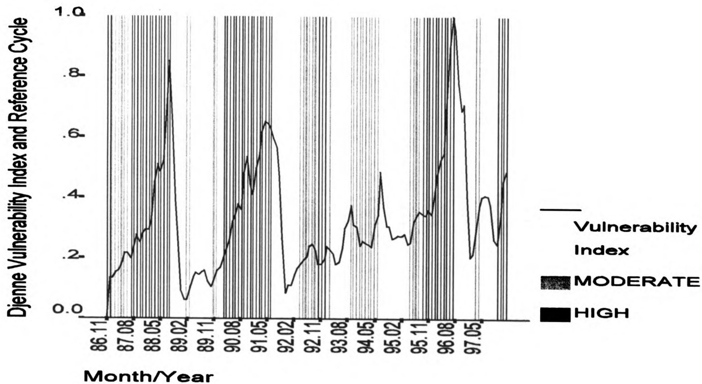


Table A4.4.2 Parameter Estimates for the Vulnerability Index, Djenne (1,3)

Parameter	Parameter Estimate	Standard Errors
ϕ_1	1.2003	.4333
ϕ_2	-.3418	.3742
γ_1	.3779	.1427
γ_{11}	-.1741	.2106
ψ_{11}	1.5390	.1687
ψ_{12}	-.5921	.1298
σ_1	.0295	.5190
γ_2	.1235	.0845
γ_{21}	-.1295	.1028
γ_{22}	.0873	.0893
γ_{23}	-.1297	.0862
ψ_{21}	.6338	.0854
ψ_{22}	-.1004	.0271
σ_2	.6282	.0756
Likelihood Value		4.60

Douentza

As with DJenne, the vulnerability index created for Douentza presented graphically in Figure 4.4.3 begins at the nadir for for the same reasons. The index depicts high vulnerability to food insecurity throughout 1987 and 1988 with a major jump at harvest time in 1987. The vulnerability index captures the increase in vulnerability with a turning point in July 1989 providing a one month advance indicator as depicted by the SAP reports.

The Douentza index hovers around the August 1990 level until its next turning point in April 1991. In early 1991, conditions in the cercle are reported to include some migrations in search of food and areas at risk. The food security conditions improve after harvest although some arrondissments are under surveillance. The index continues to decline and this corresponds to a satisfactory food security situation in the cercle as reported by SAP. There is some migration out of Douentza cercle due to poor conditions. Household reserves are noted as weak as of October 1993. The index does not seem to capture this situation perhaps because of the large food aid deliveries or that the problems are localized to the North. The vulnerability index appears to capture this as there is a turning point in February 1994 with a rise that continues until the harvest which was very good in 1994.

Conditions deteriorate throughout 1997 and are exacerbated by an influx of refugees. The index continues to rise over this period . Overall, the vulnerability index captures the vulnerability conditions with some lead time for most of the sample period. However, it fails to capture the vulnerability situation in 1993 perhaps because of the significant food aid deliveries in the region depressing prices and thus a signal through prices is absent or appropriately signaling the need for food aid.

Figure A4.4.3 Douentza Vulnerability Index and Reference Cycle Mapping of Vulnerability to Food Insecurity November 1986 to January 1998

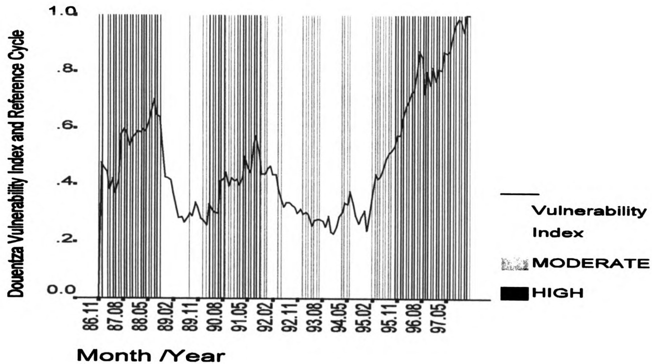


Table A4.4.3 Parameter Estimates for the Vulnerability Index, Douentza (3,3)

Parameter	Parameter Estimate	Standard Errors
ϕ_1	1.8604	.1174
ϕ_2	-.8653	.1092
γ_1	.1473	.0829
γ_{11}	-.4289	.1029
γ_{12}	.4924	.0900
γ_{13}	-.1910	.1140
ψ_{11}	1.1359	.1034
ψ_{12}	-.4329	.0680
σ_1	.0831	.2460
γ_2	-.0130	.0575
γ_{21}	.1289	.1050
γ_{22}	-.0679	.1214
γ_{23}	-.0368	.0090
ψ_{21}	.6212	.0982
ψ_{22}	-.0965	.0305
σ_2	.5784	.0731
Likelihood Value		-5.1249

Tenenkou

The first dramatic turning point for the Tenenkou vulnerability index (Figure A4.4.4) appears in September 1988. Vulnerability increases throughout 1988 with many areas with household reserves exhausted by May and access and cost of cereals prohibitive by June. The poor harvest of 1989 pushes up prices and there is a noted decline in cereals in the market. These conditions of high vulnerability appear to be captured by the index with a sharp increase from the nadir of the index in September 1989.

The index is increasing during 1991 and 1992 with a turning point in October 1992, providing one month advance notice of the increase in vulnerability in November 1992. By September 1994 conditions improve as a good harvest ensues and is reflected as a drop in the vulnerability index. There is a sharp increases in the index in early 1995 which corresponds to a high level of disease among livestock, a key income source in the region. There is also a high level of cholera and measles reported as well an influx of refugees. These conditions along with a poor harvest create conditions of high vulnerability in the cercle until harvest.

Overall, the index constructed for Tenenkou captures significant turning points accurately and in advance of assessments made by SAP.

Figure A4.4.4 Tenenkou Vulnerability Index and Reference Cycle Mapping of Vulnerability to Food Insecurity October 1986 to January 1998

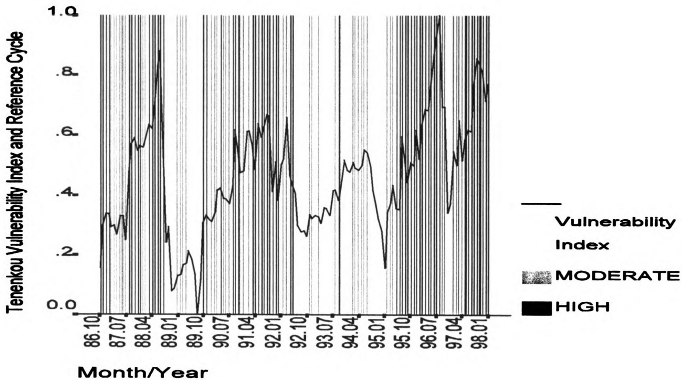


Table A4.4.4 Parameter Estimates for the Vulnerability Index, Tenenkou (1,2)

Parameter	Parameter Estimate	Standard Errors
ϕ_1	1.6045	.1570
ϕ_2	-.6436	.1259
γ_1	-.3293	.0887
γ_{11}	.4453	.0555
ψ_{11}	1.3171	.3942
ψ_{12}	-.4337	.2596
σ_1	.0290	.0410
γ_2	.0455	.0841
γ_{21}	.1434	.0913
γ_{22}	-.1292	.0677
ψ_{21}	.0642	.0892
ψ_{22}	-.0913	.0269
σ_2	.5535	.0667
Likelihood Value		1.02

Youvarou

The index constructed for Youvarou (Figure A4.4.5) has similar turning points to the Tenenkou index with the exception of the end of the sample period. Increases in the index persist until August 1988 when improvements are noted from the effect of food aid deliveries and stable conditions return due to a good harvest that serves to reconstitute household reserves.

The index shows May 1993 as a turning point for moderate vulnerability in the cercle, this is confirmed by the SAP assessments with progressively increasing prices, measles outbreaks, and low levels of millet in markets by August. The index appears to capture conditions throughout 1994,1995, and 1996; there is an improvement in food security when a good harvest ensues. By April 1997 there is another turning point indicating moderate vulnerability for the rest of 1997 which appears to understate the severity of conditions as presented in the SAP assessments. However, the next turning point in January 1998 is captured.

Overall, the Youvarou vulnerability index appears to capture the significant turning points in the food security conditions in the cercle. The index does fail to capture the magnitude to problems occurring in 1997 but does report relatively moderate vulnerability.

Figure A4.4.5 Youvarou Vulnerability Index and Reference Cycle Mapping of Vulnerability to Food Insecurity October 1986 to January 1998

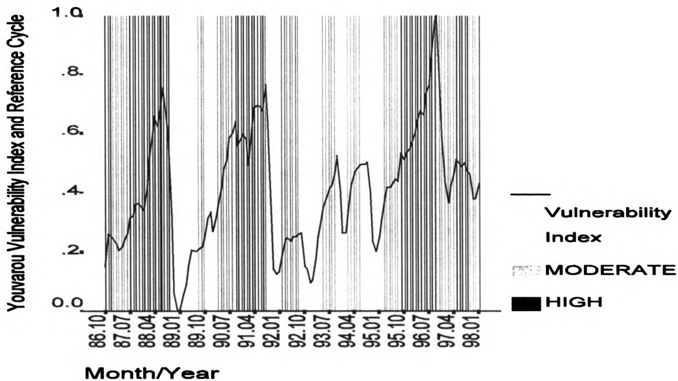


Table A4.4.5 Parameter Estimates for the Vulnerability Index, Youvarou (1,1)

Parameter	Parameter Estimate	Standard Errors
ϕ_1	1.3037	.2831
ϕ_2	-.4249	.1845
γ_1	.3960	.0284
γ_{11}	-.1509	.1039
ψ_{11}	1.8704	.1861
ψ_{12}	-.8746	.1741
σ_1	.0005	.00025
γ_2	-.0238	.0724
γ_{21}	-.0072	.0750
ψ_{21}	.6511	.0812
ψ_{22}	-.0362	.0815
σ_2	.5972	.0682
Likelihood Value		22.73

A.4.5 Comparing the Single Index of Vulnerability to Food Insecurity and the Simple Index

Figure A4.5.1 through A4.5.5 provide a mapping of the reference cycles, the simple index (exponentially smoothed millet prices), and the single index of vulnerability to food insecurity. A brief discussion of the mappings follows.

Segou

The Segou simple index (Figure A4.5.1) captures the increase in vulnerability post-1995 with a coincident turning point. The highest values for the simple index appear in this time frame appropriately. However, shifts in vulnerability in earlier periods are not depicted with timeliness. The single index increases appropriately with turning points that capture the more dramatic shifts in vulnerability conditions. This rise reflects the upwrd trend in NDVI in Segou. In Segou, the more complex index is superior to the simple index.

DJenne

Figure A4.5.2 reveals the single index for DJenne to provide key turning points ahead of the simple index. The single index also capture the severity of conditions more appropriately (higher index values correspond to higher vulnerability levels. However, the results suggest that both indexes fail to capture the moderate vulnerability conditions in mid-1994.

Douentza

The simple and single indexes (Figure A4.5.3) mark similar performances post-1995. However, the simple index performs better by appropriately capturing vulnerability conditions in late 1990 and into early 1992.

Tenenkou

The simple index provides smoother and more distinctive turning points with appropriate levels relative to the single index (Figure A4.5.4). Here the adjusted NDVI doesn't improve upon the simple index performance as an early warning indicator. This may be due to the fact that Tenenkou is primarily a livestock trading region rather than a agricultural area.

Youvarou

The results for Youvarou are similar to those of Tenenkou. The simple index appears to outperform the single index. Households depend on the market for their grain and cereal staples so the exponentially smoothed millet price, the simple index, might have more use as an early warning indicator in these regions. Market forces depict conditions of vulnerability to food insecurity through the simple index.

Table A4.4.5 Comparing the Smoothed Millet Price Index and the Reference Cycles

Region	Periods of Moderate Vulnerability	Periods of High Vulnerability	Key Turning Points in Simple Millet Index	Key Turning Points in Vulnerability Index
Segou	April 1988 to July 1988 November and December 1989 September and October 1990 January 1991 to March 1991 July and October 1991 January to July 1992 January to April 1993 March and April 1995	August to December 1992 May 1993 to October 1994 May 1995 to October 1995 April to December 1997	February 1990 July 1993 June 1995	August 1989 October 1991 September 1993 November 1994 January 1997
DJenne	January 1987 to June 1987 February and March 1989 November and December 1989 April 1992 to September 1992 February 1993 September 1993 to June 1994 May 1995 to August 1995 March and April 1997	November and December 1986 July 1987 to August 1988 February 1990 to June 1991 November and December 1992 September 1995 to July 1996 October 1997 to January 1998	August 1987 March 1990 June 1995	November 1986 March 1989 October 1989 January 1992 June 1995 October 1997
Douentza	August 1989 January and February 1990 September to December 1990 October 1991 to May 1992 January 1993 to July 1993 March to June 1994 February 1995 to September 1995	November 1986 to September 1988 March to August 1990 January to September 1991 October 1995 to January 1998	November 1987 April 1990 March 1995	November 1986 March 1990 January 1995

Region	Periods of Moderate Vulnerability	Periods of High Vulnerability	Key Turning Points in Simple Millet Index	Key Turning Points in Vulnerability Index
Tenenkou	February to July 1987 January and February 1988 January to April 1989 January to July 1990 February and March 1992 November 1992 to February 1993 August 1993 to October 1993 February 1994 to July 1994 February to April 1995 September 1996 to April 1997	October 1986 to January 1987 August 1987 to December 1987 March to August 1988 October and November 1989 April 1990 March 1991 to May 1992 May 1995 to August 1996 May 1997 to January 1998	August 1987 February 1990 May 1993 July 1995 January 1998	July 1987 December 1988 September 1989 August 1992 January 1995 October 1996
Youvarou	January 1987 to June 1987 August 1989 to August 1990 February to August 1992 May to September 1993 February to June 1994 March to August 1995 October 1996 to April 1997 October 1997 to January 1998	October to December 1986 July 1987 to September 1988 September 1990 to July1991 September 1995 to September 1996 May 1997 to September 1997	June 1987 January 1990 March 1993 March 1995	April 1987 January 1989 December 1991 February 1993 February 1994 December 1994 April 1997 *Note: Decline in NDVI*

Figure A4.5.1 Segou Vulnerability Index, Simple Index, and Reference Cycle Mapping of Vulnerability to Food Insecurity April 1988 to January 1998

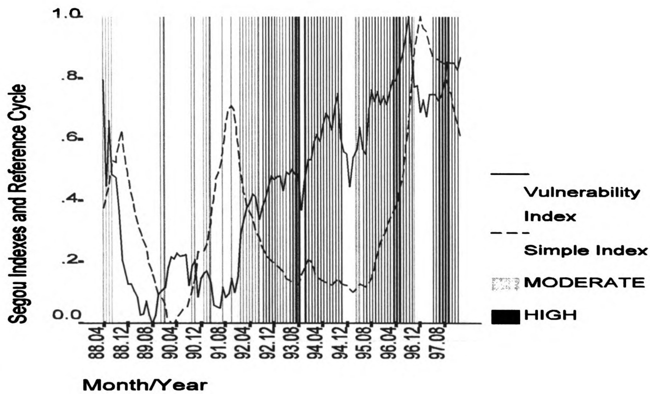


Figure A4.5.2 DJenne Vulnerability Index, Simple Index, and Reference Cycle Mapping of Vulnerability to Food Insecurity November 1986 to January 1998

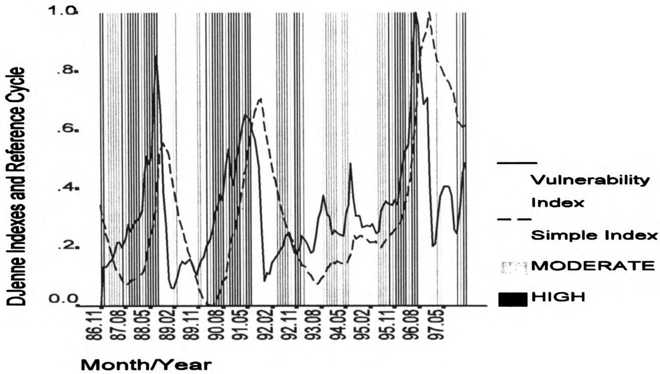


Figure A4.5.3 Douentza Vulnerability Index, Simple Index, and Reference Cycle Mapping of Vulnerability to Food Insecurity November 1986 to January 1998

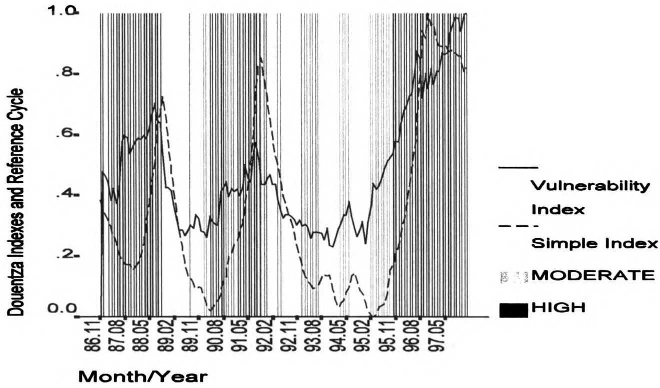


Figure A4.5.4 Tenenkou Vulnerability Index, Simple Index, and Reference Cycle Mapping of Vulnerability to Food Insecurity October 1986 to January 1998

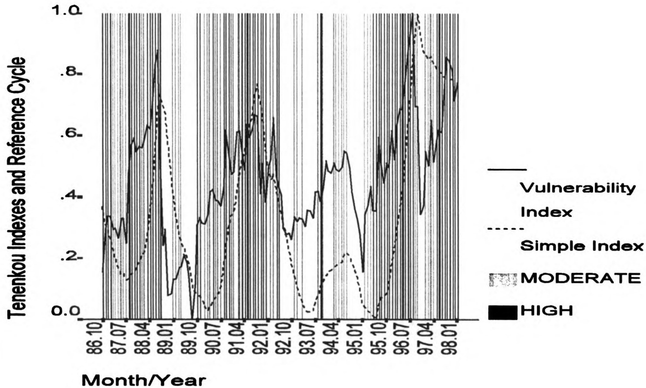
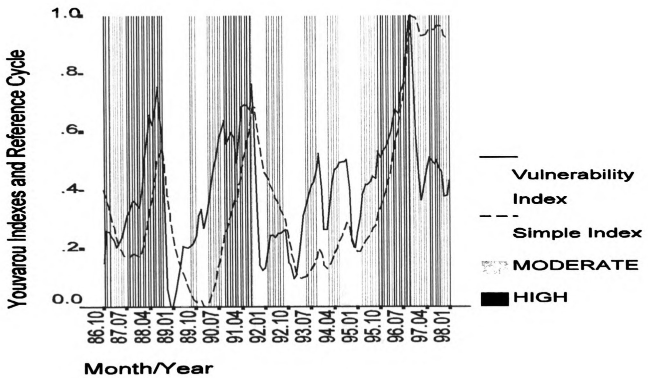


Figure A4.5.5 Youvarou Vulnerability Index, Simple Index, and Reference Cycle Mapping of Vulnerability to Food Insecurity October 1986 to January 1998



References

Alamgir, M., 1981. "An Approach toward a theory of famine." In J. Robson (ed.) *Famine: Its Causes, Effects, and Management*. Gordon and Breach, New York

Alderman, Harold, 1992. "Intercommodity Price Transmittal: Analysis of Food Markets in Ghana." *Working Paper* #884, World Bank, Washington, D.C.

Balke, N.S. and T. B. Fomby, 1997. "Threshold Cointegration." *International Economic Review* 38, *627-46*

Banerjee, Anindya, Juan Dolado, John W. Galbraith, and David F. Hendry, 1993. *Cointegration, Error-Correction, and the Econometric Analysis of Non-stationary Data.* Oxford University Press, Oxford.

Becker, Jasper, 1996. *Hungry Ghosts: Mao's Secret Famine*. The Free Press, a Division of Simon and Schuster Inc., New York, NY

Bingen, R. James, David Robinson and John M. Staatz, 2000. *Democracy and Development in Mali.* Michigan State University Press, East Lansing

Brock, Karen, 1999. "Implementing a Sustainable Livelihoods Framework for Policy-Directed Research: Reflections from Practice in Mali." *IDS Working Paper* No 90, Brighton: IDS

Buchanan-Smith, M. and Susanna Davies, 1995. *Famine Early Warning and Response: The Missing Link*. Intermediate Technology Publications, London

Burns, A.F. and W.C. Mitchell, 1946. *Measuring Business Cycles, NBER Studies in Business Cycles No. 2*. Columbia University Press, New York

Campbell, John Y., 1987. " Does Saving Anticipate Declining Labor Income?: An Alternate Test of the Permanent Income Hypothesis." *Econometrica 55: 124-73*

Campbell, John Y., and Robert J. Shiller, 1988. "Interpreting Cointergrated Models." *Journal of Economic Dynamics and Control* 12:505-22

Chambers, R., Longhurst R. and Pacey, A. (eds) 1981. *Seasonal Dimensions to Rural Poverty.* Frances Pinter, London

Chen, R., 1995. "Threshold Variable Selection in open-loop threshold autoregressive models." *Journal of Time Series Analysis* 16, 461-81

Crow, B. 1986. "U.S. Policies in Bangladesh: The Making and Braking of Famine?" *Development Policy and Practice: Working Paper No. 4.* The Open University, Milton Keynes

Davidson, Russell and James G. Mackinnon, 1993. *Estimation and Inference in Econometrics.* Oxford Univesity Press, Oxford

Davies, Susanna, 1996. *Adaptable Livelihoods: Coping with Food Insecurity in the Malian Sahel.* St. Martin's Press, Inc, New York

de Leeuw, Frank, 1991. "Toward a theory of leading indicators." In K. Lahiri and G. Moore (eds.), *Leading Economic Indicators: New approaches and forecasting records.* Cambridge University Press, Cambridge

Dembélé, Niama Nango and Staatz, John M., 1999. "The Impact of Market Reform on Agricultural Transformation in Mali", paper presented at the Tegemeo/ECAPAPA/MSU/USAIDWorkshop on Agricultural Transformation, Nairobi, Kenya June 27-30, 1999

Desai, Meghnad, 1988. "The Ecology of Famine". In G. Harrison (ed.), *Famine.* Oxford University Press, Oxford

Devereux, Stephen, 1993. *Theories of Famine.* Harvester Wheatsheaf, Hertfordshire, Great Britain

de Waal, A., 1989. *Famine that Kills: Darfur, Sudan, 1984-85.* Claredon Press, Oxford

Downing, Thomas, 1991. *A Framework for Vulnerability Assessment.* FEWS Working Paper. USAID, Washington, D.C.

Drèze, Jean (ed.), 1999. "The Economics of Famine." *The International Library of Critical Writings in Economics,* Elgar Reference Collection, Cheltenham, UK

Drèze, J. and Sen, A., 1989. *Hunger and Public Action*". Clarendon Press, Oxford

Drèze, J., A. Sen, and A. Hussain, 1995. *The Political Economy of Hunger.* Claredon Press, Oxford

D'Souza, F. 'Famine: Social Security and an Analysis of Vulnerability'. In G. Harrison (ed.), Famin". Oxford University Press, Oxford

Engle, R.F. and C.W.J. Granger, 1987. " Co-integration and Error-correction: Representation, Estimation and Testing." *Econometrica,* 55, 251-276

Fackler, Paul L., 1994. "Spatial Equilibrium and Tests of Market Efficiency and Integration.." *Working Paper*. Department of Agricultural and Resource Economics, North Carolina State University

FEWS, 1999. *FEWS Current Vulnerability Assessment Guidance Manual.* FEWS/USAID Washington, D.C.

Franses, Philip Hans and Van Djik, Dick. *Non-linear Time Series Models in Empirical Finance*. Cambridge University Press, Cambridge, 2000.

Glantz, M. (ed.) *Drought and Hunger in Africa: Denying Famine a Future*. Cambridge University Press, Cambridge, 1987.

Goodwin, B. and N. Piggott, 2001. "Spatial Market Integration in the Presence of Threshold Effects." *American Journal of Agricultural Economics*

Granger, C.W.J., 1981. " Some Properties of Time-series Data and their use in Econometric Model Specification." *Journal of Econometrics,* 16, 121-130

Granger, C.W. J. and Terasvirta, T., 1993. "Modelling Nonlinear Economic Relationships. " Oxford University Press, Oxford

Hamilton, James D., 1994. "Time Series Analysis." Princeton University Press, Princeton, New Jersey.

Hansen, B. E., 1997. "Inference in TAR Models." *Studies in Nonlinear Dynamics and Econometrics* 2, 1-14.

--------, 2000. "Testing for Threshold Integration." *Working Paper*, University of Wisconsin, Madison, Wisconsin (online)

Harrison, G. (ed.), 1988. *Famine.* Oxford University Press, Oxford

Harriss, Barbara, 1979. "Is There Method in my Madness: Or is it Vice Versa? Measuring Agricultural Market Performance." *Food Research Institute Studies*, Vol XVII, No 2: 197-218

Harvey, Andrew, 1990. *The Econometric Analysis of Time Series.* Wiley and Sons. New York, New York

--------- 1989. *Forecasting, Structural Time Series Models and the Kalman Filter*. Cambridge University Press, Cambridge

Hendry, David F., 1995. *Dynamic Econometrics.* Oxford University Press, Oxford.

____ 1993. *Econometrics: Alchemy or Science?* Blackwell Publishers, Oxford, UK and Cambridge, USA

Hendry, David F. and Mary S. Morgan, 1995. *Foundations in Econometric Analysis.* Cambridge University Press, Cambridge

Hussein, Karim and John Nelson, 1998. "Sustainable Livelihoods and Livelihood Diversification." *IDS Working Paper* No 69, Brighton: IDS

Johansen, S., 1988. "Statistical Analysis of Cointegrated Vectors." *Journal of Economic Dynamics and Control,* 12: 231-254

Johansen, S. and K. Juselius, 1989. "The Full Information Maximum Likelihood Procedure for Inference on Cointegration–with Applications." *Preprint 1989 #4, Institute of Mathematical Statistics*, University of Copenhagen. 58 pp

Jordon, William Chester, 1996. *The Great Famine: Northern Europe in the Fourteenth Century*. Princeton University Press, Princeton, New Jersey.

Kim, Chang-Jin and Charles R. Nelson, 1999. *State-Space Models with Regime Switching*. MIT Press, Cambridge, Massachusetts

Koop, G., M.H. Pesaran and Potter, 1996. " Impulse response analysis in nonlinear multivariate models." *Journal of Econometrics* 74, 119-47

Lahiri, Kajal and Moore, G.H., (eds.), 1991. *Leading Economic Indicators: New Approaches and Forecasting Records*. Cambridge University Press, Cambridge

Maddala, G.S. and In-Moo Kim, 1998. *Unit Roots, Cointegration, and Structural Change*. Cambridge University Press, Cambridge

Martens, M., P. Kofman and A.C.F. Vorst, 1998. " A threshold error correction for interday futures and index returns." *Journal of Applied Econometrics* 13, 245-63

Newman, Lucile F. (ed), 1995. *Hunger in History: Food Shortage, Poverty, and Deprivation*. World Hunger Program, Brown University Press, Massachusetts

Pierstrup-Andersen, 2000. Food Policy Research for Developing Countries: Emerging Issues and Unfinished Business, *Food Policy* v25, no. 2:125-41

Potter, S. M., 1995. "A Nonlinear Approach to US GNP." *Journal of Applied Econometrics* 10: 109-125

Poulton, Robin-Edward and Ibrahim ag Youssouf, 1998. *A Peace of Timbuktu: Democratic Governance, Development, and African Peacemaking.* United Nations, New York and Geneva

Rakodi, Carole, 1999. "A Capital Assets Framework for Analyzing Household Livelihood Strategies: Implications for Policy." *Development Policy Review* 17, 315-342

Ravaillion, M., 1987. *Markets and Famine*. Claredon Press, Oxford

Riley, Frank, 1993. *Vulnerability Assessment*. FEWS Working Paper. USAID, Washington, D.C.

Rivers, J.P.W. 1988. " The Economics of Famine", In G. Harrison (ed.), *Famine*. Oxford University Press, Oxford

Sargent, T. J., and C.A. Sims, 1977. "Business Cycle Modeling without Pretending to have too much a-priori Economic Theory." Iin C. Sims et al., *New Methods in Business Cycle Research.* Minneapolis: Federal Reserve Bank of Minneapolis

Stock, James H. and Mark W. Watson, 1991. "A Probability Model of the Coincident Economic Indicators." In K. Lahiri and G. Moore (eds.), *Leading Economic Indicators: New Approaches and Forecasting Records.* Cambridge University Press, Cambridge

Sen, Amartya, 1981. *Poverty and Famines*. Claredon Press, Oxford

--------------- 1999. *Development as Freedom*. Alfred Knopf Publishing, New York, NY

Steffen, Philip Nathan, 1995. "The Roles and Limits of the Grain Market in Assuring Household Food Security in Northern Mali: Implications for Public Policy". Ph. D. Dissertation, Michigan State University, East Lansing

Timmer, Peter C., 1987. *The Corn Economy of Indonesia.* Cornell University Press, Ithaca, New York.

Tong, H., 1990. *Nonlinear Time Series: A Dynamical Systems Approach*. Oxford University Press, Oxford.

Tsay, R. S., 1989. "Testing and Modeling Threshold Autoregressive Processes." *Quarterly Journal of the American Statistical Association,* 84:231-240.

Walker, P., 1989. *Famine Early Warning Systems: Victims and Destitution.* Earthscan, London

Woolridge, J.M., 1990. "A unified approach to robust, regression based specification tests." *Econometric Theory* 6, 17-43

------------, 1991. "On the application of robust, regression-based diagnostics to models of conditional means and conditional variances." *Journal of Econometrics* 47, 5-46

Von Braun, Jochim, Tsfaye Teklu and Patrick Webb, 1999. *Famine In Africa*. For *The International Center for Food Policy Research* by John Hopkins University Press, Baltimore and London

Yade, Mbaye, Chohin-Kuper, A., Kelly, V., Staatz, J., Tefft, J., 1999. " The Role of Regional Trade in Agricultural Transformation: The Case of West Africa Following the Devaluation of the CFA Franc", Paper presented at the Tegemeo/ECAPAPA/MSU/USAIDWorkshop on Agricultural Transformation, Nairobi, Kenya June 27-30, 1999