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Cost and benefits from regional cooperation on grain reserves: The case of ECOWAS

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In the wake of the 2007/2008 international food crisis, public food reserve re-gained the attention of policy makers. However, they come at high economic and fiscal costs. On the other hand, the imperfect correlation of supply shocks across neighboring countries entails the potential to reduce regional market volatility through intra-regional trade integration and storage cooperation. In this chapter, optimal reserve levels are theoretical derived in order to assess costs and benefits from regional storage cooperation. The model is then applied to the West African region which is in the process of establishing a region-wide reserve. Accordingly, regional stocks under cooperation in an emergency reserve can be 40 percent less than without cooperation. Limited intra-regional trade reduces the need for stock releases significantly. Full market integration would diminish regional consumption variability to 3.4 percent, less than for every other individual West African country, but is not effective in dampening severe supply shortfalls. Cooperation in a stabilization reserve in addition to trade integration has only limited impact on consumption stability, and thus storage cooperation shall be restricted to an emergency reserve.

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1. Introduction

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

Child mortality and general food insecurity in West Africa are among the highest in the world [FAO et al., 2013; von Grebmer et al., 2013]. The region is a major rice importer and is dependent on these imports to meet food consumption targets. International food aid has been an important factor to offset fluctuations in national production, but has decreased rapidly since the middle of the last decade [FAOSTAT, 2014]. For these reasons, the ECOWAS community decided to make plans for a regional emergency reserve.[1]

Regional food reserves are a viable and comparably cheap means, as an alternative to national reserves [FAO et al., 2011; Wright and Cafiero, 2011]. This is not a new idea. International risk sharing and multinational insurance schemes were heavily discussed in the 1970s [Johnson, 1976; Reutlinger et al., 1976; Konandreas et al., 1978]. By the concept of any insurance, pooling national supplies stabilizes regional food availability due to the imperfect correlation of national production shocks [Koester, 1986]. However, potential benefits from cooperation can only be realized when countries agree on common rules under which the reserve operates. In other words, how much each country contributes and under which circumstances releases from the reserve are authorized. This requires that all countries benefit from cooperation vis-à-vis without cooperation.

Academic literature on regional storage cooperation is scant. Existing studies underline the potential of risk sharing without explicitly conceptualizing the link to storage. This study aims at closing the gap by providing a methodology to evaluate potential benefits from regional storage cooperation. The main objective is to examine whether storage cooperation could enhance food security in West Africa. Specifically, various possible storage policies are tested and an efficient

[1] For a detailed description of the current proposal: see ECOWAS Commission et al. [2012].

load distribution among participating countries is discussed. Generally, the methodology is applicable to any group of countries and not limited to West Africa.

The remainder of the chapter is structured as follows. First, section two discusses food security and storage as well as trade as means to increase food availability and introduces the concept of regional cooperation. Then, section three outline a framework to assess benefits from cooperation and continues in defining optimal levels of storage in the presence of stochastic supply in order to stabilize national consumption. Results of the study, including sensitivity analysis, are presented in section four. Section five concludes and discuses policy implications.

2. Food reserves, trade, and benefits from regional cooperation

Annual production is subject to great fluctuation and consequently not sufficient to meet stable consumption needs in non-exporting economies. Food imports and stocks can offset these fluctuations. The empirical literature emphasizes the interchangeability of trade and storage to offset unstable production [Williams and Wright, 1991; Makki et al., 1996, 2001]. There are good reasons to believe that free market stock levels in many developing countries are not sufficiently high or optimal [Newbery and Stiglitz, 1981; Gilbert, 2011a]. Similarly, the potential gains from regional trade are not exhausted by many developing countries [Badiane et. al, 2014]. Gilbert [2011a] suggests considering a country's specific characteristics to determine the right policy. So, exporters can easily regulate domestic food availability by flexible export quantities. Trade is also advantageous if supply shocks between countries are independent or negatively correlated [Koester, 1984; Badiane et. al, 2014]. In contrast, importers and countries that switch between net-importer and net-exporter can successfully insure themselves against high international prices through security stocks. Furthermore, high transportation costs (e.g. for landlocked countries) and/or long periods of shipment make public reserves favorable to trade. Trade can also transmit market instability from partner countries into national markets [Makki et al., 2001]. Moreover, reliance on imports to manage food availability can be problematic when partner countries are non-cooperative and restrict exports at times [Gouel and Jean, 2013]. This was a frequently observed practice during the price surges in 2007/2008 [Martin and Anderson, 2012; Porteous, 2012]. For these reasons, food reserves have a structural advantage over trade integration; at least from a government's perspective.[2]

Broadly, two types of reserves can be distinguished: first, emergency or strategic reserves; and second, buffer stocks. The former is established to overcome food supply shortfalls as consequence of weather related shocks, such as droughts or floods, pests, political instability [Lynton-Evans, 1997]. In the event of a crisis, additional food is brought into the system via targeted food subsidies (e.g. food stamps, food-for-work, school feeding programs etc.). In contrast, buffer stocks operate to generally stabilize commodity prices at both ends of the distribution. In doing so, public institutions buy and sell in order to increase market supply or demand. The objective of the buffer stock is to keep prices within a band of predetermined floor and ceiling prices [Newbery and Stiglitz, 1981]. Purchases and sales can be realized in the open market, but also through contract farming and subsidized sales to public and private entities. The main danger persists in the need to operate permanently which implies to intervene in markets permanently. Intervention levels of existing national reserves and buffer stocks do vary significantly.[3]

The gains from cooperation rest on the concept of risk pooling. Risk pooling or diversification originates from the insurance and finance literature and is the business concept of every insurance company. Pooling uncertain outcomes of multiple individuals reduces the volatility of their joint outcome. Expected losses remain the same, but insurance companies can reduce accrued liabilities if (and only if) losses of policyholders are not perfectly correlated. On the same account, a group of countries can reduce the stocking norm of their food reserves by sharing the risk of supply shocks. Statistically, the co-variance and correlation of individual risks is the key determinant for gains from cooperation. If shocks are idiosyncratic, then risk sharing is feasible. On the contrary,

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[2] On the one hand, deepening trade relations requires the trading partners to be equally willing to cooperate; on the other hand, trade integration usually takes time to establish business relations and trust between actors.

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

if shocks are highly correlated, benefits from cooperation will be small [Townsend, 1995]. From this, it is possible to conclude that supply instability in one region (group of countries) is lower if national supply quantities are independent or negatively correlated. The potential of regional risk sharing with respect to supply shocks of major food crops in Africa is well acknowledged in existing studies [Koester, 1986; Badiane et. al, 2014]. Since supply variability is the reason to acquire food reserves, smaller supply variability implies lower stock levels in the reserve.

Wright and Cafiero [2011] also discuss the role of regional reserves to increase a country's commitment to refrain from export regulation in times of a food crisis. These commitments seem unfeasible under the common WTO discipline. At the same time, governments dispose of ways to impede exportation through over-bureaucratizing of the legal process. Hence, it is conceivable to combine storage and trade cooperation. In doing so, participating countries provide a share of their national supply to be exported (if harvests are sufficiently high) and receive the entitlement to stock releases at periods of crisis in return.

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

3. Assessment of costs and benefits from cooperation

In order to assess costs and benefits from regional cooperation, we compare consumption variability and reserve levels under regional cooperation vis-à-vis without cooperation. In other words, optimal stocking norms are defined for each individual country and for specific groups of countries. If a country's welfare is given by

$$U = H\left[\mathrm{VAR}\big(C(\alpha)\big)\right] - G(\alpha) \qquad (1) \qquad ,$$

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

then welfare increases with consumption stability and decreases with higher stock levels of the reserve. A government chooses the optimal policy by opting for a stock-to-use ratio (α) that maximizes social welfare. Accordingly, there is a trade-off when increasing the stock level of the reserve. Higher stocks guarantee greater consumption stability, but are associated with higher operational costs.

The optimal α maximizes social welfare without cooperation. On the contrary, in case of regional storage cooperation, the level of consumption variability, and thus the optimal stock-to-use ratio, is not anymore determined by the individual country through welfare optimization, but a common decision among all member countries. Heterogeneity among regional partners explains disagreements about common regional policies. For instance, countries with high supply instability may be satisfied with a relatively moderate level of consumption stability. Against this, countries with stable national supply need regional consumption stability to be sufficiently high to benefit from intervention. In regional integration, states hand over decision making power voluntarily to supernational entities and create a political power that overrules national policies [Heinonen, 2006]. Applying a game theoretical approach, the median voter will decide on the level of consumption stability in such a setting [Alesina et. al, 2005]. In consequence, countries with similar economic structures lose less in comparison to countries with deviant structures.

Thus, the benefits from regional risk sharing are evaluated against the costs from a potentially suboptimal choice of the stock-to-use ratio. Following the framework from above, net-benefits (X_i) from cooperation for each country i are given by the difference in social welfare before and after joining the regional agreement:

$$\mathrm{N}_i = \mathrm{H_i}\,[\mathrm{VAR}(\hat{\mathrm{C}}_\mathrm{i})] - \mathrm{H_i}\,[\mathrm{VAR}(\mathrm{C}_\mathrm{i}^*)] + \mathrm{G_i}\,(\alpha_\mathrm{i}^*) - \mathrm{G}_i\,(\hat{\alpha}_\mathrm{i}) \qquad (2)$$

where $\mathrm{VAR}(\mathrm{C}_\mathrm{i}^*)$ is consumption variability resulting from an optimal α_i^* for an individual country without cooperation or the optimal level of target consumption chosen by the country. Analog, $\mathrm{VAR}(\hat{\mathrm{C}}_\mathrm{i})$ is consumption variability under cooperation determined by $\hat{\alpha}$ which is jointly selected by the member countries.

However, without specifying the functions $\mathrm{H_i}$ and $\mathrm{G_i}$ welfare impacts are not unambiguously appraisable. Definite predictions are possible when benefits increase and costs decrease, and vice versa when benefits decrease and costs increase. Yet in the remaining cases a specific functional form of $\mathrm{H_i}$ and $\mathrm{G_i}$ is required or a clear assessment.

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

4. Optimal stocks and stocking rule

In this analysis, two possible reserves are considered. First, an emergency reserve that releases stocks whenever supply falls short of a predetermined level. And second, a buffer stock which stabilizes supply in both directions.

4.1 Emergency reserve

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

$$\mathrm{C_t} = \mathrm{Q_t} + \mathrm{IM_t} - \mathrm{EX}_t = \mathrm{X_t} \qquad (3)$$

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

In case production falls short of a desired level of minimum consumption can be achieved through additional imports. However, the experience, not only from West Africa, shows availability varies drastically from year to year despite food imports. Furthermore, international prices fluctuate and make the food import bill unpredictable [Sarris et al., 2011]. In such a situation, the emergency reserve steps in to lift consumption to the desired minimum level. Following Konandreas et al.

[1978], the desired minimum level is referred to as target consumption level c^* (e.g. 95 % of long-term trend). Then, consumption in a given year is:

$$C_t = \max\left[X_t, c^* E[C_t]\right] \qquad (4)$$

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

In words, when national supply is higher than the target level, consumption just equals total supply. In contrast, whenever supply is lower than the target level, the reserve releases whatever is necessary to close the gap to satisfy at least $c^* \times 100$ % of the expected consumption. In expectation, consumption always equals supply. In order to satisfy (4), stocks need to compensate for supply shortfalls of more than $(1 - c) \times 100$ %. Subsequently, the ratio of consumption to be stored (α) is defined as the ratio between stocks and expected consumption:

$$S^* = \max_t [0, c^* E[X_t] - (X_t)] \;\; for\; t = t_1, \ldots\ldots, t_n \qquad (5)$$

$$\alpha^* = \frac{{S^*}^*}{E[C_t]} \qquad (6)$$

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

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

$${C^R}_t = \sum_i C_{it} \qquad (7)$$

where ${C^R}_t$ is regional consumption which is the sum of the consumption in each member country given by (4).

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

$$S^R = \sum_i S_i^* = \sum_i \max_t [0, {c^*}_i E[X_{it}] - (X_{it})] \;\; for\; t = t_1, \ldots\ldots, t_n \qquad (8)$$

where S^R are regional stocks and all other parameters are described as above.

If national supply shortfalls are not perfectly correlated, then the common regional reserve must carry only enough stocks to balance the sum of shortfalls that occur in a particular year.

$$S^R = \max_t[0, \sum_i \hat{c}\, E[X_{it}] - (X_{it})\ ]\ \ for\ t = t_1, \ldots\ldots, t_n \qquad (9)$$

where $\max_t[0, \sum_i \hat{c}\, E[X_{it}] - (X_{it})\ ]$ is the largest historic shortfall in regional supply over the period t_1 to t_n. $\hat{c}$ is the consumption target under regional cooperation which does not vary across country i. If supply never falls below $\hat{c}\, E[X_t]$, no stocks shall be carried.

The regional reserve shall be endowed with stocks by contributions from its member countries.

$$\widehat{S_i} = s_i\, S^R = \widehat{\alpha} E[X_{it}] \qquad (10)$$

$$with\ \widehat{\alpha} = \frac{S^R}{E[C^R{}_t]} \qquad (11)$$

$$\tilde{S}_i = \frac{S_i}{\sum_{i=1}^{n} S_i}\ S^R \qquad (12)$$

where s_i is a country's share in regional consumption; $\widehat{S_i}$ and $\tilde{S}_i$ are national contributions to the regional reserve under equal and relative contributions. Under equal contributions all countries have the same stock-to-use ratio $\widehat{\alpha}$. Under relative contributions $\widehat{\alpha}_i$ varies across countries by the extent to which national stocks vary across countries without regional cooperation.

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

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

$$T^R{}_t = \sum_i \max[0, X_{it} - E[X_{it}]] \qquad (13)$$

$$S^R = \max_t[0, [\sum_i \hat{c} E[X_{it}] - (X_{it})] - T^R{}_t]\ \ for\ t = t_1, \ldots\ldots, t_n \qquad (14)$$

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

4.2 Stabilization reserve

As opposed to the emergency reserve described in the previous section, the stabilization reserve is derived from the classical storage literature [Gustafson, 1958]. This implies that stocks are part of national supply and demand. In each year a constant portion (γ) of total available supply is stocked in, which is a linear approximation of Gustafson's pioneering stocking rule. In this way, stocks change over time. After years with good harvests, stocks are higher and lower after bad harvests. In doing so, the market identity from above (3), changes to:

$$C_t = X_t - \Delta S_t \qquad (15)$$

$$\Delta S_t = S_{t+1} - S_t \qquad (16)$$

$$S_{t+1} = \gamma(S_t + X_t) \qquad (17)$$

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

Inserting (15) in (14) allows writing consumption as:[4]

$$C_t = (1-\gamma)(X_t) + (1-\gamma)S_t \qquad (18)$$

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

$$S_t^* = \frac{\gamma E[X_t]}{(1-\gamma)} \qquad (19)$$

$$\alpha^* = \frac{\gamma}{1-\gamma} \qquad (20)$$

[4] For the complete analytical derivation: see Kornher (2015).

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

The objective of the stabilization reserve is to stabilize consumption. Hence, eventually the interest is to see how consumption variability depends on the stocking parameter (γ). Taking the variance of (18) yields:

$$\mathrm{VAR}\ (C) = \frac{1-\gamma}{1+\gamma}\ \mathrm{VAR}\ (X) \qquad (21)$$

$$\mathrm{CV}\ (C) = \sqrt{\frac{1-\gamma}{1+\gamma}}\ \mathrm{CV}\ (X) \qquad (22)$$

where $\mathrm{VAR}\ (C)$ and $\mathrm{VAR}\ (X)$ are variance of consumption and supply; $\mathrm{CV}\ (C)$ and $\mathrm{CV}\ (X)$ are the respective coefficients of variation.

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

5. Results

5.1 Supply patterns in West Africa

Table 1 provides economic and agricultural statistics on West African countries involved in this analysis. Heterogeneity between countries exists with respect to income level and food security status. While Ghana and Cape Verde have relatively low prevalence of hunger and malnutrition, still 12 % of the total ECOWAS population is undernourished with alarmingly high figures in the Sahel zone. With the exemption of Mali and to some extent Burkina Faso, all countries depend on imports to guarantee sufficient supply of grain. In general, it is observed that coastal countries have larger import-to-production ratios with a ratio above one in Cape Verde, Cote d'Ivoire, Liberia, Senegal, and Mauritania. Overall Nigeria's prominent role in the region is to note. Due to its population, more than 40 % of regional production originates from Nigeria, and thus the country would take a leading role in any regional cooperation agreement.

[Table 1 here]

The subsequent analysis is based on fluctuations in national food production and supply. Supply is calculated as production plus imports. In this way, extreme fluctuations in production of many import dependent countries are extenuated. Therefore, the analysis with regard to supply shocks is considered to be more instructive. All imports are considered to be from international markets. In the analysis with intra-regional trade, these international imports are considered to be part of the national supply.

Since production increases with agricultural productivity and population growth, unadjusted measures of variability as variance and coefficient of variation become inappropriate measures of variability [Cuddy and Della Valle, 1978]. One possibility is to correct coefficient of variation and variance by the fitness of a trend function [Koester, 1984]. Alternatively, variability can be measured after de-trending the time series. Thus, variability in supply is given as the variation around a trend. A linear trend clearly does not fit to supply data of several countries in the region. Therefore, it is opted for de-trending by the Hodrick-Prescott-filter (HP-filter).[5]

An example is given in Figure 1 that shows national supply in Ghana. Actual supply quantities are depicted by the blue line, while the red line indicates HP-filter trend values for a smoothing parameter of 6.25. The deviation of actual supply from trend supply becomes stationary and variability can be computed by:

$$\mathrm{CV} = \sqrt{{}^{1}\!/_{\mathrm{n}} \sum (\mu - \mathrm{X_t}/\bar{\mathrm{S}}_{\mathrm{t}})^2} \quad /\mu \qquad (23)$$

where $\mathrm{X_t}$ is total supply in t and $\bar{\mathrm{X}}_{\mathrm{t}}$ the trend value of supply determined by the HP-filter. By definition μ equals 1.

Table 2 displays each country's contribution to total regional grain supply in 2014 as well as the coefficient of variation in production and supply over the period from 1980 to 2014. In brief, there are two general observations. First, supply variability is substantially lower than production variability, in particular for countries with high import-production ratio. Second, no country exhibits production and supply variability that is lower than the figure for the region as a whole. Therefore, the basic grounds for benefits from cooperation are factual.

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

[Figure 1 here]

[Table 2 here]

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

5.2. Emergency reserve

This subsection discusses optimal stocking norms for an emergency reserve as defined earlier. The critical parameter to choose is the target consumption level. A target consumption level of j-% can be represented by j-% of annual production (dashed line in Figure 1).[6] The lighter solid line in Figure 1 illustrates this for a target consumption level of 95 %. Then, the deviation of actual supply from target consumption is computed and the maximum historic shortfall identified. In the instance of Ghana, the maximum shortfall happened in 1983. The size of the shortfall depends on the target consumption chosen. Target consumption levels of individual countries are hypothetical and cannot be observed. A possible way to determine target consumption levels is to assume that each country uses the reserve to mitigate the x-% largest supply or production shocks. From the standard deviation of these shocks of each country, the target consumption level with respect to any quantile can be computed. Normalized standard deviations are equal to the coefficient of variation displayed in Table 2. Assuming a normal distribution of supply shocks, target consumption levels across countries for the one, five, and 10 % quantile are displayed in Figure 2.[7]

[6] Recall that production/supply = consumption.

[7] 1, 5, and 10 % quantiles reflect the frequency of interventions of the national reserve. Thus, absorbing the 10 % largest supply shocks demands the highest frequency of supply shocks.

[Figure 2 here]

Figure 2 contains important information. Intuitively, the larger the tail of the distribution (the greater the quintile), the lower target consumption will be. As elaborated above, higher target consumption levels also require larger stocking norms. Second, target consumption levels vary significantly across countries being highest for Nigeria, Cote d'Ivoire, and Guinea, and lowest for Cape Verde. Third, the lower national supply variability, the higher are target consumption levels given a particular quintile. This is also intuitive, the more stable national supply is, the higher target consumption must be to balance relatively moderate supply shocks. In the following, median values will serve as possible target consumption levels for the region. In addition, reserve levels for a target consumption of 99 %, 97 %, 95 %, and 90 % are considered in the simulation.

5.2.1 Emergency reserve without intra-regional trade

The stocking norm is defined as the maximum historic shortfall from target consumption over the past 35 years. The respective stocking norms for all countries and various levels of target consumption are summarized in Table 4. Apart from the median target consumption levels in Table 3, target consumption levels of 99 %, 97 %, 95 %, and 90 % are considered.

Accordingly, optimal stocking norms are highest for large countries. The corresponding stock-to-use ratios show the relative level of the stocking norms. All countries that are characterized by high supply variability also have the largest optimal stocking norms within an emergency reserve. Total regional stocks according to the maximum historic shortfall rule are between 231,137 and 6.2 million tons. The values for target consumption levels of 95 % and above are well in the range of actual stock levels according to USDA and FAO CBS. However, one would define optimal emergency reserve stocks that are smaller than actual stocks since total stocks also include speculative and working stocks of private market participants. In this respect, lower levels of target consumption seem to be more reasonable.

On the other hand, several countries with low supply variability hardly stock anything at target consumption levels below 95 % as seen in Table 3. The table lists optimal stocking norms in 2014 based on supply data for various levels of target consumption by country. Accordingly, Nigeria and Guinea would not store anything with a target consumption of 88 % and below, and thus would not benefit from regional storage under all stocking norms as selected by the median values form Figure 2. With a target consumption level of 84 %, Cote d'Ivoire and Senegal would also quit the regional reserve, followed by Benin, Burkina Faso, Cameroon, Guinea-Bissau, Mali, and Togo. Hence, target consumption needs to be chosen sufficiently high in order to enable benefits from cooperation for all West African countries. For this reason, the subsequent presentation of simulation results in the text is limited to target consumption levels of 90 % and above. Detailed results in table form are shown for a target consumption of 95 %, the detailed results for 90 %, 97 %, and 99 % are presented in the Appendix.

Under storage cooperation, optimal stocking norms can be significantly lower if shortfalls from target consumption levels are independent or not perfectly positively correlated. The potential for the ECOWAS region to benefits from this independencies of production and supply shocks is underlined by analysis of Badiane et al. [2014].

[Table 3 here]

Finally, results for a regional reserve are provided in Table 4. For both production and supply the remaining columns contain the optimal stocking norm under three scenarios. First, optimal stocks without storage cooperation under autarky. Second, stocks for the case of equal contributions to the regional reserve.[8] Lastly, stocks with relative contributions to the regional reserve required under autarky. The first column reveals the probability of shortfalls in production and supply, respectively.[9] The last row contains the total level of stocks for the whole region if countries operate individual reserves, and if they cooperate. Total stocks for individual storage amount to 3,989,905 metric tons for production only and 3,788,989 metric tons for supply, respectively. In contrast, with cooperation regional stocks only need to be 2,342,642 and 2,452,834 metric tons. This equals a reduction by 41 and 35 % compared to the initial amount. Since relative contributions imply that all countries benefit from cooperation in the same manner, the relative reduction applies for all countries alike. The positive effect of regional storage cooperation holds regardless of the rule according to which contributions are shared, but some countries, namely Guinea and Nigeria, do lose with proportionally equal contributions. The difference between both types of contributions for each country is represented in Figure 3.It becomes evident that countries with relatively low levels of supply variability prefer

[8] Equal contributions imply, proportionally equal to a country's share in regional consumption.
[9] The probability of shortfall is computed from historic shortfalls.

relative contributions to the regional reserve. Nigeria, the largest single contributor, could save resources of more than 300,000 metric tons by contributing under relative vis-à-vis equal contributions. Similarly, Guinea, Cote d'Ivoire, Mali, and Cameroon would be able to reduce their contributions under the relative contribution scheme. In fact, the average stock-to-use ratio in the region (5% for 95% target consumption) represents a threshold. All countries that have an above average stock-to-use ratio without regional cooperation are better off by consulting equal instead of relative contributions, while all countries with below-average stock-to-use ratio prefer relative contributions.

[Table 4 here]

[Figure 3 here]

For the sake of clarity, the tables for the additional target consumption levels are presented in the appendix only, yet the effect on total regional stocks is illustrated in Figure 4. So, benefits from cooperation are relatively lower for higher levels of target consumption. With 99 %, and 97 % target consumption, regional stocks under cooperation are around 25 %, respectively 30 %, lower than without cooperation. Against this, benefits from cooperation are relatively greater with target consumption of 90 %. Accordingly, regional stocks could be 62 % lower with regional cooperation vis-à-vis without cooperation.

[Figure 4 here]

Noteworthy, a regional reserve without integration of markets or transfers between countries is required to act significantly more often than national reserves as the probability of shortfalls increases. Hence, the total quantity needed to compensate for production and supply shortfalls is equal with or without storage cooperation. Benefits from cooperation emerge from the lower levels of stocks carried only at a time. However, these benefits are substantial as countries also require to renew their reserve stocks on a regular base, even if they are not used to offset supply shock

Last, what are the welfare implication from the simulation results above? First and most importantly, with reasonably high levels of target consumption optimal stocking norms can be selected so that all countries benefit. However, preferences are not homogeneous and low levels of target consumption discriminate countries with low supply variability. Since preferences of countries cannot be observed, net benefits with heterogeneous preferences are possible to judge only in two instances. Firstly, in the case target consumption chosen by the region is lower than for a country without cooperation, while stocking norms are lower in cooperation. Then, a country benefits from cooperation. As opposed to this, net benefits from cooperation are unambiguously negative if target consumption under cooperation is higher than under regional cooperation and stocking norms are higher than without cooperation. Indeed, the latter can be excluded by choosing target consumption levels above 90 %. Intuitively, countries with large supply variability prefer equal contribution to the regional reserve. Yet it is important to create incentives for all countries to join the reserve in order to utilize full benefits from cooperation.

5.2.2 Emergency reserve with intra-regional trade

When allowing intra-regional trade, the analysis is analogous to the scenario without trade. So, maximum historic shortfalls and associated stocking norms in autarky remain unchanged. The only difference is that supply shortfalls in neighboring countries are balanced through trade first, before the reserve releases stocks. Participating countries are committed to export only when actual supply exceeds estimated supply as computed by the HP-filter.

[Figure 5 here]

Figure 5 presents required stocks with intra-regional trade in comparison to the scenario without intra-regional trade. Apparently, trade hardly reduces the level of required stocks. Most notably are gains when stocks are based on a consumption shortfall of 10 %.

The results of the simulation are explained by the choice of the criterion to determine reserve levels according to historic consumption shortfalls. The historically largest shortfall occurred in 2007, while only very few countries would have been able to export in this year. These exports are not high enough to offset supply shortfalls of other countries. Albeit small differences in the reserve level, regional trade would reduce the frequency of stock-outs significantly. So, the probability of shortfall is maximum 43 % as compared to between 89 and 100 % across all levels of target consumption for the emergency reserve without intra-regional trade. Allowing for five percent shortfall in consumption, with intra-regional trade the probability of shortfall is only between 20 and 26 % for supply and production, respectively.

[Figure 6 here]

These benefits are founded on intra-regional exports. Average annual exports over the period from 1980 to 2014 for based on production and supply figures are presented in Figure 6. Total annual exports amount to 1.13 million tons based on production and 1.16 million tons based on supply data. As measured by the expected supply in 2014, they range between 0.7 to 0.9 % of total supply in 2014 for Guinea and Cameroon and 4.59 and 7.9 % for Cape Verde. By the definition according to which exports are determined, countries with higher production and supply fluctuations automatically export more than countries with less variation. This occurs since these countries exhibit greater negative and positive deviations from the trend. Generally, exports are at a realistic magnitude. Net welfare benefits can be computed analogous to the case without intra-regional trade.

5.3 Stabilization reserve

The optimal stocking rule under national stockholding can be estimated using actual stock data. Since USDA stock data for small countries exhibits limited quality, the FAO CBS stock data is preferred and utilized in this analysis. The stocking parameter can be obtained by estimating following equation with OLS:

$$\mathrm{S}_i = \gamma_i \left(\mathrm{S}_{t-1} + \mathrm{Q}_{t-1} + \mathrm{IM}_{t-1} - EX_{t-1}\right) + \varepsilon_{\mathrm{it}} \quad (24)$$

where all variables are as described above and $\varepsilon_{\mathrm{it}}$ is the normally distributed error term.

Notably, the constant is omitted in the estimation. First, storage is non-negative and negative values for stocks are not possible. Second, stocks need to increase with supply starting from zero if supply is zero.[10] Results are presented in Figure 7 which depicts the stocking parameter γ conditional on the level of supply variability estimated by the coefficient of variation around a trend as described above.

The red line represents the overall positive correlation between supply variability and the stocking rule. A slope parameter of 0.30 implies that on average the stocking parameter increases by three percentage points when supply variability is 10 percentage points higher.[11] Yet there are notable exemption of the relationship.[12] Niger, Sierra Leone, and Nigeria store only six percent of its total available supply although supply variability is relatively high. In contrast, the Gambia and Chad experience similar supply variability as Niger, but store 24 and 19 % respectively. All other countries in the region store roughly between eight and 17 %. Taking the sum of individual stocks as optimal choice for the region, it averagely stores around nine percent of its annual supply due to the low value for Nigeria.

[Figure 7 here]

[Figure 8 here]

Using the policy parameter and the information on each country's supply variability, it is possible to compute the consumption variability as chosen by each country (see equation (22)). Figure 8 draws consumption and supply variability with the position of each country. The red line represents parity of consumption and supply variability, where countries without storage would lie. With additional storage countries move to the right away from the red line. Hence, the larger the stocking parameter γ, the farther away from the parity line countries are. Moreover, with lower supply variability it is less efficient to decrease consumption variability by increasing storage by one unit. Accordingly, Cameroon requires to store 18 % of its total available supply to reduce consumption variability by one percent. In contrast, Ghana achieves a reduction in consumption instability of 0.8 % by only storing nine percent of its available supply.

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[10] The estimation is associated with several problems (non-stationarity, number of observations) and results have to be interpreted with caution. Yet the objective is not to establish causality or to compute confidence intervals. Instead, it is attempted to obtain country preferences without storage cooperation.

[11] When Cape Verde, as outliner, is excluded the slope parameter changes only marginally.

[12] Be reminded that an increase of 0.1 is quite substantial regarding the range of γ between zero and one.

The costs of stabilization are already described by the stocking parameter γ. The full dimension of the costs become more visible when looking at the amount of stocks required to reach a desired level of consumption stability. Table 5 presents optimal stocks levels and stock-to-use ratio for γ given by the country-level stock data and compares them to actual levels. The resulting stock-to-use ratio is $\alpha = \frac{\gamma}{1-\gamma}$, and thus just corresponds to γ in an exponentially positive way. With γ > 0.5, stocks already amount to expected consumption levels with a stock-to-use ratio greater than one. Notably, the linear stocking rule predicts actual stocks and stock-to-use ratios quite precisely.

[Table 5 here]

The last row of Table 5 provides stock figures for the region as a whole. Given the current stock level of around 7 million tons, the regional stocking rule would imply that nine percent of total supply needs to be stocked in. This is associated with a consumption variability of 3.4 %, as compared to 3.1 % without storage. It is also possible to illustrate the initial optimization problem of the government directly as the trade-off between costs and benefits. More concretely, the trade-off between consumption stability and operational costs. Figure 9 pictures the trade-off for the region as a whole. The doted black line indicates the status quo of roughly seven million tons of stocks associated with a coefficient of variation for consumption of 3.1 %. The dashed black line represents a stock level of 11.1 million tons resulting from a stocking parameter of 0.135, which is the median parameter across all member countries.

[Figure 9 here]

The amount of stocks required increases over-proportionally in the reduction of consumption instability. So, in order to reach consumption stability up to only 2.7 %, the region would require roughly 20 million tons of stocks. On the other hand, without any stocks required consumption variability through market integration or transfers between countries is only 3.4 %, two percent less than for Nigeria which has the lowest supply variability. As a result, most gains origin from trade integration and not from storage cooperation. In other words, under regional trade integration consumption stability is massively enhanced, but increasing stocks have only little impact on the level of consumption variability. Benefits from regional trade cooperation are massive. Indeed, individual stabilization reserves by all countries would need an unrealistically large amount of stocks to achieve a consumption variability of 3.4 %. Costs and benefits of cooperation can be evaluated for a particular level of consumption variability the region desires. We assume the stocking parameter observed is chosen as the optimal stocking rule by each country. Since trade integration is associated with massive benefits in form of a reduction of consumption instability, countries may lose only if the regional stocking parameter exceeds the one chosen by the country in autarky. Hence, net benefits are strictly positive for all countries up to a stock-to use ratio of 6.1 % for Niger, 6.7 for Nigeria and Sierra Leone, 9.0 for Burkina Faso, 9.8 for Ghana, continuing in the same manner according to α_i^* in Table 5.

[Figure 10 here]

Lastly, it is possible to test how a linear stocking rule would have performed over the course of the last 35 years. This is illustrated in Figure 10 with associated target consumption levels. Despite regional trade integration, target consumption levels of 99 %, 97 %, and 95 % are undershot multiple times.[13] Thus, regional trade integration reduces consumption variability significantly, but is unable to combat severe supply shortfalls. Conversely, a linear stocking rule that guarantees net benefits from cooperation for all countries (α =6.1 percent) would have guaranteed target consumption of 97 % over the whole period. Clearly, a linear stocking rule is effective in buffering positive and negative supply shock. However, the effects are rather small as compared to benefits from trade integration within the whole region. This may change if the number of participating countries reduces.

6. Conclusion

In this study a methodology for the assessment of costs and benefits from regional storage cooperation is outlined and exercised for the West African region. Building on the influential works by Johnson (1976) and Koester (1986), the methodology links supply and consumption variability and accounts for potential benefits from cooperation through imperfect correlation of production and supply shocks among neighboring countries. In doing so, the work complements previous studies by conceptualizing the link to storage.

[13] To be exact, shortfalls are accordingly: 99 % - 11 times, 97 % - 7 times, 95 % - 3 times, and 90 % never.

The principles of risk pooling allow to reduce carry-over stocks, to guarantee at least 95 % of the expected trend consumption, within West Africa by 35 to 41 % without welfare transfers or trade between countries. For other levels of minimum consumption, the benefits are between 25 to 60 %. National contributions to the reserve can be organized in such a manner that all countries benefit strongly from cooperation. However, in this way releases from the reserve occur frequently and stocks need to be re-filled on a regular basis. If limited intra-regional trade takes place between surplus and deficiency areas, optimal regional stocks under cooperation hardly change. However, the need for stock release intervention reduces significantly. So, trade is very effective to smooth consumption when supply fluctuations are moderate. In contrast, reserves are required to dampen large supply shortfalls. These benefits are large enough in order to allow additional costs the may arise from storage cooperation. Last, complete market integration in West Africa would greatly benefit countries with high supply variability. Without any storage undertaken, regional supply variability is 3.4 % which is higher for each country included in the analysis. Storage cooperation beyond full market integration would reduce consumption variability only marginally. Furthermore, trade integration without storage is incapable of dampening severe supply shortfalls as an emergency reserve does.

It is also important to consider incentives for countries to join a regional reserve. Under relative low levels of target consumption in an emergency reserve, countries with low supply variability do not benefit. Yet these countries are of particular importance to utilize the full benefits from regional cooperation. The advantages of cooperation diminish rapidly when countries with limited supply variability or counter-cyclical shock patterns refuse to participate in the alliance. However it should be noted, a regional emergency reserve guaranteeing relative high levels of target consumption needs to carry large amounts of stocks which are associated with high operational costs.

These findings are of great relevance for the ongoing debate on public food storage, trade integration, and regional reserves. Trade liberalization is widely considered as an effective instrument to balance supply variability and production shortfalls. In contrast, public storage is associated with substantial market distortions and comes at high fiscal costs. Nevertheless, a number of developing countries responded to the global food crisis in 2007/2008 by implementing and enhancing public storage to increase food security. This is also driven by the unpredictability of food availability at international markets as exporters attempt to insulate domestic markets. Regional storage cooperation was brought up for discussion as a viable and comparably cheap means and as an alternative to national reserves. Moreover, storage cooperation could enhance commitment of exporters to regional trade agreements (Wright and Cafiero, 2011).

West Africa has taken a pioneering role with the intention to implement a region-wide emergency reserve. Political and economic integration in West Africa is among the most advanced in Africa. However, at present, intra-regional trade is limited partly caused by bad infrastructure and bureaucratic hindrances at national boundaries. The results from this study should be understood as encouragement to regional storage cooperation in the region. Three message can be taken away. First, production and supply patterns in the region facilitate massive benefits from cooperation. Second, trade integration is more effective than storage to smooth supply effectively, but storage is required to dampen extreme supply shortfalls. Last, there is great potential for storage cooperation with regard to an emergency reserve and less with regard to a stabilization reserve. Yet clear rules with regard to national contributions and releases and, if needed, to regional trade management are essential to organize regional storage with mutual benefits. Administrative complexity is likely to be smaller with a limited number of partner countries. Therefore, future research should attempt to evaluate costs and benefits for subsets of countries with the attempt to identify countries that are particularly feasible to form a coalition. Moreover, the potential benefit from intra-regional trade integration should be analyzed more rigorously.

Tables:

Table 1: Key statistics: ECOWAS

	Population (in 100,000)	GDP per capita PPP	% of under-nourished	Total production (in 1,000 mt)	Import/production (in %)
Benin	10,323	1,791	8.1	1,667	21
Burkina Faso	16,934	1,634	25.9	4949	9

Cape Verde	498	6,412	-	7	2.86
Cote d'Ivoire	20,316	3,012	21.4	1,276	116
Gambia, The	1,849	1,666	14.4	214	58
Ghana	25,904	3,974	3.4	2,645	44
Guinea	11,745	1,255	17.3	2,292	21
Guinea-Bissau	1,704	1,242	8.7	175	74
Liberia	4,294	878	31.4	150	227
Mali	15,301	1,641	7.9	5,032	3
Niger	17,831	913	12.6	4,308	13
Nigeria	173,615	5,863	8.5	22,042	32
Senegal	14,133	2,269	20.5	1,182	150
Sierra Leone	6,092	1,927	28.8	897	28
Togo	6,816	1,390	16.5	1,142	23
Total	327,355	4,123	12	47,978	30
Cameroon	22,253	2,711	15.7	3,047	37
Chad	12,825	2,081	33.4	1,647	18
Mauritania	3,889	3,042	9.3	222	207

Source: AFDB [2013]; von Grebmer et al. [2013]; USDA [2014].

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

Table 2: Production and supply instability in West Africa

	Share in regional production	CV production	Share in regional supply	CV suppl
Benin	2.9	7.6	2.7	7.6
Burkina Faso	8.9	10.3	7.5	9.1

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

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

Table 3: Optimal stocking norms vs. actual stocks in 2014.

	Optimal reserve levels: supply														Actual stocks	
	99%		97%		95%		90%		88%		84%		78%		USDA	FAO CBS
	S_i^*	α_i^*	S_i^*	α_i^*	S_i^*	α_i^*	S_i^*	α_i^*	S_i^*	α_i^*	S_i^*	α_i^*	S_i^*	α_i^*	S_i^*	S_i^*
Benin	152,677	8%	127,936	7%	103,195	5%	42,379	2%	32,037	2%	11,354	1%	-	-	107,000	162,000
Burkina Faso	593,667	11%	500,825	9%	407,983	8%	203,667	4%	140,506	3%	55,756	1%	-	-	364,000	495,000
Cameroon	203,148	5%	170,363	4%	148,788	4%	94,852	2%	73,277	2%	30,128	1%	-	-	148,000	866,000
Cape Verde	15,455	57%	14,800	54%	14,144	52%	12,505	46%	11,849	44%	10,538	39%	8,571	32%	-	7,000
Chad	357,082	17%	317,808	15%	278,533	13%	180,347	9%	141,073	7%	80,930	4%	34,576	2%	106,000	564,000
Cote d'Ivoire	181,273	6%	139,631	5%	99,615	4%	35,635	1%	10,043	0%	-	-	-	-	301,000	467,000
Gambia, the	48,382	14%	41,486	12%	34,589	10%	22,209	6%	19,160	6%	13,061	4%	3,914	1%	29,000	48,000
Ghana	477,451	12%	422,149	11%	366,847	9%	228,592	6%	173,290	4%	129,889	3%	83,183	2%	476,000	325,000
Guinea	124,296	4%	87,947	3%	51,597	2%	10,864	0%	-	-	-	-	-	-	201,000	511,000
Guinea-Bissau	26,092	8%	23,423	7%	20,755	7%	14,084	4%	11,415	4%	6,078	2%	-	-	24,000	69,500
Liberia	53,601	10%	48,902	9%	44,203	8%	32,455	6%	27,756	5%	20,446	4%	12,343	2%	53,000	56,000
Mali	417,047	7%	303,936	5%	223,631	4%	78,210	1%	49,735	1%	2,156	0%	-	-	764,000	855,000
Mauritania	111,038	15%	101,159	14%	91,279	12%	66,580	9%	56,701	8%	36,942	5%	7,303	1%	59,000	95,500
Niger	681,052	13%	585,455	11%	503,972	10%	345,241	7%	289,035	6%	176,625	3%	72,619	1%	225,000	522,000
Nigeria	2,167,705	7%	1,572,822	5%	977,939	3%	128,646	0%	-	-	-	-	-	-	1,539,000	850,000
Senegal	308,029	10%	258,230	8%	208,432	7%	83,935	3%	34,137	1%	-	-	-	-	197,000	492,000
Sierra Leone	149,723	13%	134,597	12%	119,471	11%	81,657	7%	66,531	6%	36,280	3%	8,628	1%	0	87,000
Togo	117,762	8%	105,888	7%	94,014	7%	64,329	5%	52,455	4%	28,707	2%	-	-	95,000	171,000
Total	6,185,480	9%	4,957,354	7%	3,788,989	5%	1,726,187	2%	1,189,001	2%	638,891	1%	231,137	0%	4,688,000	6,643,000

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

Note : Note: Stock level in mt; The difference in stock levels between USDA and FAO CBS is explained by the issues with regard to USDA data and small countries as well as less-traded crops as sorghum and millet that comprise a significant share of total grain consumption in the region.

Table 4: Optimal stock levels in 2014 for target consumption of 95 %

	Production				Supply			
	P_i	${S_i}^*$	$\hat{S}_i$	$\tilde{S}_i$	P_i	${S_i}^*$	$\hat{S}_i$	$\tilde{S}_i$
Benin	26%	98,832	68,249	58,004	29%	103,195	66,181	66,804
Burkina Faso	26%	461,771	209,158	271,009	29%	407,983	182,765	264,111
Cameroon	11%	163,986	134570	96,242	14%	148,788	146,499	96,319
Cape Verde	43%	7,572	298	4,444	40%	14,144	885	9,156
Chad	37%	301,534	79,510	176,968	31%	278,533	73,389	180,311
Cote d'Ivoire	14%	84,520	55,554	49604	20%	99,615	97,416	64,487
Gambia, the	34%	70230	9,566	41217	43%	34,589	12,069	22,391
Ghana	17%	287,853	118,080	168,939	26%	366,847	136,789	237,481
Guinea	17%	57,988	99,377	34,033	14%	51,597	96,782	33,402
Guinea-Bissau	29%	21,528	7566	12,635	31%	20,755	10,768	13,436
Liberia	31%	20,306	7941	11,918	31%	44,203	18,083	28,615
Mali	37%	216774	243921	127,223	31%	223631	199,491	144,770
Mauritania	46%	49,666	9552	29,149	29%	91,279	25,604	59,090
Niger	29%	607,626	204,524	356,610	31%	503972	182,173	326251
Nigeria	17%	928,445	951,527	544,897	14%	977,939	1,010,583	633,077
Senegal	40%	429,613	56,908	252,136	26%	208432	106131	134,930
Sierra Leone	31%	105,992	35,788	62,206	31%	119,471	38,301	77,341
Togo	23%	75,671	49553	44,411	20%	94,014	48,925	60,861
Total	97%	3,989,905	2,342,642	2,342,642	97%	3,788,989	2,452,834	2,452,834

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

Note: Stock levels in mt; P_i is the probability of intervention when production and supply are below the target consumption (99%). ${S_i}^*$, $\hat{S}_i$, $\tilde{S}_i$ are stocks without cooperation, with equal, and relative contributions.

Table 5: Actual and optimal stock levels under a linear stocking rule

	γ^*	CV_c	S^*	S_{2013}	α^*	$\frac{S_{2013}}{C}$
Benin	0.105	6.8	220,802	162,000	11.8	12.8
Burkina Faso	0.083	8.4	466,615	495,000	9.0	8.5

Cameroon	0.178	5.0	899,228	866,000	21.7	16.0
Cape Verde	0.169	25.5	5,089	7,000	20.3	20.3
Chad	0.193	10.9	496,928	564,000	23.9	22.3
Cote d'Ivoire	0.095	5.2	290,463	467,000	10.5	9.3
Gambia, the	0.239	11.2	107,609	48,000	31.5	30.4
Ghana	0.089	9.4	379,520	325,000	9.8	9.2
Guinea	0.138	4.9	438,248	511,000	16.0	14.3
Guinea-Bissau	0.164	8.7	59,828	69,500	19.6	17.3
Liberia	0.144	12.8	86,482	56,000	16.9	14.7
Mali	0.117	8.4	746,375	855,000	13.2	10.1
Mauritania	0.159	8.2	137,177	95,500	18.9	20.7
Niger	0.057	11.4	314,910	522,000	6.1	5.4
Nigeria	0.063	5.1	1,915,352	850,000	6.7	7.0
Senegal	0.140	7.2	491,235	492,000	16.3	16.2
Sierra Leone	0.063	10.4	72,532	87,000	6.7	5.3
Togo	0.132	7.1	211,342	171,000	15.2	14.9
Region	-	3.1	7,063,305	6,643,000	-	10.3

Source: Author's computation based on USDA (2014) and FAO CBS (2014).

Note: country level γ is obtained by the regression (24); CV consumption is computed as $CV_c = \sqrt{\frac{1-\gamma}{1+\gamma}}\ CV(X)$ (see equation (22)); the optimal regional γ is unknown.

Figures:

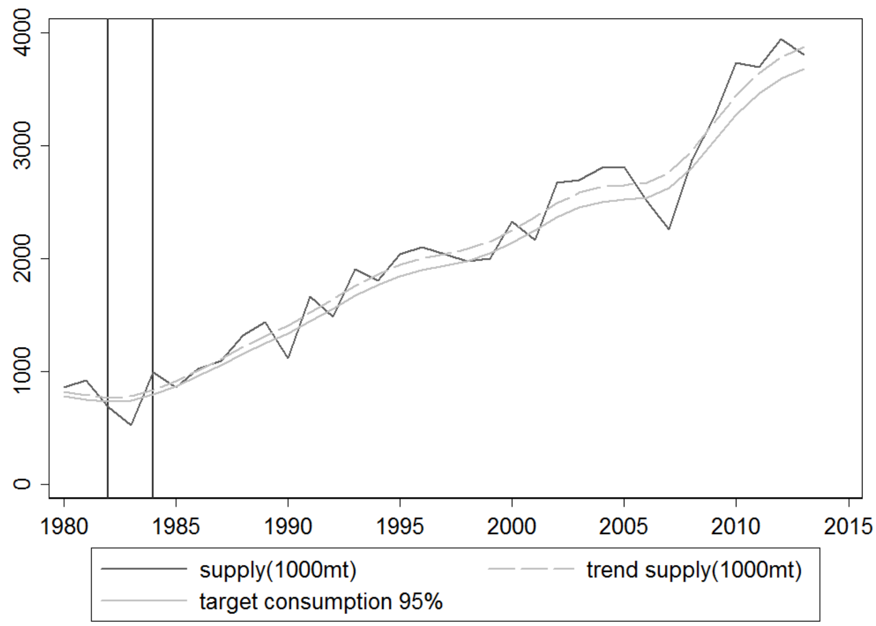

Figure 1: Grain supply in Ghana 1980-2014.

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

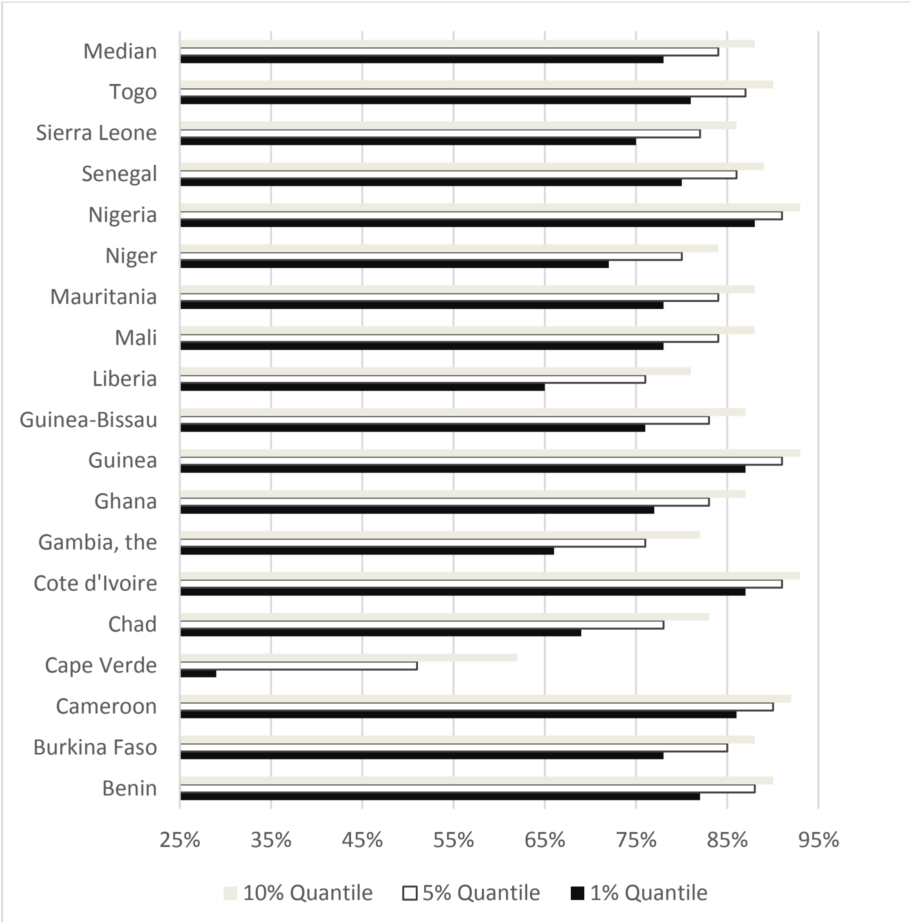

Figure 2: Possible target consumption levels by country

Source: Author’s illustration.

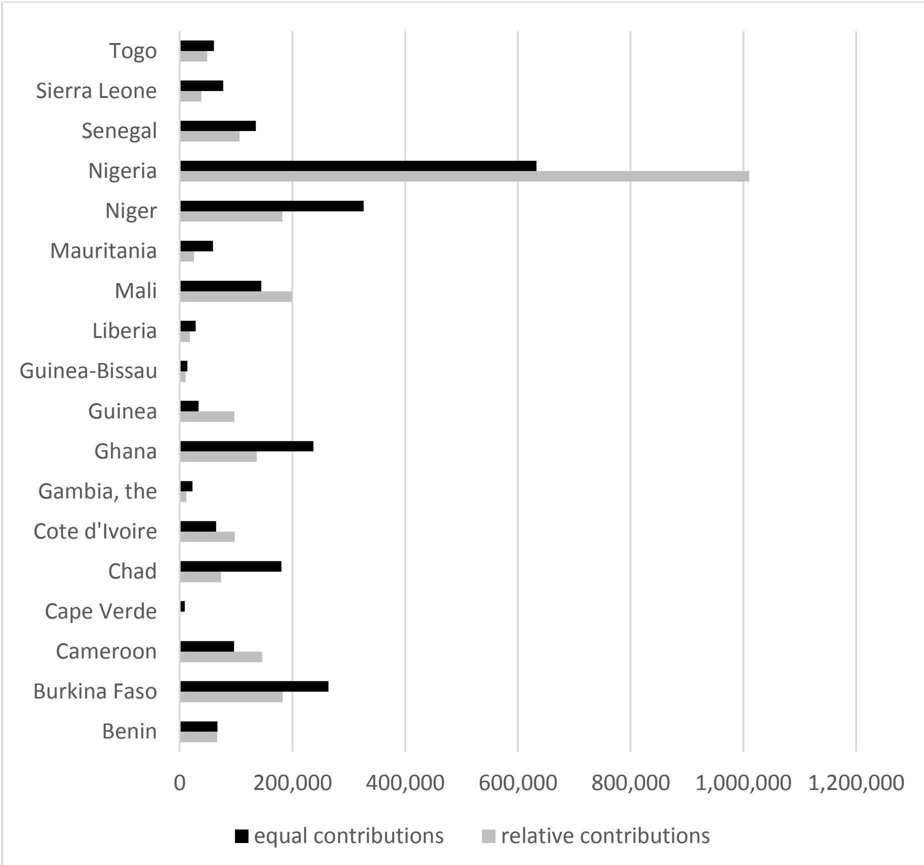

Figure 3: Contributions to a regional reserve with 95 % target consumption by country (based on supply)

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

Note: Equal contributions to the reserve imply and identical stock-to-use ratio across countries, while relative contributions demands higher stock-to-use ratios in countries with higher variability in supply.

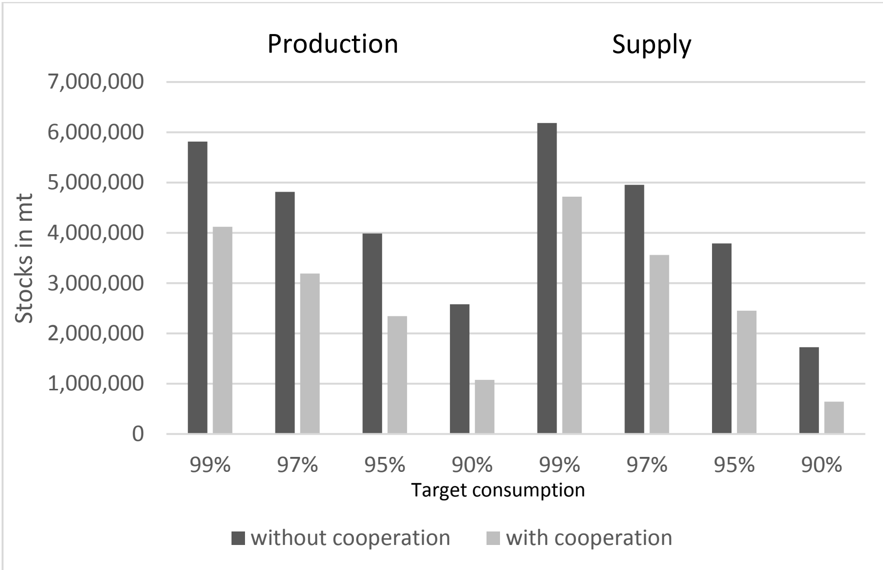

Figure 4: Regional stocks with and without storage cooperation (without intra-regional trade)

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

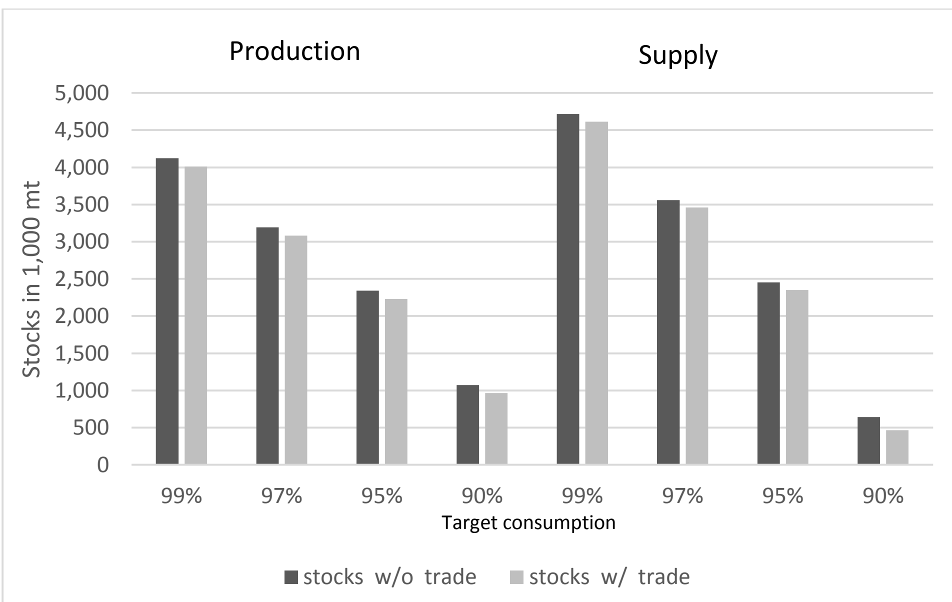

Figure 5: Regional stocks for an emergency reserve with intra-regional trade

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

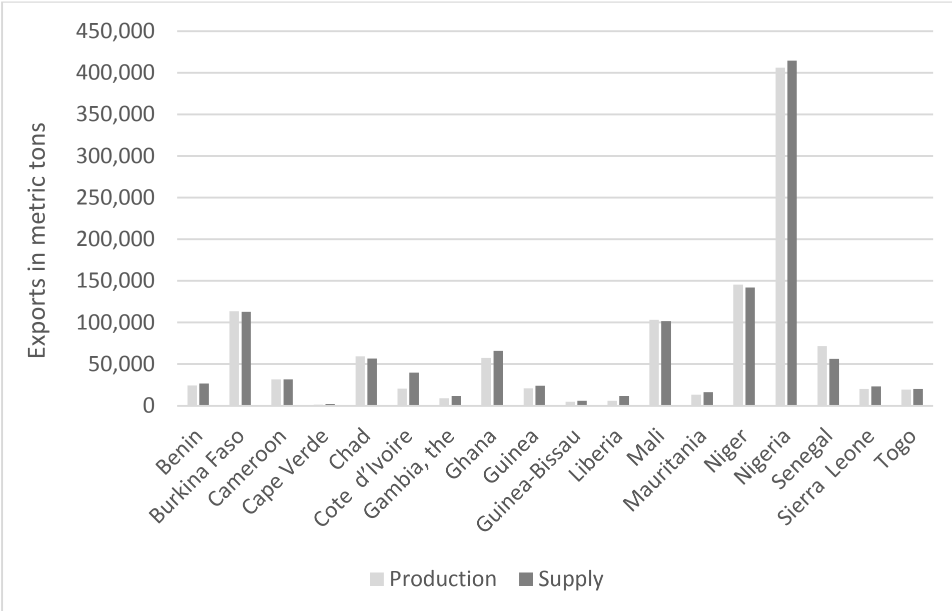

Figure 6: Average annual exports by country 1980-2014

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

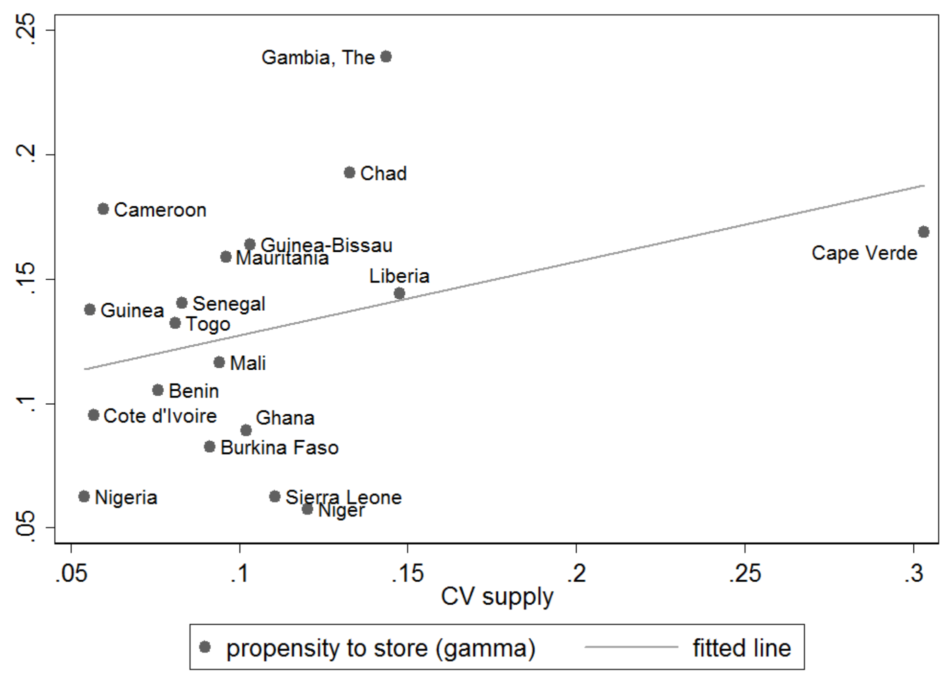

Figure 7: Stocking parameter and supply variability across study countries

Source: Author's illustration based on USDA (2014) and FAO CBS (2014).

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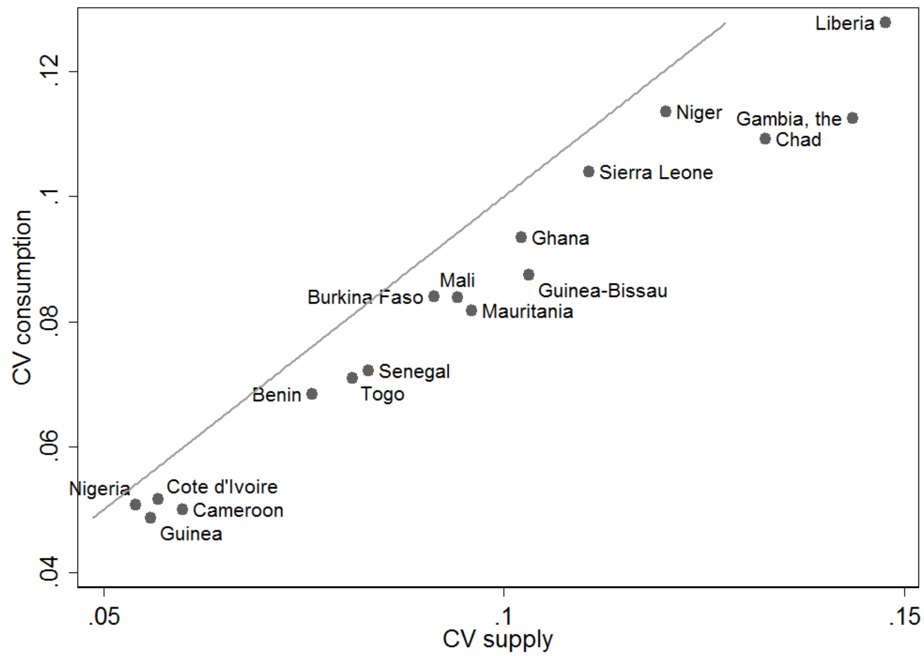

Figure 8: Consumption and supply variability across study countriesSource: Author's illustration based on USDA (2014) and FAO CBS (2014).

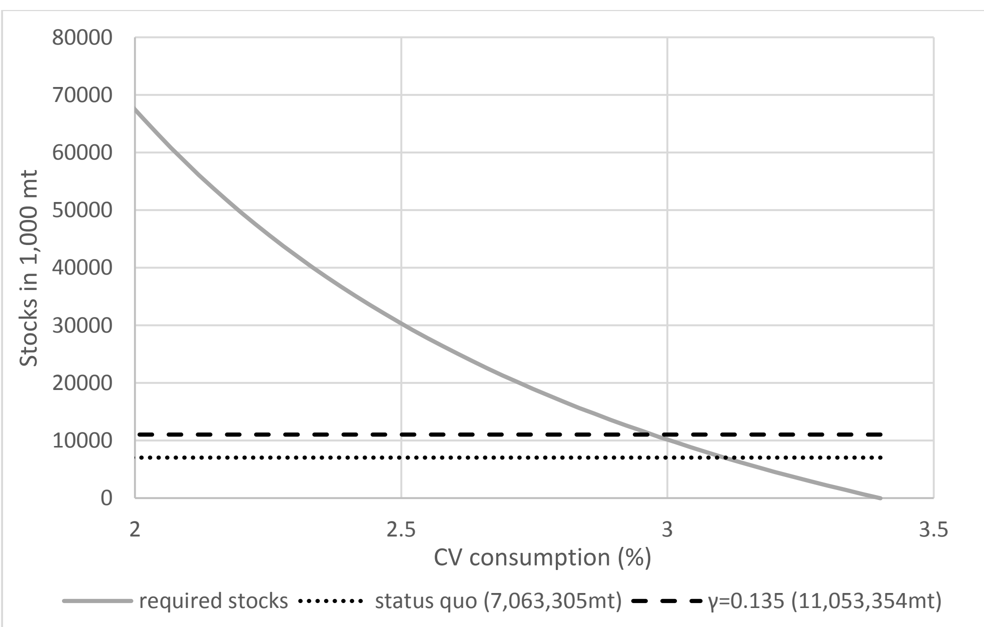

Figure 9: Regional consumption variability at different stock levels

Source: Author's illustration based on USDA (2014) and FAO CBS (2014).

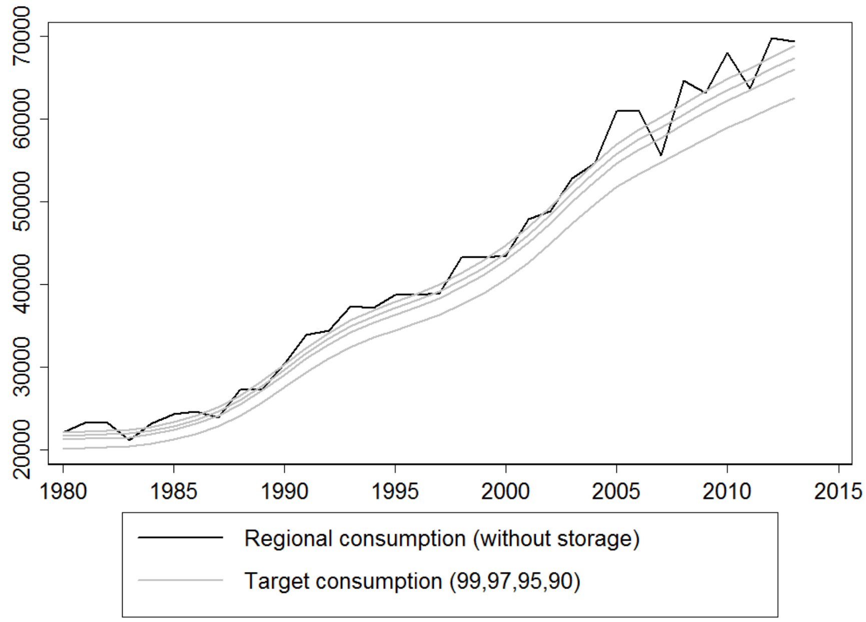

Figure 10: Regional consumption under trade integration without storage

Source: Author's illustration based on USDA (2014) and FAO CBS (2014).

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Appendix: Supplementary tables

Table A1: Optimal stock levels in 2014 for target consumption of 99 %

	Production				Supply			
	P_i	S_i^*	$\hat{S}_i$	$\tilde{S}_i$	P_i	S_i^*	$\hat{S}_i$	$\tilde{S}_i$
Benin	40%	141,604	120,137	100,356	37%	152,677	127,265	116,424
Burkina Faso	40%	631,234	368,174	447,361	40%	593,667	351,453	452,700
Cameroon	49%	214,049	236,879	151,698	26%	203,148	281,713	154,911
Cape Verde	49%	8,101	524	5,741	52%	15,455	1,701	11,785
Chad	49%	368,209	139,960	260,953	46%	357,082	141,125	272,293
Cote d'Ivoire	37%	127,531	97,789	90,382	43%	181,273	187,327	138,229
Gambia, the	43%	79,208	16,839	56,135	55%	48,382	23,208	36,894
Ghana	43%	357,196	207,853	253,148	43%	477,451	263,042	364,079
Guinea	43%	90,030	174,930	63,805	46%	124,296	186,109	94,782
Guinea-Bissau	43%	26,771	13,318	18,973	46%	26,092	20,706	19,896
Liberia	40%	27,477	13,978	19,473	49%	53,601	34,774	40,873
Mali	58%	419,760	429,367	297,487	55%	417,047	383,615	318,019
Mauritania	49%	56,683	16,814	40,172	46%	111,038	49,237	84,672
Niger	37%	779,525	360,017	552,456	37%	681,052	350,313	519,335
Nigeria	43%	1,786,527	1,674,944	1,266,127	43%	2,167,705	1,943,323	1,652,981
Senegal	49%	477,554	100,173	338,447	52%	308,029	204,087	234,887
Sierra Leone	37%	128,728	62,996	91,231	46%	149,723	73,652	114,171
Togo	43%	95,910	87,226	67,972	40%	117,762	94,081	89,800
Region	100%	5,816,099	4,122,000	4,122,000	100%	6,185,480	4,716,730	4,716,730

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

Note: Stock levels in mt; P_i is the probability of intervention when production and supply are below the target consumption (99%). S_i^*, $\hat{S}_i$, $\tilde{S}_i$ are stocks without cooperation, with equal, and relative contributions.

Table A2: Optimal stock levels in 2014 for target consumption of 97 %

	Production				Supply			
	P_i	S_i^*	$\hat{S}_i$	$\tilde{S}_i$	P_i	S_i^*	$\hat{S}_i$	$\tilde{S}_i$
Benin	34%	120,218	93,057	79,668	37%	127,936	96,089	91,907
Burkina Faso	34%	546,502	285,182	362,163	37%	500,825	265,358	359,785
Cameroon	29%	189,018	183,483	125,260	17%	170,363	212,702	122,386
Cape Verde	49%	7,836	406	5,193	40%	14,800	1,285	10,632
Chad	43%	334,871	108,411	221,916	40%	317,808	106,554	228,308
Cote d'Ivoire	23%	106,025	75,746	70,262	31%	139,631	141,438	100,309
Gambia, the	37%	74,719	13,043	49,515	54%	41,486	17,523	29,803
Ghana	37%	317,677	161,000	210,522	34%	422,149	198,605	303,265
Guinea	34%	74,009	135,498	49,045	31%	87,947	140,519	63,179
Guinea-Bissau	34%	24,150	10,316	16,004	40%	23,423	15,634	16,827
Liberia	40%	23,892	10,827	15,833	37%	48,902	26,255	35,130
Mali	46%	309,623	332,581	205,185	49%	303,936	289,642	218,342
Mauritania	49%	53,175	13,024	35,238	37%	101,159	37,175	72,671
Niger	34%	693,576	278,864	459,627	34%	585455	264,498	420,581
Nigeria	34%	1,285,869	1,297,387	852,134	34%	1,572,822	1,467,271	1,129,890
Senegal	43%	453,584	77,593	300,586	43%	258,230	154,092	185,508
Sierra Leone	34%	117,360	48,796	77,773	40%	134,597	55,609	96,692
Togo	31%	85,791	67,564	56,853	29%	105,888	71,035	76,069
Region	100%	4,817,894	3,193,000	3,193,000	97%	4,957,355	3,561,283	3,561,283

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

Note: Stock levels in mt; P_i is the probability of intervention when production and supply are below the target consumption (99%). S_i^*, $\hat{S}_i$, $\tilde{S}_i$ are stocks without cooperation, with equal, and relative contributions.

Table A3: Optimal stock levels in 2014 for target consumption of 90 %

	Production				Supply			
	P_i	S_i^*	$\hat{S}_i$	$\tilde{S}_i$	P_i	S_i^*	$\hat{S}_i$	$\tilde{S}_i$
Benin	11%	49,479	31,300	20,578	11%	42,379	17,315	15755

Burkina Faso	23%	271,876	95,923	113,071	20%	203,667	47,818	75,717
Cameroon	9%	101,408	61,716	42,175	9%	94,852	38,329	35,263
Cape Verde	34%	6,910	137	2,874	34%	12,505	231	4,649
Chad	23%	218,190	36,465	90,743	23%	180,347	19,201	67,048
Cote d’Ivoire	6%	30,755	25,478	12,791	3%	35,635	25,487	13,248
Gambia, the	29%	59,007	4,387	24,540	31%	22,209	3,158	8,257
Ghana	14%	257,176	54,153	106,957	11%	228,592	35,789	84,984
Guinea	6%	17,936	45,576	7,460	6%	10,864	25,322	4,039
Guinea-Bissau	17%	14,974	3,470	6,227	14%	14,084	2,817	5,236
Liberia	26%	15,564	3,642	6,473	23%	32,455	4,731	12,066
Mali	11%	110,280	111,866	45,864	14%	78,210	52,194	29,076
Mauritania	37%	40,894	4,381	17,007	17%	66,580	6,699	24,753
Niger	20%	392,751	93,798	163,341	20%	345,241	47,663	128,351
Nigeria	3%	497,369	436,384	206,851	9%	128,646	264,404	47,827
Senegal	29%	369,686	26,099	153,749	9%	83,935	27,768	31,205
Sierra Leone	23%	77,571	16,413	32,261	20%	81,657	10,021	30,358
Togo	14%	50,373	22,726	20,950	11%	64,329	12,800	23,916
Region	89%	2,582,200	1,074,000	1,074,000	89%	1,726,187	641,747	641,747

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

Note: Stock levels in mt; P_i is the probability of intervention when production and supply are below the target consumption (99%). S_i^*, $\hat{S}_i$, $\tilde{S}_i$ are stocks without cooperation, with equal, and relative contributions.