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École des Hautes Études en Sciences Sociales

Quels changements organisationnels pour l'agriculture africaine?

Essais sur les réformes des filières cotonnières et les assurances à indices météorologiques

présentée par
Antoine Leblois

en vue de l'obtention du grade de
docteur en Économie

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Thèse intitulée:

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Soutenue publiquement par:

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RÉSUMÉ

Le secteur agricole africain a été le parent pauvre des politiques de développement du siècle dernier, ne favorisant pas l'émergence d'une révolution verte comme en Asie du Sud ou, dans une moindre mesure, en Amérique Latine. Le continent détient pourtant une capacité de production importante mais les rendements observés restent très faibles.

De nombreux défis menacent par ailleurs le développement du secteur agricole et la sécurité alimentaire en Afrique Subsaharienne : croissance démographique élevée, augmentation du prix des énergies fossiles nécessaire à l'intensification telle que l'ont connue les pays occidentaux, réchauffement climatique etc.

Dans ce contexte, il est nécessaire de repenser certains choix organisationnels afin de permettre un développement du secteur agricole à même de faire face à ces défis. La sécurité alimentaire en Afrique est intrinsèquement liée aux revenus des ménages ruraux, pour lesquels la production agricole joue un rôle majeur. L'approvisionnement futur du continent semble dépendre de l'adoption d'innovations autorisant une intensification agricole qui permettrait une gestion durable des ressources rares.

Nous étudions deux formes de changements organisationnels que sont la structure de marché des filières coton en Afrique Subsaharienne et les assurances fondées sur des indices météorologiques. Dans les deux cas il s'agit de limiter la vulnérabilité et ses effets de pièges à pauvreté afin d'augmenter l'investissement agricole et donc le rendement moyen de long terme, en dépit de contraintes latentes de crédit et des risques qui pèsent sur le processus productif et la commercialisation.

Dans le premier cas, nous étudions l'impact des réformes du secteur du coton en Afrique Sub-saharienne qui ont eu lieu de 1985 à 2008. La particularité historique du secteur est la grande concentration de l'achat de coton, réalisé au niveau national, l'existence d'un prix minimum garanti en début de période de culture et la fourniture d'intrants à crédit, qui est garanti par la future produc-

tion de coton. Ces particularités on favorisé la culture du coton et la diffusion de nouvelles technologies durant la seconde partie du XXe siècle. D'autre part des investissements importants eurent lieu dans les années 60 à 80, autant dans la recherche que la vulgarisation ou les infrastructures.

L'adoption de techniques d'intensification, souvent coûteuses, s'est en effet généralisée chez les producteurs de coton grâce au crédit aux intrants remboursé en nature à la récolte, elle même payé à un prix fixé au semis. Toutefois le pouvoir de monopsone a aussi pu avoir des effets dévastateurs, du fait de la proximité de la filière avec les pouvoirs politiques ou de l'asymétrie du pouvoir de négociation des producteurs face aux sociétés cotonnières. C'est ce que nous cherchons à comprendre dans une étude empirique économétrique, comparant les performances des pays ayant mis en œuvre différents types de réformes et ceux ayant conservé le modèle de monopole national, parmi 16 importants producteurs d'Afrique Subsaharienne. Nous mettons d'abord en exergue le rôle des investissements en recherche et en infrastructures avant les réformes. Nous discutons ensuite l'intérêt relatif du processus de réforme qui semble exercer un effet de sélection sur les producteurs, augmentant les rendements au prix d'une réduction des surfaces cultivées.

Dans le second cas nous étudions le potentiel d'assurances contre la sécheresse fondées sur des indices météo ou de végétation. De telles assurances permettent d'indemniser rapidement les producteurs en fonction de l'observation de la réalisation de l'indice. L'objectivité et l'indépendance de la réalisation de l'indice pour le principal et l'agent permettent de limiter l'anti-sélection et de supprimer l'aléa moral que fait naître l'asymétrie d'information quant à l'ampleur des dommages dans le cas d'une assurance classique. Toutefois, ces assurances souffrent d"un inconvénient : l'imparfaite corrélation entre la réalisation observée de l'indice et le bénéfice de l'activité agricole. Nous étudions le potentiel de ces assurances dans le cas du mil au Niger et du coton au Cameroun. Nous nous penchons principalement sur le choix des indices, la calibration du contrat ainsi que sur le

risque de base, c'est à dire la corrélation imparfaite entre l'indice et les rendements. Ces questions n'ont en effet été que très peu traitées en dépit d'un grand nombre de projet pilotes mis en œuvre dans les pays en développement et plus particulièrement en Afrique Sub-saharienne ces dernières années. Nous montrons l'importance du choix et du calcul des indices (source de données et simulation de la date de semis), de la calibration des paramètres de l'assurance ainsi que les limites intrinsèques à ce type de produit de mutualisation. Nous comptons parmi ces limites l'importance du risque de base spatial dans cette zone et celle des risques non-météorologiques (comme les variations de prix).

Mots clés : Agriculture, réformes, sécheresse, assurance indicielle, adaptation aux changements climatiques, résilience.

ABSTRACT

The African agricultural sector has been neglected by development aid during the last fifty years. It has not undertaken a green revolution, as it happened in Asia. The continent has a great potential for agricultural production but yields and technology adoption are still very low. Moreover many recent threats to food security represent a challenge for future development in Africa. Demographic growth, increase in commodity prices and price volatility, land use pressure and climate change are probably the most latent threats.

In such context, it is necessary to develop new patterns of development for African agriculture. Those patterns should draw the consequences from past policies, which either relied on large investments and in favouring a development of the same nature that the one observed in rich or emerging economies. It seems that improving institutions and the environment to foster the evolution of African agriculture would be more adapted than previous strategies that consist in applying the same methods employed in the past.

Food security can be achieved by improving rural households' income. Those households is composed by a vast majority of smallholders, for which agricultural production is a major resource for living. The necessary transition for stimulating production in remote areas seem to rely on fostering technology adoption and improve incentives for investments that would increase the productivity or the value added to smallholder production.

We study two major organisational changes that are the reforms of cotton sector market structure in sub-Saharan Africa and index-based insurances. In both cases the point is to look at the potential of every organisation choice, reduce vulnerability and its effect, in particular the poverty trap phenomenon. The final objective is improve long run yield by foster investments, in spite of the risks borne by farmers and the tied budget constraint, consequence of the absence of financial (especially credit) markets.

The cotton sectors inherited from the institutions of the colonial era, characterised by the concentration in cotton purchasing activities, often made by a parastatal at the national level. Those institutions contributed to generalise cotton production and to the diffusion of new technologies and agricultural practices, especially thanks to the distribution of quality inputs on credit, with future cotton production as collateral. Cotton production and technology adoption were also probably driven by the existence of a minimum guaranteed price set at the beginning of the cultivation season, the investments in infrastructures, research and extension services at the same national level. However, the concentration of the purchasing of cotton also poses some problems, reducing the bargaining power of producers and the proximity of the cotton

We look at the productivity response to cotton sector reforms that took place since 1985 in sub-Saharan Africa using the data from 16 cotton producers on the 1961-2008 period. We compare the performance of those countries with regard to their institutional choices. We first put into perspective the role of pre-reform investments before showing that if reforms may increase yields it could be to the cost of a shrinking area cultivated with cotton.

In a second part we study the potential use of meteorological indices to smooth consumption over time and space. Such insurance policies are able to allow quick indemnifications for farmers enduring meteorological shocks. The realisation of the index is independent from the action of the principal and the agent, limiting moral hazard issues and the need for costly damage assessment arising from information asymmetry in traditional insurance contracts. Those insurance however suffer from the limited correlation between the index and the observed yield.

We will study the potential of meteorological indices to limit the risk growers face in millet cultivation in Niger and cotton cultivation in Cameroon. We study, in particular, the index choice, the calibration of insurance contract parameters, the necessity of observing the sowing date and the level of basis risk. The large spatial variability of rainfall over the sudano-sahelian zone is a good reason to

use such insurance, it however also explain the high level of basis risk of a given index that is observed using a network of rain gauges, itself installed at a cost. We discuss in both cases the relative importance of basis risk and the potential of such insurance to pool yield, and compare them to other risks, such as intra-village yield and price shocks.

Keywords : Agriculture, reforms, drougth, index-based insurance, climate chande adaptation, resilience.

CONTENTS

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LIST OF ABBREVIATIONS

API	Antecedent Precipitation Index
AWRI	Available Water Ressource Index
BCR	Bounded Cumulative Rainfall index
CARA	Constant Absolute Risk Aversion
CR	Cumulative Rainfall index
CEI	Certain Equivalent Income
CFAF	CFA Franc, for *Communauté financière africaine*
CFDT	*Compagnie Française Des Textiles*
CRRA	Constant Relative Risk Aversion
DARA	Decreasing Absolute Risk Aversion
ENSO	Southern Oscillation
EDI	Effective Drought Index
ESA	Eastern and Southern Africa
FAO	Food and Agriculture Organization
FEWS, fewsnet	Famine Early Warning Systems network
GDD	Growing Degree Days
GHCN	Global Historical Climatology Network
GPS	Global Positioning System
GS	Growing Season
HBA	Historical Burn Analysis
HDA	Historical Distribution Analysis

IRD	*Insitut de Recherches pour le Développement*
LAI	Leaf Area Index
LDC	Least Developped Countries
MFI	micro-finance institution
NDVI	Normalized Difference Vegetation Index
NOAA	National Oceanic and Atmospheric Administration
PDSI	Palmer Drought Severity Index
PET	Potential Evapotranspiration
PG	Producers Group
RCT	Randomized Controlled Trials
RMSL	Root Mean Square Loss
SSA	SubSaharan Africa
SAFI	Savings and Fertilizer Initiative
OPCC	*Organisation des Producteurs de Coton du Cameroun*
VAR	Value At Risk
WCA	Western and Central Africa
WII	Weather Index-based Insurance
WTP	Willingness To Pay
WFP	World Food Programme
WRSI	Water Ressource Satisfaction Index

INTRODUCTION

Comme le souligne le rapport de 2008 de la Banque Mondiale sur le développement (World Development Report, *Agriculture for Development*, 2008) l'agriculture contribue significativement à la réduction de la pauvreté dans les pays en développement. En effet, sur les 5.5 milliards d'individus qui vivent dans ces pays, 3 se trouvent en milieu rural et l'agriculture représente la première source de revenus pour 86% d'entre eux. 75% des individus pauvres à l'échelle mondiale vivent en milieu rural et 60% de la force de travail des pays les moins avancés est employée dans ce secteur qui représente en moyenne 25% de leur PIB.

Les menaces récurrentes qui pèsent sur la sécurité alimentaire en Afrique laissent à penser que le développement agricole doit être au centre des discussions sur le développement de cette région. Nous essaierons donc dans cette introduction de montrer les déterminants historiques d'une telle situation pour dégager les enjeux du développement agricole actuels et futurs en Afrique. Nous définirons finalement les deux changements organisationnels sur lesquels cette thèse se penche.

0.1 Agriculture et développement en Afrique état des lieux

0.1.1 Contexte : déclin de l'aide extérieur et potentiels de l'agriculture africaine

En dépit d'études académiques confirmant l'importance de son rôle dans les politiques de réduction de la pauvreté dans les pays en développement (DeJanvry and Sadoulet, 2002 et Christiaensen et al., 2011), le secteur agricole a été négligé par les politiques de développement du siècle dernier. Ce phénomène s'est accru ces 20 dernières années (Fig. 1) et l'on peut observer une baisse de la part relative de l'aide à ce secteur qui a été réduite de 12 à moins de 6% de l'aide totale entre

1995 à 2007 [1].

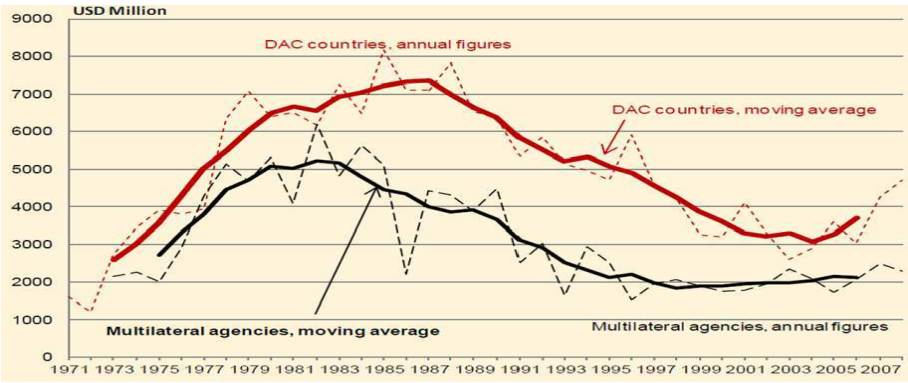


FIGURE 1 – Aide publique au développement des bailleurs internationaux et des pays de l'OCDE à destination du secteur agricole, et moyenne mobile sur 5 ans (1973-2008), en prix constant de 2007. Source : OCDE (CAD database), issu de Dethier et Effenberger (2011)

L'écart de rendements s'est creusé entre le continent africain et les autres régions du monde en développement comme l'Asie du Sud ou dans une moindre mesure l'Amérique Latine (Fig 2). Ceci peut s'expliquer par l'adoption limitée des technologies utilisées dans les pays riches après la révolution industrielle, puis en Asie et en Amérique Latine. L'augmentation de la production agricole africaine s'est en effet principalement fondée sur la mise en culture de nouvelles terres comme le montre la Figure 2. Ceci peut expliquer le très fort potentiel de production que détient le continent (Fig. 3) surtout par rapport aux autres régions.

Cette adoption limitée de technologies peut-être dû à l'absence de technologies adaptées au milieu ou à la faible capacité d'adoption de technologies coûteuses en raison de la structure de l'économie rurale dans ces pays. Certains pointent le rôle négatif de la grande hétérogénéité des régions sur la diffusion des connaissances au sein du continent (Pardey et al. 2007), d'autres la trop lente introduction durant les années 80 et 90, de variétés à hauts rendements adaptées aux milieux (Everson and Gollin 2003). Quoi qu'il en soit, le potentiel d'extension des terres

1. Malgré une potentielle inversion de la tendance depuis 2005, en tout cas en ce qui concerne les bailleurs nationaux que sont les pays de l'OCDE.

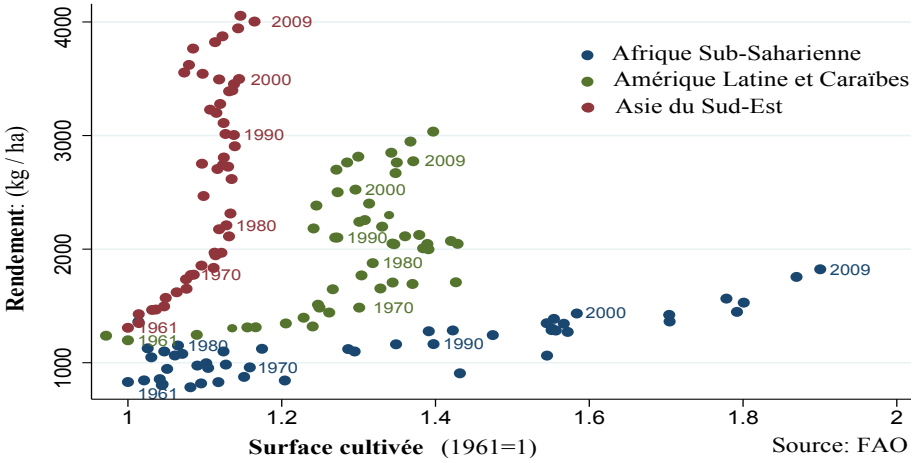


FIGURE 2 – Rendements céréaliers (hg/ha) en fonction des surfaces cultivées (par rapport à la surface cultivée en 1961) en céréales dans différentes régions en développement (1961-2009). Source FAO, 2011.

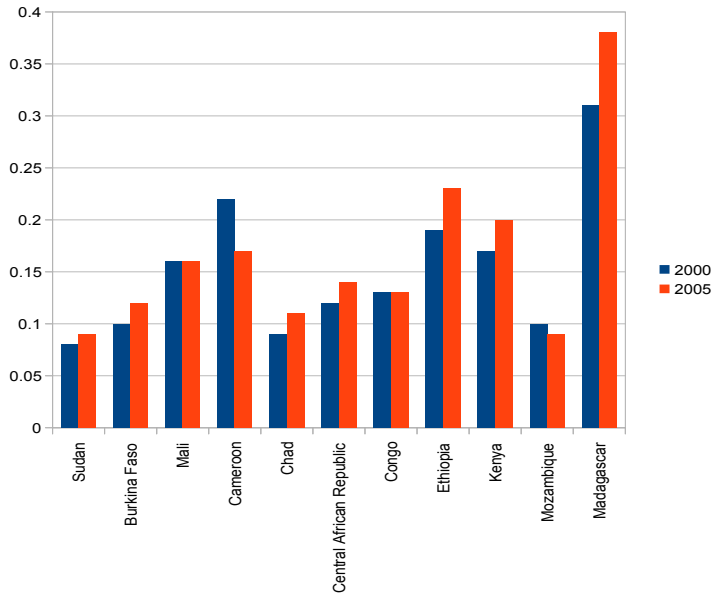


FIGURE 3 – Part des rendements observés en fonction du rendement maximum potentiel estimés (avec un apport d'intrants optimal) en 2000 et 2005. Source : Fisher and Shah (2010).

arables étant, pour de nombreux pays, limité en Afrique, il semble que favoriser la hausse des rendements et donc l'adoption de technologies soit le seul moyen de faire croître la production à l'heures actuelle. Comme l'ont mis en évidence

Hayami and Ruttan (1971, 1985) qui comparent l'évolution du secteur agricole aux États-Unis et au Japon, les pays doivent développer un mode de production utilisant intensivement le facteur qu'ils détiennent en abondance : les terres pour les État-unis et le travail pour le Japon.

Pour expliquer ce constat et discuter les stratégies de développement futures du secteur agricole africain, il nous semble nécessaire de commencer par rappeler l'évolution des politiques de développement et des travaux académiques depuis la seconde guerre mondiale, pour ensuite montrer les défis et les possibilités qui s'ouvrent pour l'agriculture en Afrique. Nous finirons par décrire le rôle de catalyseur qu'a joué le coton sur l'usage d'engrais et celui de frein que jouent probablement les risques, en s'attardant particulièrement sur les risques météorologiques.

0.1.2 Les politiques agricoles et leur contexte

Nous nous inspirerons largement dans cette section et la section suivante de la revue de littérature de J.-J. Dethier et A. Effenberger (2011). De 1950 à 1970, les politiques de développement ont été axées sur l'investissement public. D'abord orienté dans les années 50 vers une approche de développement des communautés, ces dernières se sont heurtées aux structures traditionnelles qui prévalaient alors : les élites accaparant l'aide. Dans les années 60, on appliqua une approche davantage fondée sur des programmes intégrés de développement rural, en cherchant à atteindre les plus pauvres, toujours avec l'aide publique, apportée par les institutions internationales. La subvention massive d'intrants et les programmes de vulgarisation et de formation se sont alors de nouveau heurtées aux réalités locales, par manque de considération envers les institutions existantes. Le coût important de ces programmes les empêchèrent de se généraliser et même souvent de dépasser la phase pilote.

Dans les années 80, l'aide fut orientée vers les infrastructures et l'éducation, mais le temps des certitudes quant au progrès et aux voies à emprunter en matière

de modernisation agricole s'achève brutalement en 1974 avec le 1er choc pétrolier. La crise financière dans laquelle se trouve le dispositif de développement le pousse vers une approche de marché, qui échoua de même, toujours en décalage avec les plus petits producteurs. Ces derniers se trouvaient encore sur des petits marchés relativement peu intégrés, à défaut d'informations et d'accès au marché du crédit ou de l'assurance. Le processus des institutions Bretton Woods, couplé à un manque d'appréhension de la complexité du terrain et probablement à un manque de pluridisciplinarité [2], ont laissé les petits producteurs en dehors des innovations techniques.

0.1.3 Économie du développement et agriculture

E. Boserup (1965) considérait déjà l'évolution des systèmes agraires, et plus particulièrement l'intensification de l'usage des terres, comme la clef de voûte (avec la dynamique interne aux ménages et l'émancipation des femmes) du changement technique, de la transition démographique et du développement économique.

Toutefois, les économistes ont longtemps cherché à déterminer si le développement de l'agriculture était nécessaire, si le chemin optimal de croissance passait forcement par un stade avancé de développement agricole et quel était l'intérêt de ce secteur dans le processus de développement et son impact sur la croissance. L'apport de Schultz (1953) dans ce domaine consiste à montrer l'importance de l'offre alimentaire pour subvenir aux besoins primaires de la population, étape nécessaire au développement. Cette théorie est ensuite validée par Kuznets (1966) qui montre que l'importance de ce secteur décroît avec le développement économique (phénomène de réallocation sectorielle). Ces questionnements ont encore des échos dans les études académiques récentes. Par exemple, le travail de Gollin (2010) ou de Collier et Dercon (2009) pose cette même question au regard des évolutions récentes de réallocations sectorielles, avec l'idée que les échanges au

2. Comme le pointe M. Dufumier (1996) les projets de cette époque ont été souvent éloingnés de la réalité du terrain du fait d'une absence d'analyse générale.

niveau international peuvent se substituer au développement de ce secteur. Ces travaux concluent tout de même à la nécessité du développement préalable du secteur agricole dans certaines circonstances.

La rationalité des acteurs du développement et la taille optimale des exploitations ont aussi été des sujets très prolifiques. Schultz (1964) a formulé l'hypothèse que les petits producteurs sont rationnels et qu'ils maximisent leur profit et répondent aux incitations de prix, hypothèse qui prévaut encore aujourd'hui. C'est alors le manque de transfert en technologies adaptées des gouvernements qui demeure l'explication principale des cercles vicieux à l'origine de la faible accumulation de capital productif. Schultz mettant déjà en avant le manque d'accès aux marchés aux intrants et préconisait aussi de faciliter leur adoption en permettant l'appropriation du savoir-faire, par le biais de l'éducation, des services de vulgarisation et de nouvelles technologies compatibles avec les arbitrages et le savoir faire des paysans.

Finalement, la question de la taille de l'exploitation a constitué une grande part du débat, menant à la conclusion que les politiques des dernières décennies (libéralisation et subventions d'intrants) ont particulièrement bénéficié aux gros producteurs davantage qu'aux petits. Cette question est encore discutée, par exemple dans l'article de Collier et Dercon (2009), qui défendent l'idée que l'avenir du secteur agricole africain réside dans les grandes fermes permettant des économies d'échelles. L'objectif étant d'être compétitifs face aux pays émergents et de développer une agriculture commerciale pouvant répondre aux besoins contemporains tels que l'intégration aux nouvelles technologies, à la finance et la à logistique internationale.

Cependant, dans les années 80, les crises de la dette ont mené les économistes à concentrer leur recherches sur la question de la stabilisation et de l'ajustement, sous l'égide du consensus de Washington. C'est cela qui a éloigné longtemps l'économie des questions pratiques et normatives qui se posent aujourd'hui quant aux formes institutionnelles et aux modes organisationnels qui pourrait accompagner

au mieux le développement de l'agriculture traditionnelle dans l'objectif de lutter contre la pauvreté. L'intérêt des marchés tant que la réalité de leurs imperfections font consensus, mais les institutions nécessaires au contrôle de ces imperfections et le rôle de l'état reste à définir.

0.2 Un renouveau depuis 2000

0.2.1 Pression croissante sur les ressources

Depuis plus d'une décennie, des menaces envers le développement et la lutte contre la pauvreté en Afrique se concrétisent :

- La population devrait augmenter en Afrique et atteindre 2 milliards d'individus en 2050 et 3.5 en 2100 selon les projections. Cela correspond à une densité moyenne de la population passant de 50 habitants au kilomètre carré en 2010 à 120 en 2050 et 220 en 2100. En comparaison, la densité était de 11 habitants au kilomètre carré en 1950 [3]. La grande majorité des pays observant une forte croissance de leur population sont concentrés en Afrique Sub-Saharienne (Figure 4). Ces évolutions, couplées à celle des modes de vie, mènent à penser que le besoin en production agricole sera accru dans une large mesure. La Figure 5 montre l'évolution de la production végétale nécessaire (comparée au niveau de production de 1995) pour pourvoir une quantité suffisante en énergie végétale. Cela correspond à une croissance annuelle des rendements de 5%, à surface cultivée constante, pour les pays dont le besoin est pultiplié par 10, contre 2% au Vietnam, en Irak, en Birmanie, au Pakistan, en Jordanie, en Syrie, en Inde et en Iran et entre 3 et 4% au Yemen, au Cambodge, au Bangladesh, au Laos et au Nepal.
- Ensuite le GIEC (2007) prévoit un réchauffement climatique global. En ce qui concerne l'Afrique de l'Ouest, malgré une incertitude concernant

3. Source : Division de la population, département de l'économie et des affaires sociales du secrétariat des Nations Unies : prévisions de la population mondiale, 2010, accès en Juillet 2012 au le lien suivant : http ://esa.un.org/unpd/wpp/unpp.

l'évolution du niveau et des variations des précipitations due à la grande complexité et la faiblesse des modèles pour prédire l'évolution du phénomène de mousson, la hausse des températures à long terme semble inéluctable. Cette dernière a un impact avéré, en particulier en Afrique, sur la production agricole selon de nombreuses études statistiques (Schlenker et Lobell, 2010 et Roudier et al. 2011).

- La hausse des prix des produits alimentaires peut être une chance pour les producteurs du Sud. Elle constitue une menace certaine pour les classes moyennes urbaines (cf. Fig. 6 et 7) mais peut aussi menacer les pays qui ne sont pas auto-suffisants. De plus, la grande variabilité des prix agricoles représente une menace importante pour les petits producteurs qui ne sont pas protégés contre ces variations, et qui n'ont pas les moyens de spéculer et de stocker, contrairement aux négociants. D'autres part, cette hausse des prix agricoles s'accompagne aujourd'hui d'une hausse du prix des intrants. Or, la production de ces intrants est intensive en énergie, ce qui annule l'impact positif sur le bénéfice des producteurs et limite l'intensification en accroissant le risque qui l'accompagne (nous développerons ces relations dans la section suivante).
- Finalement, la forte dégradation des sols africains et la tendance à la baisse de leur fertilité est connu depuis plus de 10 ans (Yanggen et al., 1998). A cette contrainte sur la productivité des terres, vient s'ajouter une course à l'achat des terres arables du continent par des fonds spéculatifs qui menace leur disponibilité pour nourrir les populations. La Banque Mondiale estime que près de 60 millions d'hectares (superficie approximative de la France) ont été achetés (ou loués sous forme de baux amphitéotiques) par des fonds privés en 2009 (Deininger et al., 2011). La figure 8 montre la surface de terres acquises dans 13 pays africains en pourcentage de la somme de terres arables disponible.

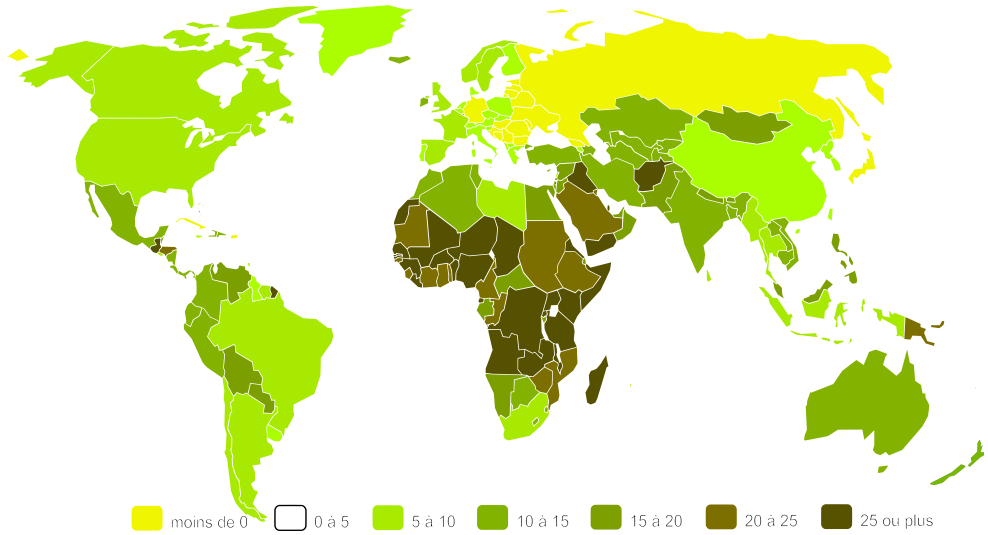


FIGURE 4 – Taux de croissance (net) des populations nationales en 2012. Source : INED (2012).

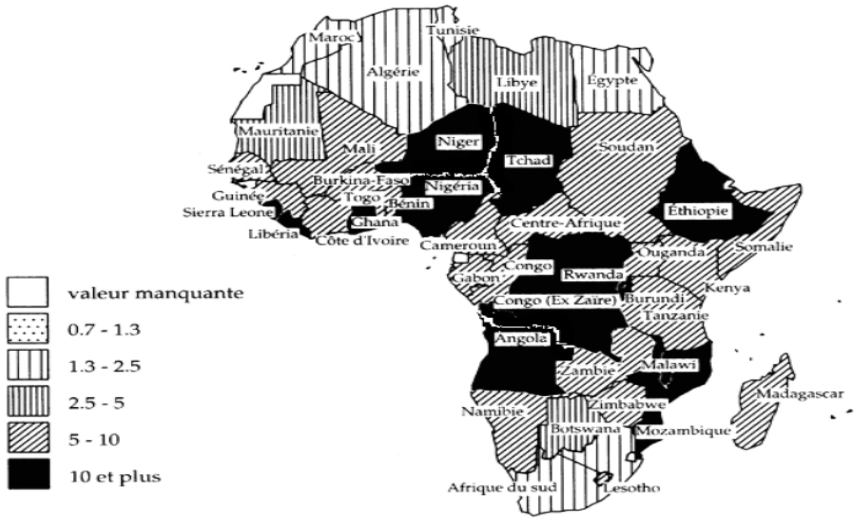


FIGURE 5 – Évolution des besoins en énergie d'origine végétale selon le pays entre 1995 et 2050 en Afrique (nombre par lequel il faut multiplier les besoins de l'année 1995 pour obtenir les besoins de l'année 2050). Source : Collomb (1999).

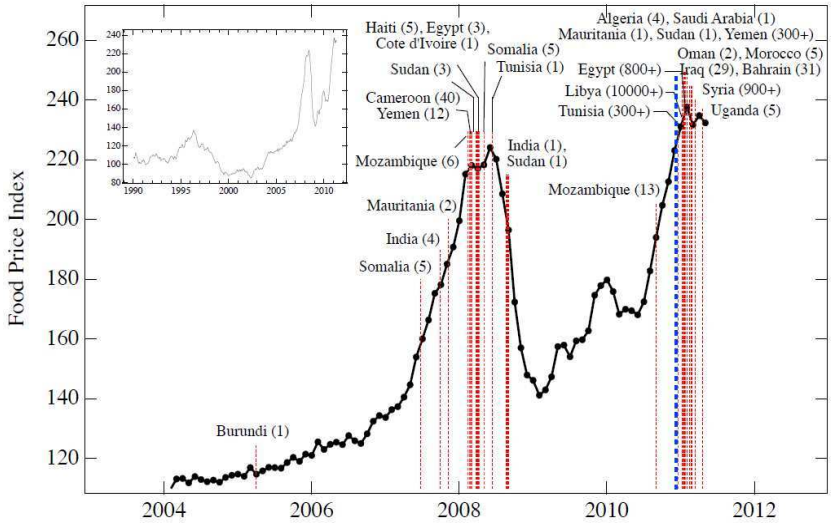


FIGURE 6 – Indice des prix alimentaires (FAO) de Janvier 2004 à May 2011. Les lignes rouges en pointillés indiquent le début des émeutes de la faim et les manifestations associés aux revendications sur le niveau de vie. Le chiffre entre parenthèse indiquent le nombre de morts recensés dans les médias. La ligne bleue indique la remise du rapport du NECSI au gouvernement des État-Unis mettant en exergue le lien entre niveau de l'indice, mécontentement social et l'instabilité politique. Le graphique en haut à gauche montre l'évolution des prix de 1990 à 2011. Source : NECSI.

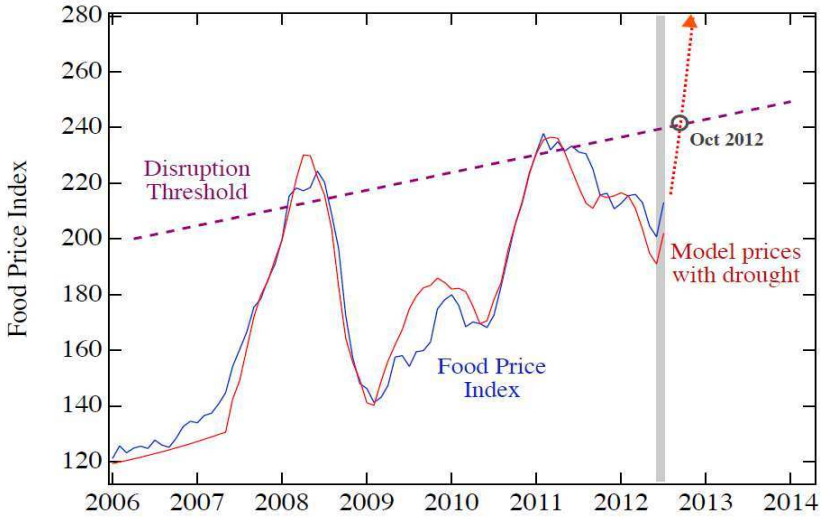


FIGURE 7 – Indice des prix alimentaires et prévisions du modèle du NECSI. Source NECSI.

0.2.2 Retour de l'agriculture : des approches complémentaires et non-exclusives

L'agriculture revient sur le devant de la scène depuis le début du siècle et plus récemment avec la hausse du prix des matières agricoles[4], du moins en ce qui

4. Souvent en conséquences de chocs météorologiques sur lesquels nous reviendrons dans cette introduction, comme la sécheresse en Russie causant indirectement de nombreuses émeutes

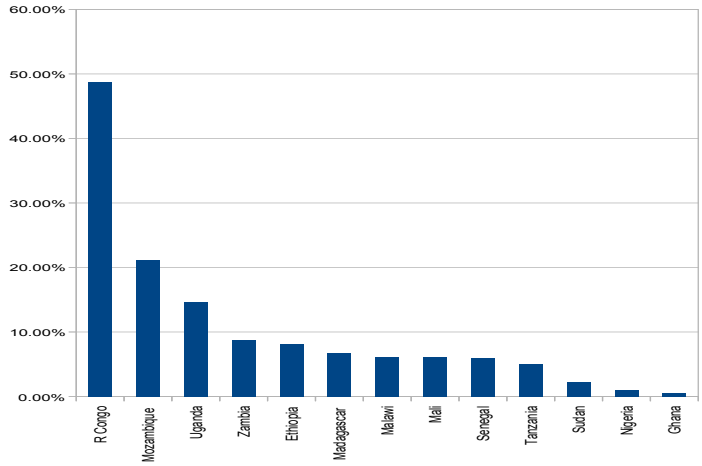


FIGURE 8 – Part des superficies agricoles faisant l'objet de transactions foncières vers des institutions étrangères dans l'ensemble des terres arables de certain pays africain. Source : (FAOSTAT, 2011).

concerne le domaine de l'économie du développement.

Concernant l'Afrique, de nombreux travaux récents et stimulants se penchent sur le sujet et tentent souvent de réorienter le débat de fond par exemple en montrant le rôle des innovations dans l'émergeance d'une nouvelle révolution verte en Afrique (Otsuka and Larson, forthcoming), ou en pointant les nouvelles contraintes auxquelles cette région devra faire face et le rôle des sciences du climat (Selvaraju, Gommez and Bernardi, 2011) ou encore en recensant les succès passés pour s'en inspirer (Haggeblade and Hazell, 2012).

Depuis les années 2000, en effet, l'économie du développement se concentre davantage sur le rôle et l'importance de l'agriculture dans la baisse de la pauvreté. L'adoption de technologies par les petits producteurs a été l'inspiration principale des politiques de développement jusqu'aujourd'hui (De Janvry, Sadoulet and Murgai, 2002) avec parfois une vision très optimiste quand au potentiel des ces dernières (Gollin, 2011). Toutefois il est important de noter que, depuis le milieu des années 2000, des investissements considérables ont eu lieu en Afrique

de la faim dans les classes moyennes urbaines en Afrique du Nord et au Moyen orient en 2008, cf. Fig 6.

sub-saharienne (46% du budget totale de l'agence CGIAR) avec une contribution limitée à la croissance des rendements, en particulier en comparaisons avec les autres régions du monde (Binswanger-Mkhize and McCalla 2010).

On retrouve toujours les différents courants de pensées qui prirent part au débat depuis la seconde guerre mondiale, au sein d'une approche plus globale et intégrée, ceci peut-être au coût d'une dispersion des recherches et des financements du développement. Le rôle de l'éducation, de l'accès au crédit et des externalités comme barrières à l'adoption des technologies (Foster and Rosenzweig, 2010) mais aussi des infrastructures restent des explications prépondérantes. Le manque d'incitations provient aussi d'un problème d'infrastructures et d'offre d'engrais de qualité à un prix abordable du fait de l'enclavement et du manque d'accès aux marchés internationaux. À titre d'exemple, le rapport issu de la commission Blair a mis en évidence que le coût de dédouanement d'un container à Dakar est l'équivalent de celui de son transport vers un port européen, que le transport d'une voiture du Japon à Abidjan coûte 1 500 dollars US alors que le transport dŠune voiture d'Abidjan à Addis-Abeba coûterait 5 000 dollar US, et que les frais de transports pour les Etats enclavés constituent des taxes à l'exportation de 75%.

Cependant une meilleure appréhension des coûts et des bénéfices des politiques et la volonté de mettre en place des outils durables, mènent les études à cibler des modes de développement utilisant le marché, le secteur privé ou des changements organisationnels et/ou modes d'organisation ne nécessitant pas d'intervention de l'État ni d'investissement publics trop importants. De même, l'adoption de technologie est envisagée comme la conséquence indirecte de mise en place préliminaire de systèmes éducatifs ou d'information, considérés comme des conditions favorables à l'instauration d'incitations durables à l'investissement productif.

On peut citer le développement des nouvelles technologies de l'information et des communications, par exemple pour la diffusion des informations sur les prix

(Aker, 2010 concernant le développement des réseaux de téléphonie portable au Niger) permettant aux producteurs d'augmenter leur marges souvent largement captées par les négociants. L'apparition des nouvelles approches expérimentales en particulier le développement des expériences contrôlées aléatoirement, semble aussi s'inscrire dans cette volonté de favoriser les projets qui ont un rendement net maximum.

0.2.3 Le cas de la contrainte de liquidités, des risques et des pièges à pauvreté

Fafchamps (2010) résume cette évolution en pressant la communauté scientifique de tester différentes explications concurrentes de la faible adoption de technologie, qui caractérise l'Afrique, par des producteurs rationnels mais contraints. Il propose à cet effet de commencer par considérer une définition plus large de la vulnérabilité.

Les leviers majeurs considérés par la littérature pour stimuler l'investissement dans du capital de production coûteux ou l'adoption de technologie [5] sont l'allègement des contraintes de liquidités, des risques pesant sur le système productif afin de limiter les situations de piège à pauvreté. La dynamique d'un piège à pauvreté est fondée sur la dépendance des investissements futurs au niveau de richesse actuelle. Dans ces situations, un bas niveau de revenu aujourd'hui limite le potentiel niveau de revenu de long terme en interdisant les investissements par exemple du fait d'une contrainte de subsistance. Le rendement agricole serait donc maintenu à un niveau bas en raison de contraintes qui pèse sur la dynamique des ressources des ménages. L'exemple du manque d'épargne en fin de période de soudure (en particulier après une mauvaise récolte) peut par exemple empêcher l'investissement et la hausse des rendements, a long terme, par la reproduction de cette situation.

De même, le risque pesant sur le retour d'investissement est aussi une source

5. Ceci est discuté plus largement dans la section 3.2.1 du chapitre 3.

potentielle du manque d'investissement. Les risques principaux que sont les prix internationaux et les chocs exogènes (météorologiques, attaques de criquets...) conditionnent en effet le retour sur investissement nécessaire à la subsistance des ménages ruraux. De nombreuses hypothèses ont été avancées pour expliquer le faible niveau de rendements de l'agriculture africaine, toutefois aucune n'a prévalu, comme le montrent les récentes théories en économie du développement (cf. section 0.1.3). Ces dernières hypothèses sont, entre autres, la contrainte de crédit, la nature incertaine des droits de propriétés et les risques qui limitent l'investissement. Le premier article traitant de l'aversion au risque comme source d'un niveau suboptimal d'investissement remonte à Sandmo (1971). Cette hypothèse a été mainte fois reprise pour expliquer le faible niveau de rendements (Townsend, 1994 ; Ravallion, 1994 Deaton 1990 et Rosenzweig, 1988) et en particulier le risque météorologique (Wolpin, 1982 ; Rosenzweig et Binswanger, 1993 et Paxton, 1992).

0.2.4 Nouvelles réponses organisationnelles

Nous chercherons dans ce travail à apporter une modeste contribution au débat en analysant deux modes de fonctionnement organisationnels qui pourraient être à même de favoriser un tel développement en donnant plus de latitude aux producteurs.

Premièrement, nous comparerons les organisations des systèmes de production de coton dans les pays d'Afrique sub-saharienne. Il nous semble important de rappeler pour la suite de cet exposé le rôle de catalyseur d'intensification de la filière cotonnière en Afrique de l'Ouest et du Centre. Le coton a en effet joué le rôle de culture 'locomotive' en particulier en ce qui concerne la production céréalière qui a pu profiter de la distribution d'intrants subventionnés ainsi que de services de vulgarisation et de la construction ou rénovation de routes.

Dans un deuxième temps, nous analyserons les enjeux de l'utilisation d'indices météorologiques ou issus d'imagerie satellite pour mutualiser les pertes des producteurs. Cela nous oblige à définir et à quantifier ce risque dans la zone

soudano-sahélienne où ont eu lieu ces études.

Dans le premier cas, nous adopterons une approche positive, en analysant les déterminants de la performance (rendements et surfaces cultivées) des filières cotonnières. Dans le second, nous aurons plutôt une approche normative, tentant de définir les méthodes requises pour l'élaboration d'assurance fondées sur des indices, le choix des indices et enfin le potentiel que représente ce type de produits (par exemple en comparaison avec des assurances assurant directement les rendements ou contre le risque de prix).

Dans les deux cas il s'agit de faire face à l'accès limité aux marchés et en particulier à l'absence de marchés du crédit et de l'assurance, qui maintiennent l'agriculture d'Afrique de l'Ouest au stade d'agriculture de subsistence. En effet nous montrerons que l'impact des réformes du secteur du coton dépendent largement de leur capacité à maintenir les relations de coordination qui existaient avant les réformes dans les secteurs coton, dont la forme institutionnelle est un héritage des ères coloniales. Cette relation de coordination est en effet un moyen de permettre le crédit aux intrants sans garantie nécessaire de la part des producteurs aux moment du semis, à la fin de la saison sèche (période de soudure), comme nous le montrerons dans le Chapitre II. De même, la fixation du prix d'achat de la récolte au semis protège les producteurs contre les variations intra-saisonnières du prix international du coton (Chapitre V).

0.3 Deux types de réponses organisationnelles

En résumé, les hypothèses qui sous-tendent les deux choix organisationnels que nous étudierons sont les suivantes : le coton a joué un rôle moteur dans l'intensification des filières agricoles et le risque météorologique représente un déterminant majeur de l'absence d'adoption de technologie telles que les intrants coûteux à l'exemple des engrais. C'est ce dont nous allons tenter de convaincre le lecteur dans cette troisième partie d'introduction.

0.3.1 Rôle du coton dans l'adoption de technologie et réformes

Étant donnée l'importance des structures traditionnelles dans les pays en développement et le fait que la plupart des stratégies de développement pour l'Afrique se soient confrontées à ces structures (cf. section 0.1.2) depuis 50 ans il semble important de trouver des stratégies de développement cohérentes et facilement appropriables pour les communautés traditionnelles sans permettre aux élites de capter la rente que représentent ces aides.

Au regard de ce critère et du niveau d'adoption des technologies, le coton peut-être vu, en dépit de la symbolique qui le lie directement à l'esclavage et aux périodes de colonisation, comme une réussite de programme intégré de développement agricole, au moins en ce qui concerne l'Afrique de l'Ouest et du Centre. Nous illustrons cette assertion par le fait que l'utilisation d'intrants, signe de l'intensification des cultures dans ces pays, a été largement corrélée avec le développement des surfaces cultivées en coton dans la région (Fig 9). Cette intensification a été permise malgré les forts risques (météorologiques entre autres) qui pèsent sur la culture du coton.

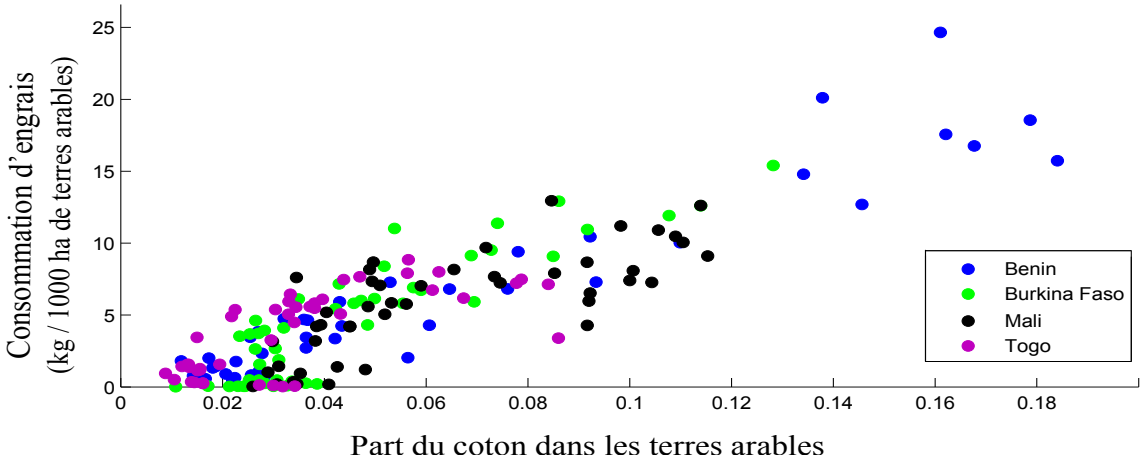


FIGURE 9 – Corrélation entre la consommation d'engrais et la part de la culture du coton dans l'ensemble des terres arables (1961-2009).

Le coton semble donc avoir été un catalyseur de l'utilisation des engrais par des petits producteurs, et reste aujourd'hui une des rares plantes cultivées de

manière intensive et à grande échelle dans la zone soudano-sahélienne.

Les enjeux sont aujourd'hui toutefois un peu modifiés et le seront peut-être dans le futur, du fait de l'appauvrissement des terres (en particulier dans les régions cotonnières) mais aussi du renchérissement graduel du prix des engrais, suivant la production d'azote très intensive en énergie (gaz) temporairement absorbé par la hausse du prix du coton et la relative qualité du coton africain encore ceuilli à la main, et donc peu abîmé contrairement aux productions mécanisés.

Nous avons toutefois fait le choix d'évaluer l'impact des réformes du secteur du coton sur la période 1960 et 2008 dans les pays d'Afrique sub-saharienne (chapitres I et II). nous tentons de déterminer si ces dernières ont eu un effet significatif sur les surfaces cultivées et les rendements, mais aussi si elles ont permises la continuité de ce rôle de catalyseur, en particulier en Afrique de l'Ouest.

0.3.2 Rôle du risque météorologique et assurances

Les famines qui ont suivi les sécheresses de 1972-1973 et 1983-1984 (Nicholson, 1986) sont les phénomènes les plus connus, et de nombreux travaux académiques montrent l'impact de ces sécheresses sur la santé (Macini and Yang, 2009 en Indonesie et Araujo-Bonjean et al, 2012 au Burkina Faso). Le risque météorologique (variations interannuelles de court et moyen terme et de petite et moyenne échelle) est aussi, depuis longtemps, pointé comme une source de sous investissement en raison de la faible dotation de l'Afrique en infrastructures d'irrigation (cf. section 0.2.2).

La variabilité interannuelle de la pluviométrie est forte au sein de l'Afrique et beaucoup de régions d'Afrique de l'Ouest (4°-20^oN ; 20^oW-40^oE) subissent des variations de long terme (plus de 10 ans). Une baisse des précipitations annuelles a été observée depuis la fin des années 60 (20 à 40% entre 1931-1960 et 1968-1990, Nicholson et al., 2000 ; Chappell et Agnew, 2004 ; Dai et al., 2004, cf. Figure 10).

Cette variabilité de long-terme est aussi accompagnée d'une variabilité spatiale importante que nous illustrons par des données des deux applications ex ante

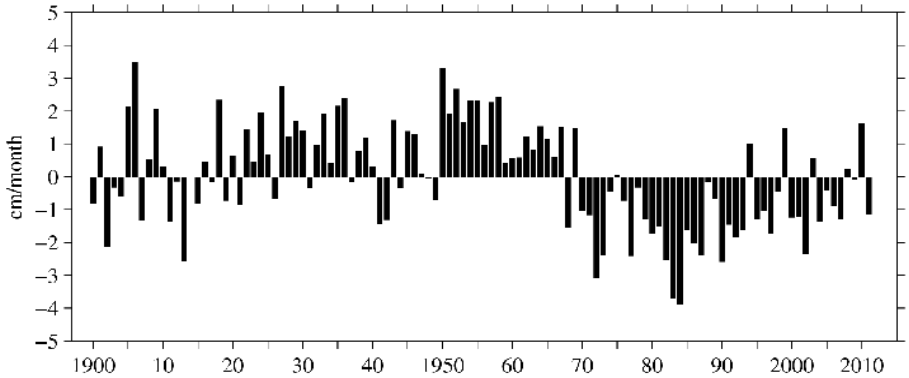


FIGURE 10 – Anomalie de précipitations au Sahel (10°-20°N ; 20°W-10°E) sur la période 1900-2011 : moyennes de cumul de pluies de Juin à Octobre. Source : National Oceanic and Atmospheric Administration (NOAA), NCDC Global history Climatology network data.

d'assurance météo. On peut observer dans la figure 11 que, pour les années 2004 et 2010, la distribution spatiale du cumul annuel de précipitations est très différent.

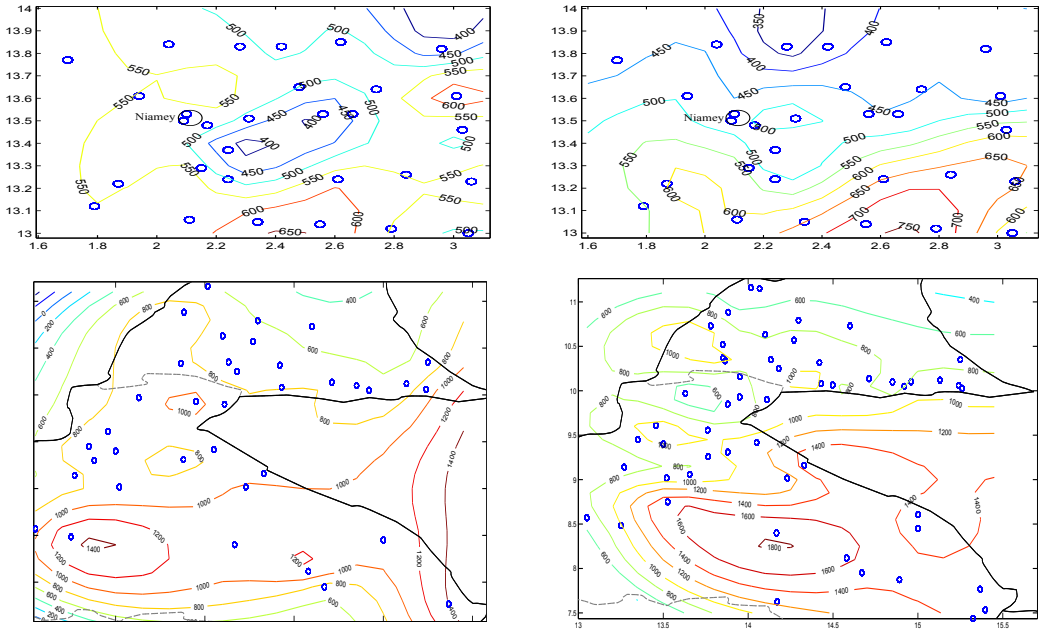


FIGURE 11 – Variation spatiale du cumul annuel pluviométrique en 2004 et 2010 dans le degré carré de Niamey au Niger (1 degré décimal) et dans la zone de production du coton au Cameroun (régions du Nord et de l'Extrême Nord, représentant l'équivalent 8 degrés décimaux) et localisation des stations pluviométriques. Source : Calculs de l'auteur.

Ces variations annuelles des précipitations sont à l'origine d'un déficit de production en céréales qui constitue la principale ressource alimentaire de cette région (Fig. 12). Nous pensons alors qu'il y a un fort potentiel pour les instruments de mutualisation spatiale et temporelle du risque météorologique dans cette région caractérisée par un climat soudano-sahélien.

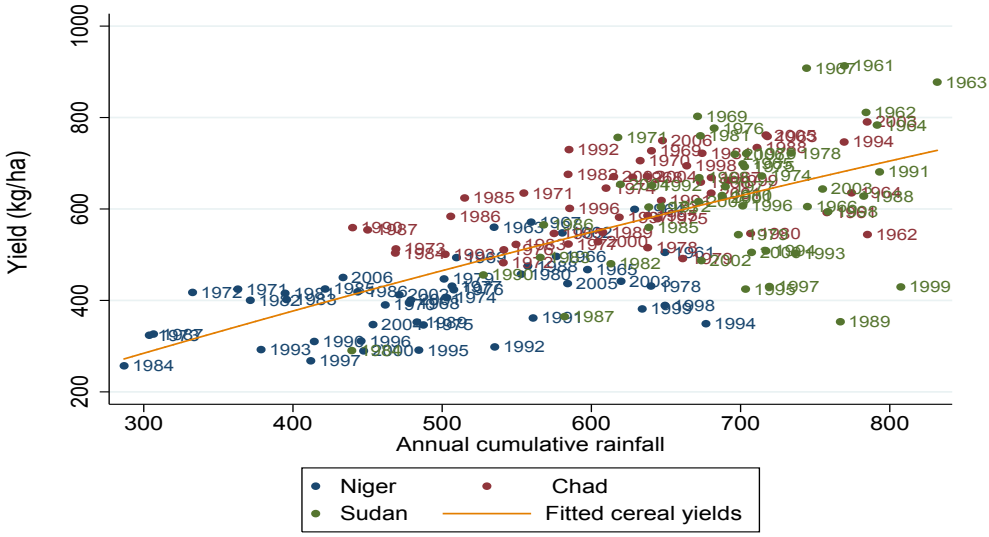


FIGURE 12 – Rendements céréaliers (kg/ha, données FAO) et cumul annuel de précipitation (mm, données CRU TS3) en zone soudanienne entre 1961 et 2006.

Pour faire face au risque de mauvaise récolte des systèmes d'assurance pourraient être mis en œuvre. Il existe aujourd'hui trois types d'assurances : les assurances récoltes, les assurances fondées sur un indice de rendement local et les assurances météorologiques.

0.3.2.1 Les assurances fondées sur des indices météorologique

En réponse à ces risque qui semblent brider l'utilisation d'intrants coûteux (Dercon and Christiaensen, 2011) et donc peut-être à l'origine des bas rendements observés, un nouvel outil paraît intéressant à tester dans le contexte Ouest africain : il s'agit des assurances fondées sur des indices météorologiques ou de végétation. Ces derniers permettent une indemnisation en fonction du niveau de l'indice, observable en temps réel ou dans un délai limité, défini ojectivement

avant la mise en oeuvre du contrat et indépendant des actions de l'assureur et de l'assuré. ces trois caractéristiques permettent à l'assurance d'être peu coûteuse (absence de coût de transaction lié à la constation du dommage, comme c'est le cas au sein d'assurances traditionnelles), exemptée des problème d'aléa moral et d'anti-sélection (absence d'asymétrie d'information concernant la réalisation de l'indice) et d'autoriser des indemnisations rapides, nécessaires en cas de sécheresse généralisée pour faire face à des situations de famine.

De plus ces assurances sont peu coûteuses en terme d'infrastructures et peuvent être couplés à des produits de crédit afin de limiter le risque de défaut et donc le prix de ces derniers (Dercon and Christiaensen, 2011). Ces avantages théoriques ont laissé penser que ce dernier type d'assurance était supérieur aux autres et déclenché un développement rapide de la littérature à ce sujet. Ceci autant au niveau micro-économique (nombreuses expériences aléatoirement contrôlées sur des produits d'assurances individuelles contre le risque météorologique dans les pays en développement) qu'au niveau macro-économique (la mise en œuvre d'un filet de sécurité fondée sur un réseau de pluviomètre, en 2006, par le Programme Alimentaire Mondial en Éthiopie et l'émergence d'une initiative de grande envergure, soutenu par l'Union Africaine, pour couvrir les risques météorologique des pays d'Afrique sub-saharienne[6] en sont la preuve).

Malgré ce développement rapide, peu d'études se sont attelé à estimer le potentiel de tels produit sur la base de données de rendements et de variables météorologiques, sûrement du fait de la rareté de ce type de données. Nous tentons donc de remédier à cette lacune en estimant ce potentiel ex ante (avant la mise en place d'un tel produit) dans le cas de la culture du mil au sein du degré carré de Niamey et du coton au Nord du Cameroun (Chapitres III, IV et V). Ces études ont bénéficiés de la collaboration étroite avec des météorologues et de récoltes de données de ce type au sein du programme d'Analyse Multidisciplinaire de la Mousson Africaine (AMMA) regroupant des recherches de différentes disciplines

6. http ://www.africanriskcapacity.org/.

(climat, météo, agronomie et socio-économie).

CHAPTER 1

SUB-SAHARAN AFRICAN COTTON POLICIES IN RETROSPECT

This chapter is based on the following article: Claire Delpeuch & Antoine Leblois, Sub-Saharan African cotton policies in retrospect, forthcoming in *Development Policy Review*.

Abstract

Calls for liberalizing cash crop sectors in sub-Saharan Africa have been voiced for decades. Yet, the impact of reforms remains elusive in empirical studies. This paper offers new opportunities to solve this problem by creating precise and consistent market organisation indices for 25 African cotton markets from 1961 to 2008. The aggregation of scores reveals interesting trends: markets are no more competitive today than in the late 1990s, 50% of production still originates from markets with fixed prices and reforms are giving rise to a new type of regulated market both in East and West Africa.

1.1 Introduction

Cotton is a key crop in sub-Saharan Africa (SSA): it is a major source of foreign currency for a number of countries, the primary cash-crop for millions of rural households and one of the only export products for which the continent's market share in global trade has increased over the past decades (Boughton et al., 2003; Baffes, 2009b). Being grown mainly by smallholders, it is believed the cotton market plays a key role in development and poverty reduction (Minot and Daniels, 2002; Badiane et al., 2002; Moseley and Gray, 2008) [1].

Since the late 1980s, Africa's 'white gold', as which cotton is sometimes known, has been central to a harsh debate on how best to encourage its production and, particularly, on the role governments should play in this process. Historically, markets in many countries have been organised around public or para-public companies, referred to in the literature as boards in Eastern and Southern Africa (ESA) or parastatals [2] in West and Central Africa (WCA), enjoying a monopoly on cotton transformation and export and a monospony on related activities such as input provision and transport. Reforms have been adopted in a large number of countries, since the late 1980s and, increasingly since the mid-1990s [3]. The nature of reforms has widely varied across countries and regions, ranging from far-reaching market and price liberalizations to only very marginal adjustments.

1. This view however has been under attack on the grounds that cotton cultivation was introduced in many African countries with a view to satisfy colonial powers more than local populations (see for example, Isacmaan and Roberts, 1995). It has recently reappeared in the literature when national household survey data on Mali provided evidence of the fact that a large share of cotton-producing households living in the fertile area of Sikasso continued to live under the poverty line despite cultivating cotton and receiving public subsidies Ű making Sikasso the poorest rural region in Mali. However, these findings have been disputed by later research pointing at inadequacies in the data and methodology of the initial analysis (see Delarue, Mesple-Somps, Naudet and Robilliard, 2009). More general concerns have also been voiced with regards to the 'unfairness' of international cotton markets regulation (see Sneyd, 2011).

2. A parastatal is a legal entity created by a government to undertake commercial activities on behalf of an owner government.

3. The privatisation and liberalisation of all the cotton sub-sectors were advocated by the World Bank and the International Monetary Fund, originally in the late 1980s, and increasingly since the mid-1990s, with the objective of strengthening their competitiveness, ensuring their financial sustainability and allowing a fair distribution of the profits between producers and ginners (Badiane et al., 2002).

Because reforms have not always yielded the expected impacts and because several countries are still considering different reform options, the institutional puzzle remains unsettled. As a result, the literature on cotton sector reforms has dramatically expanded over the past decade. While in the 1980s and 1990s it was prospective and consisted mainly of recommendations, numerous retrospective assessments have been performed over the past few years. Reform processes have, however, been studied primarily on a case-by-case basis (notable exceptions being Goreux et al., 2002; Araujo-Bonjean et al., 2003; Tschirley et al., 2009 and 2010; Delpeuch et vandeplas, forthcoming), and concentrate on a small number of countries [4]. Moreover, policy changes have often been studied only shortly after their implementation.

In order to enable a broader and longer term analysis of cotton sector market organisation, this paper aims at giving a full panorama of how market organisation has evolved in all SSA cotton producing countries from the early 1960s to the present time. We refer to 'market organisation' to describe market structure, the nature of ownership, and the regulatory framework understood as the set of rules which govern market entry, pricing, and all aspects of cotton production, transformation and sales. Based on an extensive review of the literature we compile indices describing the evolution of market organisation in 25 countries from 1961 to 2008 [5]. This enables us to make two contributions to the literature.

4. Numerous studies look at the historically biggest producers in Eastern and Southern Africa (ESA) (Mozambique, Tanzania, Uganda, Zambia and Zimbabwe) and in WCA (Benin, Burkina Faso, Chad and Mali); countries where production has declined over the last decade (such as the Ivory Coast, Nigeria and Sudan) or smaller producers (such as Kenya, Madagascar, Senegal or Togo) are rarely examined.

5. These countries include Kenya, Madagascar, Malawi, Mozambique, Sudan, Uganda, United Republic of Tanzania, Zambia and Zimbabwe in ESA and Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Democratic Republic of the Congo, The Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Mali, Niger, Nigeria, Senegal and Togo in WCA. According to FAO statistics, 32 countries produced over 1000 tons of cotton at some point between 1961 and 2009. However, we still have not found sufficient information to document our indices for the following countries: Angola, Burundi, Botswana, Ethiopia, Somalia, South Africa and Swaziland. Note that the size of our sample expands from 20 countries in 1961 to 25 countries as from 1985 as countries are included in the database only post-independence. This follows from our difficulty to find reliable and comparable data on the pre-independence period.

First, by computing average degrees of competition, private ownership and price intervention at different sub-regional levels, we verify whether the trends in cotton market organisation identified in the literature hold true when expanding the study period and the sample of countries under consideration. With a series of nuances, we confirm key findings for the different periods until the late 1990s, which suggests that cotton policies were highly uniform at the sub-regional level: public ownership was greater and competition weaker in WCA until the independences; markets then became increasingly regulated in ESA during the 1970s and 1980s; in the early to mid-1990s significant reforms took place in the latter region, leading to both increased participation of the private sector and greater competition again. However, we find that this first wave of reforms was not the start of a process, contrary to claim: such reforms have not been mirrored by other countries in the following decade. A second wave of reforms has followed in WCA, yet they have led to the creation of hybrid markets with mixed ownership and regulation but no competition. Besides, we observe a stepping away from the trend towards fully deregulated markets in a number of ESA countries as government adjusted regulation in reaction to various problems and liberalization and privatisation have even been reversed in a number of marginal producing countries. As a result, markets organisation is increasingly diverse across SSA but competition remains limited: over fifty percent of total production still originates from non-competitive markets where prices are fixed.

Secondly, expanding the information available to the largest possible array of countries and reporting key policy or institutional changes with precise time indications, and in a consistent manner for 25 countries, brings new opportunities for quantitative empirical work on the link between market organisation and performance in African cotton sectors or the political economy of cotton policies. The indices compiled in this paper have been used in the chapter II, in which we show that the link between market structure and performance is very much linked to the type of liberalization introduced and the nature of pre-reform policies Ű

this confirms the necessity of looking at the impact of structural adjustment using precise institutional variables. Further work could usefully be engaged to explore the reasons for increasing heterogeneity in organization: how much of the variation across countries is due to different structural market failures that fully liberalized systems would be unable to resolve in some countries, and how much is due to differences in bargaining power of the producer associations, the processing sector (sometimes including the parastatals) or government stakeholders who are either unwilling to give up on rents, or believe that reforms would not be beneficial to farmers? While country-specific case-studies have explored the political economy of some reform processes (e.g. Serra, 2012 and Kaminski and Serra, 2011), it remains difficult to understand the comparative pattern of institutional evolution.

The paper is organised as follows. In section 2 we comment on the methodology adopted to review cotton policies: we outline the criteria chosen to characterise cotton markets and reforms and describe our sources of information. In section 3, we identify patterns and trends in cotton sector organisation at the SSA level and for sub-groups of countries. We conclude in section 4.

1.2 Methodology: Creating indices

1.2.1 Characterising cotton markets

Building on the literature assessing the links between market organisation and performance, we have identified a number of links between market organisation and performance that we use as guidelines to characterise markets and describe their evolution [6]. The works by Tshirley et al. (2009 and 2010) were particularly useful as a means of assessment as they rest on a typology of cotton markets against which a number of performance indices are examined.

6. Given the large geographical coverage of the paper, it concentrates only on the production of seed cotton and its transformation into cotton lint; the production of by-products, oil and cakes, is not addressed in what follows.

To understand how market organisation has evolved it is important to recall that market organisation in SSA cotton markets is closely related both to the SSA rural context and to the specific requirements of cotton production (Poulton et al., 2004). Cotton farming requires inputs (fertilizers, pesticides, herbicides and seeds) that are often beyond the reach of producers given the thin profit margins that cotton offers and the still restricted use of locally-available alternative inputs. This is particularly the case in WCA where agro-climatic conditions are less favourable and needs in chemicals greater. As credit markets are almost non-existent in rural areas, production occurs almost exclusively through interlinked transactions whereby inputs are provided on credit by the ginning companies [7]. Changes in market organisation have specific implications in such a context of imperfect markets and prevalence of linkages between input and output markets; especially since formal contract enforcement institutions are typically absent in many countries of SSA [8] (Poulton et al., 2004; Delpeuch et Vandeplas, forthcoming). Contract enforcement is indeed key to ensure the sustainability of input credit schemes, witch have very direct consequences on the yields achieved by smallholder farmers and in terms of the number of farmers that can engage in cotton production (Poulton et al., 2004; Delpeuch et Vandeplas, forthcoming).

The first important dimension of market organisation is the degree of competition. It is believed to impact the share of the world price received by farmers, which in turn influences the area under cultivation and the amount of effort that farmers invest in production. Yet, competition also increases the scope for side-selling, whereby farmers sell their cotton to other buyers at harvest, rather than to the company that has pre-financed their inputs. In addition, competition is believed to influence firms' efficiency through the creation of cost minimization incentives or, conversely, the suppression of economies of scale or the introduction of new transaction costs (Tschirley et al., 2009; Delpeuch et Vandeplas, forthcom-

7. Among current significant producing countries, Tanzania is the only country where this is not the case at all.

8. Among other reasons this is due to the oral nature of many arrangements, the geographical dispersion of agents and the weakness of judiciary systems.

ing). Finally, Larsen (2003); Poulton et al. (2004) and Tschirley et al. (2009); have identified a strong link between competition and the ability of companies to coordinate on quality issues; for example, avoiding mixing seed varieties in different regions or enforcing strong quality requirements. Our first set of indices thus reports whether markets are monopsonistic, regulated (implying that firms operate as regional monopsonies or that supply is administratively allocated among firms), limitedly competitive (implying that two or three firms with large market shares exert price leadership) or strongly competitive (implying that many firms compete on prices) [9].

Another key aspect of market organisation is price fixation: fixed prices that apply across the country and throughout the year (i.e. pan-territorial and pan-seasonal prices) have been heralded as a risk mitigation and spatial redistribution instrument (Araujo-Bonjean et al., 2003). However, they discourage production from the most productive farmers, and conversely encourage production by less efficient farmers. Besides, price fixation by the government most often results in (implicit) taxation or, alternatively, in unsustainable subsidies (Baffes, 2009b). Our second set of indicators reports whether prices are fixed pan-territorially and pan-seasonally, whether the government or a public body announces an indicative price at the beginning of the season or whether prices are solely determined by market forces.

Finally, we look at the nature of ownership. Private sector involvement in ginning and cotton-related activities is indeed often seen to improve efficiency through the removal of soft budget constraints, excessive employment or political interference in management (Baffes, 2009b). Our third set of indices therefore

9. These categories very closely match those used by Tschirley et al (2009) which differentiate between 'market-based' systems, including 'competitive' systems (our strong competition category) and 'concentrated' systems (our limited competition category) and 'regulated' systems which include 'national monopolies' (which almost matches our monopsony category) 'and hybrid system' (which corresponds to what we call regulated markets). The reason we have note used the same classification is that we decided to separate the competition dimension of market organisation from that of ownership and pricing (for example our monopsony category can also reflect on a situation where only one private firm operates).

reports whether the ginning companies are entirely public, whether ownership is mixed or whether it is entirely private. Ideally, it would have been interesting to give more information into the characteristics of private ownership, differentiating, for example, between owners seeking to provide cotton with standard market attributes, and owners seeking particular quality attributes (including, for example, certain quality grades, or organic and fair trade certified cotton). However, information was not available on a sufficient scale to do so.

A series of control variables, which will be useful in the context of quantitative work, as well as a number of additional indices reflecting on more hypothetical determinants of performance are also included in our dataset. For example, good performance is sometimes attributed to the involvement of colonial enterprises or their counterparts after independence either directly or through lagged effects of past interventions (Tschirley et al., 2009). From this perspective, we report colonial ties and years during which ex-colonial institutions continued to operate. Several empirical studies also recognise the potential importance of producers' collective ownership in the ginning companies, which is often coupled with participation in sector management. Ownership by producers' organisation is thus also captured by one of our indices. These indices however are not commented upon in what follows, as we aim to concentrate on key patterns and trends. Table 1 summarizes the content of our database.

1.2.2 Sources and information compilation

As much as possible, we attempted to document our indices with objective information such as official law and regulation documents or reports of international organisations. The latter are indeed more comparable across countries and time than interview or survey-based information (Conway et al., 2005). Objective information sources were however not available for all the countries under scrutiny. We thus also used information emanating from the local and international press,

interviews and the literature[10]. This enabled us to account for the fact that poor rule enforcement and/or informal rules also impact market organisation[11]. For example, establishing the actual degree of competition of a market ideally requires information not only on the number of firms active in the market and their respective market shares, but also on their strategic behaviour and on the degree of ownership concentration behind firms with different names. Similarly, the role of regulatory bodies is at times difficult to assess without knowing the context in some detail. Based on such additional information, we report the date of effective changes, rather than the date of the official decisions underlying these changes, in cases where they differ.

When compiling the information, we refrained from using composite indices in order to be as transparent as possible. In this respect, our indices are different from those in Giuliano and Scalise (2009), the sole other agricultural market regulation indices of which we are aware. In their paper, government intervention in cash crop markets is given a score between one and four[12]. Alternatively, in this paper, (i) different indices are reported for the different dimensions of market organisation, identified in the above section and (ii) degrees in each of these dimensions are reported as separate dummy variables rather than scores.

10. Among these studies, see in particular, Kaminski et al. (2011); Savadogot and Mangenot (forthcoming) on Burkina; Minot and Daniels (2005); Gergely (2009a) on Benin; Gergely (2009b) on Cameroon; Gafsi and Mbetid-Bessane (2002) on the Central African Republic; Mbetid-Bessane et al. (2010); Azam and Djimtoingar (2004) on Chad; and Makdissi and Wodon (2004) on the Ivory Coast; Tefft (2003); Vitale and Sanders (2005) on Mali; Larsen (2006)Poulton and Hanyani-Mlambo (2009) on Mozambique; Dercon (1993); Gibbon (1999); Cooksey (2004a and 2004b); Baffes (2004); Larsen (2006); Poulton (2009) on Tanzania; Lundbæk (2002); Poulton and Maro (2007); Baffes (2004 and 2009a) on Uganda; Brambilla and Porto (2008); Kabwe and Tschirley (2009) on Zambia; Boughton et al. (2003) on Zimbabwe as well as Araujo-Bonjean et al. (2003); Goreux (2003); Bourdet (2004); Baffes (2009) on WCA and Tschirley et al. (2009) on SSA.

11. For clarity, we quote country-specific sources only in the country-case summaries (available upon request).

12. Their database contains information for the major cash crop in 88 developing countries from 1960 to 2003.

1.3 Cotton policies in SSA 1960-2009

1.3.1 1960s-1980s: An era of regulation

To describe an average market organisation at different points in time, we compute annually (i) the number of countries per level of competition, per degree of private sector ownership and per pricing system in addition to (ii) the share of production emanating from each of these groups of countries. Graphs are drawn first at the SSA level (Figure 1.1), but also differentiate between WCA and ESA (Figures 1.2 and 1.3, respectively) and between former French and British colonies (Figures 1.4 and 1.5).

As pictured in Figure 1.1, market organisation varied across SSA in the early 1960s although over half the countries already had monopolistic markets (Figure 1.1-A) and no private ownership (Figure 1.1-C).

In WCA, competition was absent in almost 90 percent of markets and a majority were monopolistic (Figure 1.2-A). The Democratic Republic of the Congo, The Gambia and Togo were the only countries in which cotton sectors were not monopolistic but regulated or moderately competitive and where some private ownership was allowed. Prices were fixed everywhere, except in Togo (Figure 1.2-E).

By contrast, in ESA only two countries (Madagascar and Malawi) had monopolistic markets at the beginning of our study period (Figure 1.3-A). Private ownership was also much higher in ESA than in WCA: it was null only in the two monopolistic markets and the Sudan (Figure 1.3-C). Prices were fixed in around half the countries: Madagascar, Malawi, the Sudan, Tanzania and Uganda (Figure 1.3-E), however a number of countries introduced fixed prices over the 1960s and 1970s. Figures 1.4 and 1.5 illustrate how differences in market organisation across regions in fact directly reflect on colonial policies: there was almost no competition and private ownership in all former French colonies, including in ESA (Figure 1.4) and much more in former British colonies, including those of

WCA (Figure 1.5).

However, looking at average market organisation in terms of production shares originating from different types of markets offers a somewhat different picture. During the 1960s and the 1970s, competitive markets accounted for only a marginal share of production in ESA and in ex-British colonies as a whole (Figure 1.3-B and 1.5-B) and production overwhelmingly originated from countries where prices were fixed (Figures 1.2-F and 1.4-F). Differences between ESA and WCA, or ex-French and ex-British colonies, were thus less marked than may be perceived when looking solely at markets. As shown in figure 3, market organisation remained very stable in WCA after the independences (that is from the mid to late 1960s to the late 1980s), and even more so in former French colonies (Figure 4) [13]. Conversely, changes were important in ESA: competition declined and regulated markets were transformed into monopolies while public ownership increased very significantly. By the early 1980s, almost three markets out of four were monopolistic and entirely publicly controlled in ESA (Figures 1.3-A and 1.3-C) [14]. As early as the mid-1970s prices were fixed in all areas except Mozambique, where the prices announced were only indicative (Figure 1.3-E).

While broadly confirming patterns identified in the literature (namely market uniformity within SSA sub-regions and a higher initial degree of regulation in WCA), our indices highlight the fact that market organisation quickly became similar in WCA and in ESA. Between the late 1970s and the mid-1980s, competition and private ownership were, on average, as little in ESA as they were in WCA. Besides, our indices suggest that the commonly used distinction between

13. The increase in the number of monopolistic markets with public ownership and fixed prices in Figure 1.2-A, 1.2-C and 1.2-E is not due to shifts in market organisation but to the emergence of new producing countries (Ghana in 1968, The Gambia in 1970, Guinea in 1983 and Guinea Bissau in 1983).

14. Production shares followed similar trends, however, noteworthy is the existence of a time-lag between the peak of production emanating from monopolistic and publicly-managed sectors, which both occur in the late 1970s, and the share of such markets, which continued to increase, respectively, until the mid and late 1980s. Similarly, while the number of regulated and mixed ownership markets has remained relatively stable from the 1960s to the mid-1980s, their market shares have significantly declined. Interesting patterns in terms of performance are therefore to be explored.

WCA and ESA should not be understood as a geographical distinction but rather as a shortcut denomination for colonial ties. It should be acknowledged, however, that the practicalities of regulation were different in WCA and in ESA, where it was organized along the lines of cooperative structures. These differences themselves are likely to be meaningful for performance and in terms of the impact of later reforms. Unfortunately, we did not find enough information to report on the functioning of these structures on a country basis.

1.3.2 Late-1980s-early 2000s: Different reform paths

Returning to Figure 1.1, this shows how cotton market organisation in SSA began to change in the mid-1980s, with a drastic acceleration of reforms in the mid-1990s. The number of monopolistic and publicly owned markets indeed continuously declined until the mid-2000s (Figures 1.1-A and 1.1-C). Prices were also liberalized in a number of countries, although the decrease is less important and stopped in the mid-1990s (Figure 1.1-E). This difference between market reform and price reform reflects the fact that the decrease in the number of publicly-owned monopolistic markets resulted from two different waves of reform: the first wave gave rise to privately operated and competitive markets where prices were liberalized and the second wave to hybrid markets characterized by mixed ownership, regulation and continued price fixation. This can be seen in the parallel increase of the number of regulated and competitive markets and the increase of entirely and partially privately operated markets in Figure 1.1-A and 1.1-C. Trends in terms of market share (Figures 1.1-B, 1.1-D and 1.1-F) are relatively similar. We document more precisely the timing and the places where these two waves of reforms took place by looking at sub-regional levels.

Changes were very different in ESA and in WCA, or rather in former British colonies and in former French colonies. Indeed, contrary to common belief, the first breakthrough occurred in WCA and not in ESA, with the liberalisation of markets and prices in a number of non-French WCA countries in the mid-1980s

(the Democratic Republic of the Congo in 1978, Ghana in 1985 and Nigeria in 1986). This first wave of liberalisation continued a decade later in ESA as illustrated by the huge shifts in trends in the mid 1990s, shown in Figure 1.3. By 1995, markets were completely privatised and liberalised in all the former British colonies of the region: Kenya (1993), Malawi, Uganda, Zambia, Zimbabwe (1994) and Tanzania (1995). Competition and prices thus remained constrained only in Madagascar and Mozambique (respectively former French and Portuguese colonies) and Madagascar was the sole country where the cotton sector remained monopolistic and purely state-owned. Production shares followed similar trends: in the mid-1990s, the shares of monopolistic and regulated markets dropped sharply (to almost nothing in the late 1990s) to the benefit of competitive markets (Figure 1.3-B). Similarly, the shares of production emanating from publicly-owned markets and from markets with fixed prices shrank drastically at the same time (Figure 1.3-D).

In contrast, in non-Anglophone WCA, reforms of what we call the 'second wave' have been much more recent and much more restricted in scope: the number of monopolies has declined only gradually, to the benefit of regulated markets but not to the benefit of competitive markets (Figures 1.2-A and 1.2-B). Public ownership has also declined with an acceleration of this trend in the late 1990s, but very few markets have become fully operated by private agents (Figures 1.2-C and 1.2-D) [15]. Prices have not been liberalised (Figures 1.2-E and 1.2-F). The most important changes occurred in Niger and Guinea Bissau, where parastatals were privatised (in 1989 and 2000) before competition was introduced (in 1998 and 2002). Competition remained limited, however, except in Niger, where it was re-enforced by new entry after 2003. In Benin, Togo, the Ivory Coast and Burkina Faso, private investors were allowed to enter ginning (in 1995, the late 1990s, 1999 and 2003), yet governments remained major shareholders of the former parastatals that continued to operate, competition remained strictly constrained and price

15. Note that companies have been privatised in 2009, i.e. after the end of our study period, in Madagascar and Senegal.

fixation was not challenged. Conversely, the Central African Republic, Guinea, Senegal and Madagascar completely privatised their parastatals (in 1990, 2000, 2003 and 2004), but continued to guarantee their monopoly position (or failed to attract competitors in the Central African Republic). Finally, public monopsonies still operate in Mali and Cameroon where market organisation was not challenged at all. As a result, by the end of the 1990s, the private sector was operating in only around half the markets of WCA and competition remained restrained in over three countries out of four. About 80 percent of production continued to originate from markets where prices were fixed.

Regarding the structural adjustment period, our results again broadly confirm the key results found in the literature, namely that of prompter and deeper reforms in ESA. The nuance identified in the preceding section still holds, however: patterns again strongly reflect colonial origin rather than geography (as illustrated by comparing Figures 1.2 and 1.3 with Figures 1.4 and 1;5). This observation suggests a strong path-dependence of institutional history.

1.3.3 Since the early-2000s: A halting of reforms?

The clear trend towards more competition identified in the above section vanishes in the 2000s.To make this clearer, in Figure 1.6, we graph the number of countries and their share of production according to whether markets display any level of competition (i.e. moderate or strong) or none (i.e. being monopolistic or regulated). As shown in Figure 1.6-A, the combined number of monopolistic and regulated markets in SSA has in fact increased in the first half of the 2000s and thus returned to its level in the mid-1990s. This is also true at the sub-regional level: competition was suppressed in ESA in the early 2000s (Figure 1.6-E) and in WCA in the late 2000s (Figure 1.6-C). Liberalisation attempts have indeed been reversed in Mozambique (in 2000), Guinea Bissau (in 2004) and the Democratic Republic of the Congo (in 2006) and regulation was re-introduced in Uganda (between 2003 and 2008). Similar patterns appear in terms of market share: the

share of non-competitive markets has increased over the first half of the 2000s and has returned, today, to the level of late 1990s in ESA and is only slightly inferior that level in WCA (Figures 1.6-D and 1.6-F). In addition, we also observe a partial reversal of the privatisation trend in WCA: the private sector no longer operates in the Central African Republic (since 2007), The Gambia (since 1996) and Guinea (since 2008).

Building on our country-case studies, we find that the observations described above are the result of three types of adjustments: state driven and private sector driven regulation and market concentration caused by market exit. In some cases, several of these trends have been at work simultaneously or successively. However, in WCA, market exit is the primary explanation for increasing state ownership or declining competition: cotton production has collapsed in marginal producing countries where private agents have exited the sector [16]. Conversely, as noted by Tschirley et al. (2010), state driven and private sector driven regulation have been the main drivers of declining competition in ESA. Fluctuations in the degree of competition in Zambia and Zimbabwe have resulted from reinforced regulation of the ginning sector in Zimbabwe (Poulton and Hanyami-Mlambo, 2009) and informal cooperation by the two biggest firms in Zambia, in an attempt to limit the scope for side-selling (Brambilla and Porto, 2009).

As a result of the limited scope of reforms in WCA and the adjustments that took place post-reform in a number of countries, we find that, on average, cotton markets in SSA remain largely publicly-owned and scarcely competitive: only nine countries out of the 25 under consideration have achieved some level of competition and over half of total SSA production still originates from markets where prices are fixed (Figures 1.6-A and 1-E) [17].

16. Similar issues arise in bigger producing countries too. In Burkina Faso, for example, the state has re-increased its ownership share in the ex-parastatal to over 65 percent because the French private investor has refused to engage in the needed recapitalisation.

17. The reversal of reforms might be even more significant than indicated by our indices. Indeed, regulatory bodies and policies are being created and implemented in a number of countries, the impact of which remains difficult to estimate and thus is not taken into consideration in our indices (for example the Cotton Development Authority in Kenya). Besides, we have

Moreover, according to some analysts, even the most competitive African cotton markets would be far from perfectly competitive Ű especially when the scope of reforms is put into perspective with the more general institutional and political context of the countries examined (Coocksey, 2004; Van de Walle, 2001). Looking at the cotton sector in Tanzania, understood to be amongst the most competitive in SSA, Larsen (2005) and Coocksey (2004) report that the way private agents have to obtain licences from the marketing board and other administrations to enter the different segments of the cotton sector limits effective competition.

Finally, we observe that the recommendations formulated to countries where reforms have not been adopted or implemented yet are increasingly cautious and context-specific. Privatisation is seen as insufficient or even undesirable under certain conditions and competition as having to be controlled in certain market contexts (Baghdadli et al., 2007). Hence, while Baffes (2005) advocated further privatisation of the parastatals in WCA as well as further liberalisation of all sub-sectors, Tschirley et al. (2009 and 2010) conclude that no market sector type seems to have performed so well that it can be considered best under all circumstances [18]. Perhaps as a consequence, countries in which markets have barely evolved over the past three of four decades (Cameroon and Mali) seem to envision reforms that would lead to regulated rather than competitive markets.

1.4 Conclusion

The aim of this paper is to offer a comprehensive view on cotton market organisation and regulation evolution all over SSA. Notwithstanding a series of nuances, we find that the trends in policy evolution identified in the literature broadly hold when expanding the sample of countries under consideration in the pre-reform period and in the aftermath of reforms. This suggests that cotton

found indications that public spending through subsidies seems to be increasing in a number of countries.

18. The somehow limited completeness of reforms achieved in reforming countries might have participated in the softening of reform recommendations, on the grounds of realism.

policies were relatively uniform at the sub-regional level.

However, our findings for the last decade significantly alter the conclusions commonly accepted. We show that the trend towards more competition and less public ownership engaged with reforms in some countries in the 1990s was not mirrored by other countries in the following decade. We also find that adjustments have taken place post-reform leading to a decrease of the level of competition and/or of the level of privatization in almost half the countries under consideration. While cotton sectors are commonly described as moving towards increased more competition and private ownership, we thus show that trajectories are in fact less linear. Of course, this is not to say that reforms have failed everywhere; while adjustments occurred in many countries, liberalization or privatization were completely reversed primarily in the smallest producing countries (hence with limited impact on trends in terms of production shares). However, while this paper does not intend to comment on the desirability of reforms, it describes the difficulty of achieving competition: fifteen to twenty years after reforms were initiated, in many countries, markets are far from stable.

This finding is crucial when it comes to explaining the performance of markets' post-reforms or the determinants of policy choices. As they provide comparable information for 25 countries with relatively similar economic contexts and histories over 46 years, our indices offer promising opportunities for future quantitative empirical work. Indeed, the literature on the effects of cash-crop markets reforms in SSA largely remains inconclusive. Positive supply and productivity responses have been identified elsewhere, notably in Asia (e.g. Rozelle and Swinnen, 2004) but little cross-cutting findings emerge from comparative studies in SSA, except for the timidity of impacts (e.g. Kheralla et al., 2002; Akiyama et al., 2003). Analysing the impact of reforms at the sector level, with detailed information on their pace and scope, might therefore help solve the difficult identification of supply response in the African context (see the chapter II).

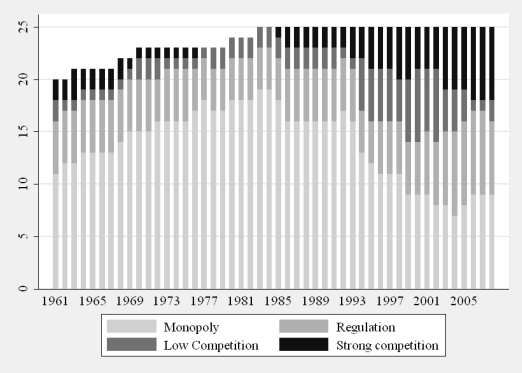
Finally, our findings also point to the crucial need for additional research

into the organisation of African agricultural markets. Indeed, first, there are reasons to believe that what we observe for cotton reforms could be similar for the reforms of other cash crops. Second, while our indices provide information on some important dimensions of market organisation, they do not fully describe the functioning of markets, within some of the categories we describe. Information remains scarce, for example, on the modalities of Eastern African cooperative market structures operation before liberalization or, for the recent period, on how governance issues in SSA might impede the functioning of market-based systems, despite formal competitive market organisations. In addition, as standards and codes are developed by the private sector, notably in relation to the development of a market for organic or fair trade cotton, it will be important to also monitor the impact of these initiatives on pricing practices, and competition.

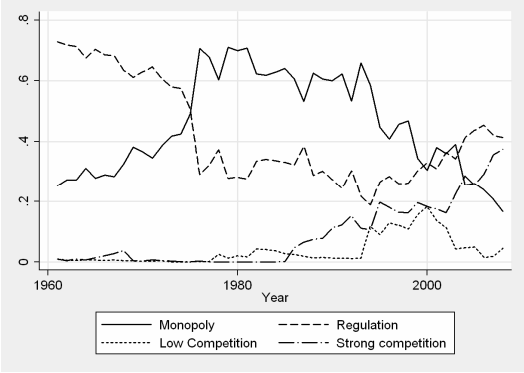
Table 1.I: Market organisation indices

Indices	**Description**
Degree of competition	
Strong competition	Several firms compete on prices to purchase cotton from farmers
Limited competition	2 or 3 firms enjoy a large combined market share & exert price leadership
Regulation	Several firms operate but there is no competition because of regional monopsonies or administrative allocation of supply among them
Monopsony	One company buys cotton from farmers & sells cotton lint
Price fixation	
Fixed prices	Prices are fixed pan-territorially and pan-seasonally
Price indication	An indicative (non-binding) buying price is announced at the start of the season
Free market price	Prices fluctuate according to local supply and demand
Ownership*	
No private capital	Private investors are not allowed to enter ginning
Some private capital	Both the public and the private sector are active in ginning
Only private capital	The state does not intervene at all in ginning
Col. institution as a monopoly	A colonial institution is the sole ginner
Ex-col. institution majority shareholder	An ex-colonial institution remains the majority shareholder in the ginning sector
Ex-col. institution shareholder	An ex-colonial institution retains shares (any) in the ginning sector
Producers shareholders	Producers have shares (any) in some of the ginning companies
Controls	
French colony once	The country was a French colony once
British colony once	The country was a British colony once
CFDT once	The CFDT has operated as a ginning monopoly
British board once	A British Board has operated as a ginning monopoly
Other or no colonizer	The country never was a French or a British colony.

* We consider ownership by ex-colonial institutions as 'public' when firms are owned by ex-Metropolitan states.

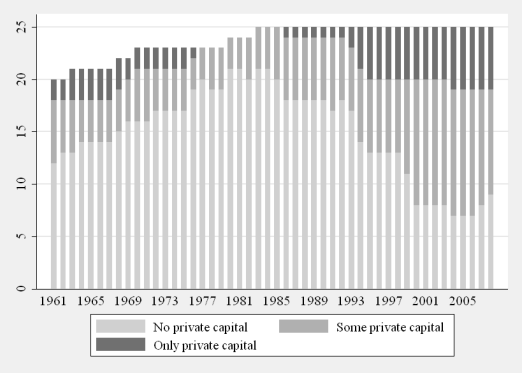


1-A Nb of countries by d° of competition in SSA

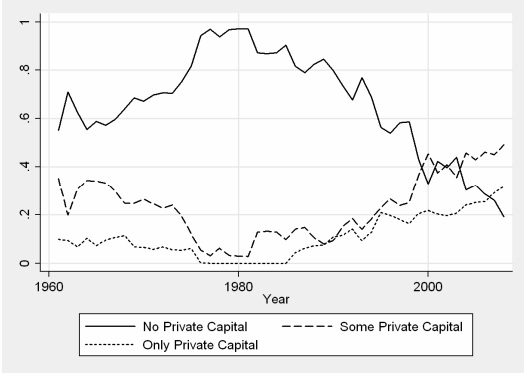


1-B Production share by d° of competition in SSA

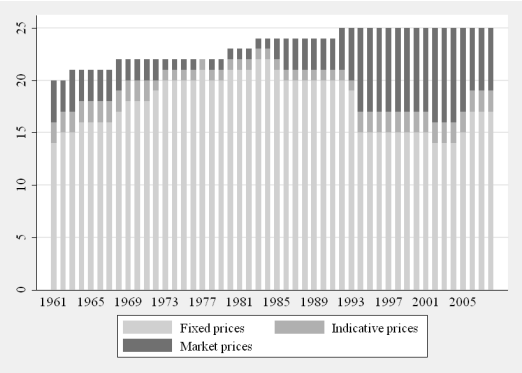
Competition is 'strong' if many firms compete on prices and 'limited' when 2 or 3 firms with large market shares exert price leadership. 'Regulation' implies that firms operate as regional monopsonies or that supply is administratively allocated.



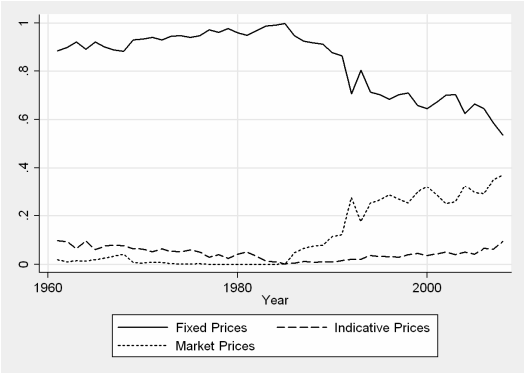
1-C Nb of countries by d° of ownership in SSA



1-D Production share by d° of ownership in SSA



1-E Nb of countries by price system in SSA

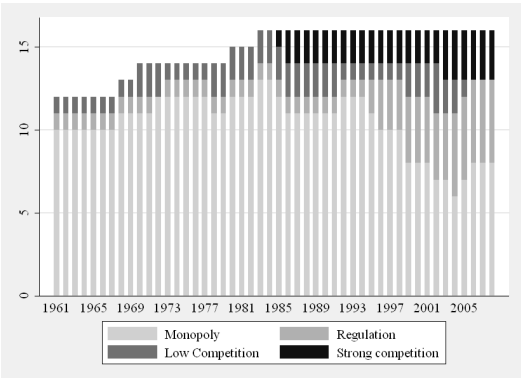


1-F Production share by price system in SSA

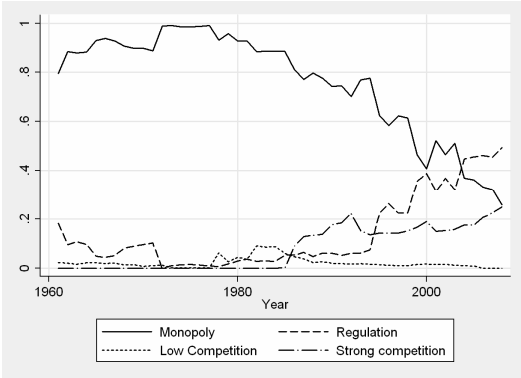
SSA includes Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Democratic Republic of the Congo, The Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Kenya, Madagascar, Malawi, Mali, Mozambique, Niger, Nigeria, Senegal, Sudan Togo, Uganda, United Republic of Tanzania, Zambia and Zimbabwe.

Source: compilation by the authors

Figure 1.1: Market organisation in SSA (1961-2008).

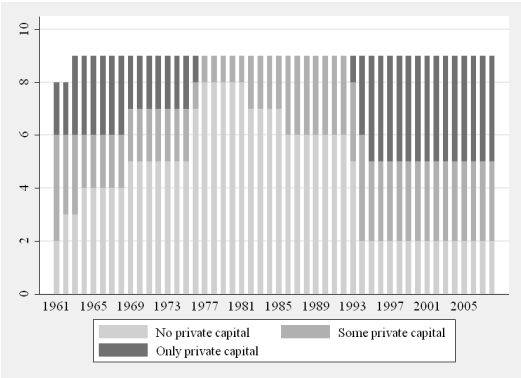


2-A Nb of countries by d° of competition in WCA

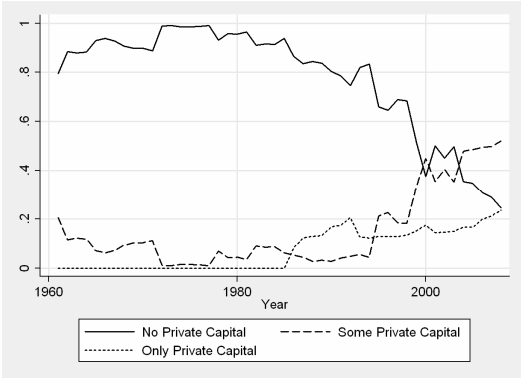


2-B Production share by d° of competition in WCA

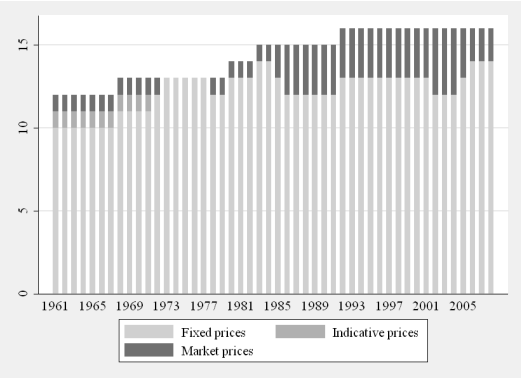
Competition is 'strong' if many firms compete on prices and 'limited' when 2 or 3 firms with large market shares exert price leadership. 'Regulation' implies that firms operate as regional monopsonies or that supply is administratively allocated.



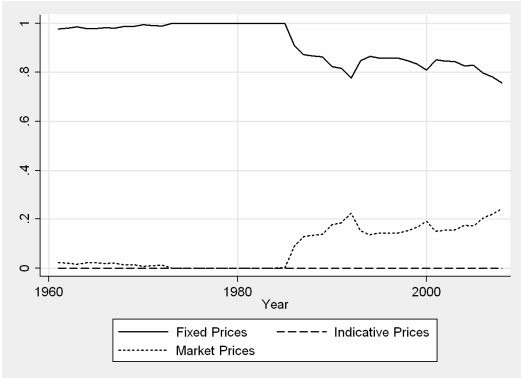
2-C Nb of countries by d° of ownership in WCA



2-D Production share by d° of ownership in WCA



2-E Nb of countries by price system in WCA

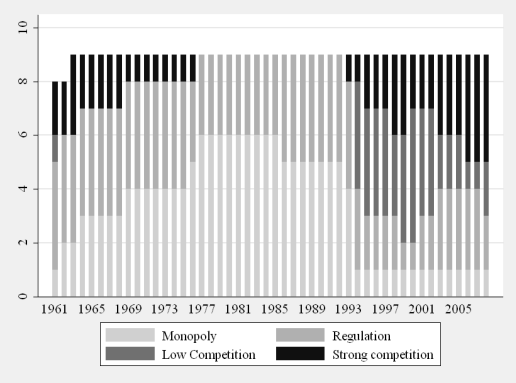


2-F Production share by price system in WCA

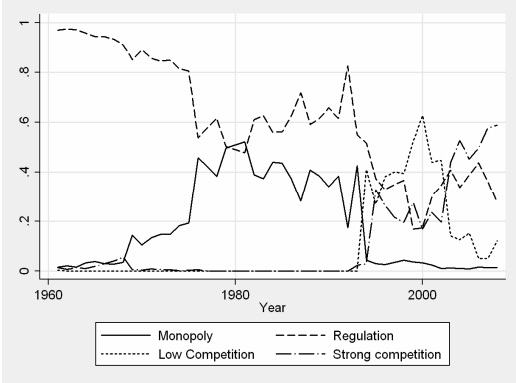
WCA includes Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Democratic Republic of the Congo, The Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Mali, Niger, Nigeria, Senegal and Togo.

Source: compilation by the authors

Figure 1.2: Market organisation in WCA (1961-2008).

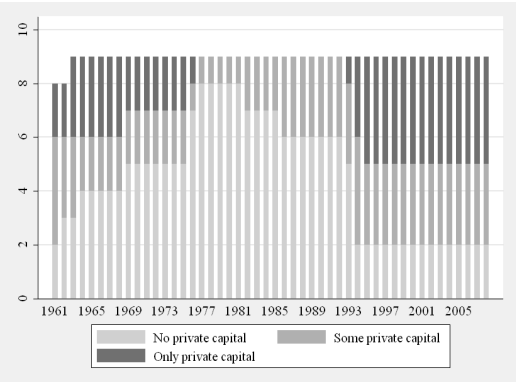


3-A Nb of countries by d° of competition in ESA

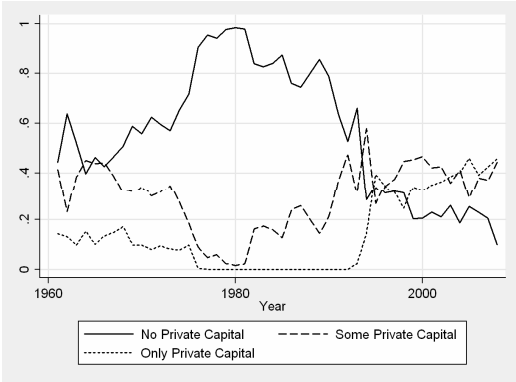


3-B Production share by d° of competition in ESA

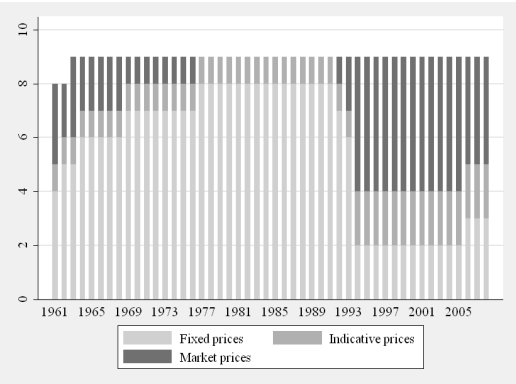
Competition is 'strong' if many firms compete on prices and 'limited' when 2 or 3 firms with large market shares exert price leadership. 'Regulation' implies that firms operate as regional monopsonies or that supply is administratively allocated.



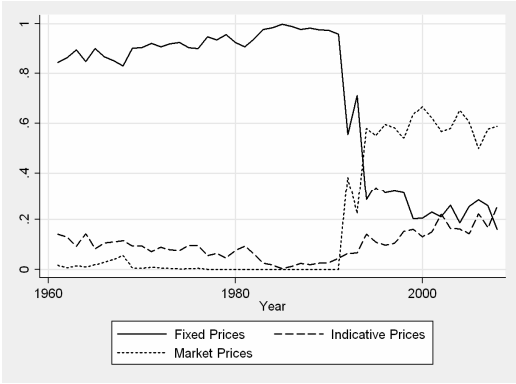
3-C Nb of countries by d° of ownership in ESA



3-D Production share by d° of ownership in ESA



3-E Nb of countries by price system in ESA

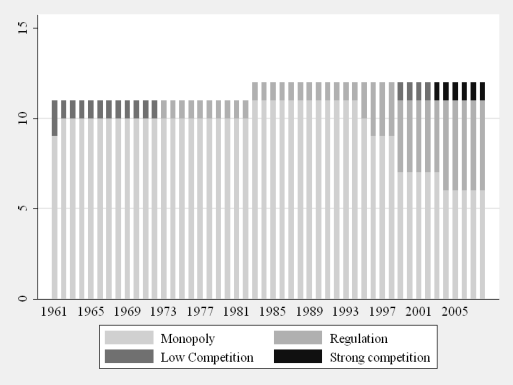


3-F Production share by price system in ESA

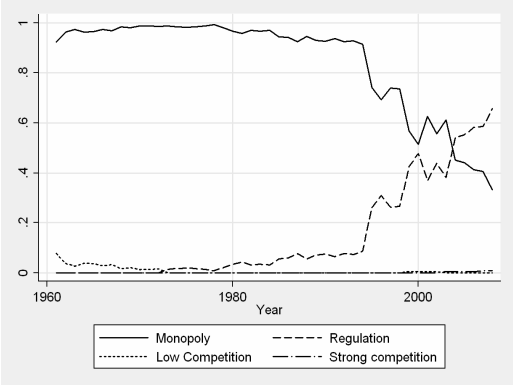
ESA includes Kenya, Madagascar, Malawi, Mozambique, Sudan, Uganda, United Republic of Tanzania, Zambia and Zimbabwe.

Source: compilation by the authors

Figure 1.3: Market organisation in ESA (1961-2008).

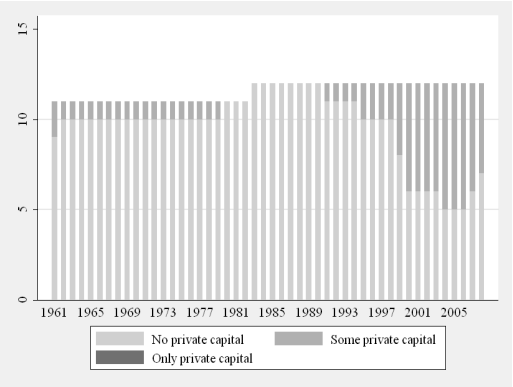


4-A Nb of countries by d° of competition in FFC

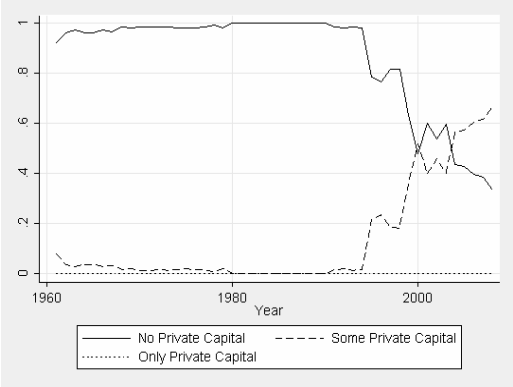


4-B Production share by d° of competition in FFC

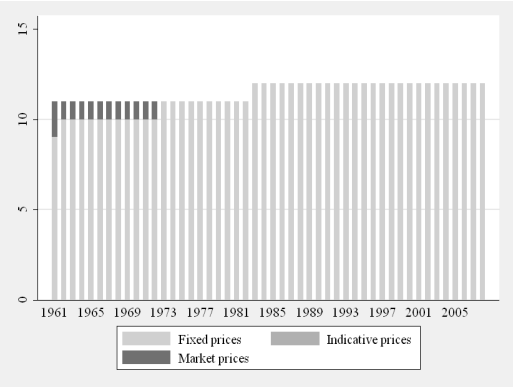
Competition is 'strong' if many firms compete on prices and 'limited' when 2 or 3 firms with large market shares exert price leadership. 'Regulation' implies that firms operate as regional monopsonies or that supply is administratively allocated.



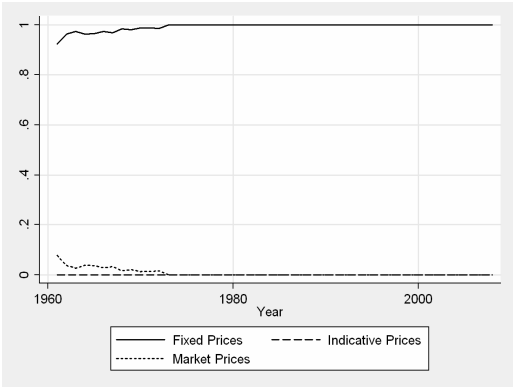
4-C Nb of countries by d° of ownership in FFC



4-D Production share by d° of ownership in FFC



4-E Nb of countries by price system in FFC

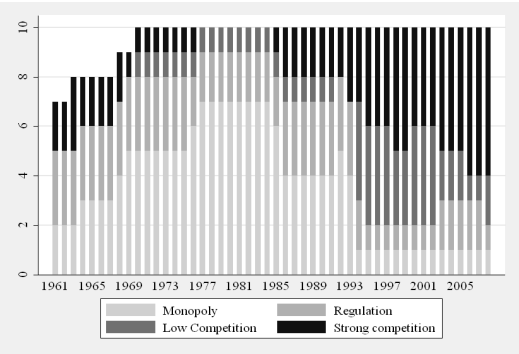


4-F Production share by price system in FFC

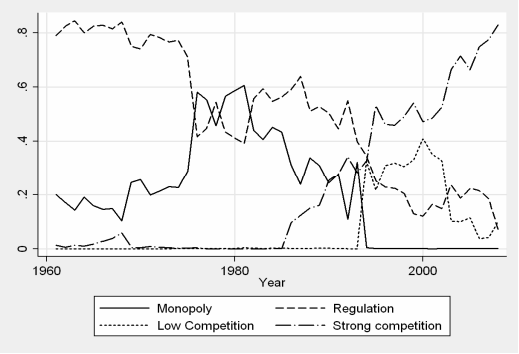
Former French colonies include Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Guinea, Ivory Coast, Madagascar, Mali, Niger, Senegal and Togo.

Source: compilation by the authors

Figure 1.4: Market organisation in Former French Colonies (FFC) (1961-2008).



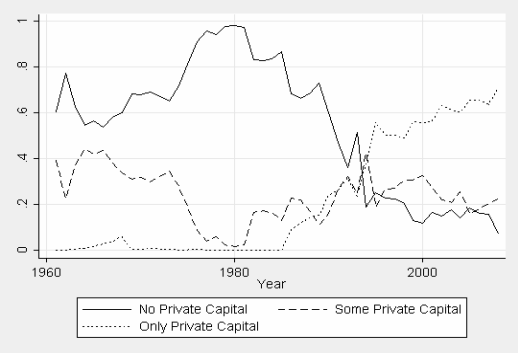
5-A Nb of countries by d° of competition in FBC



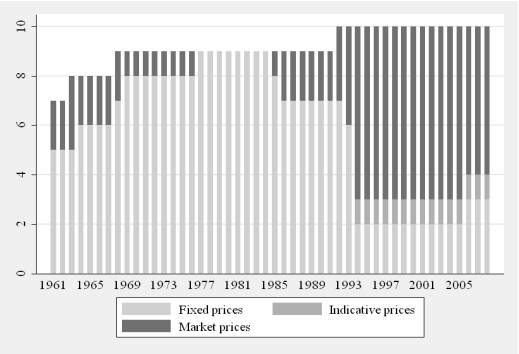
5-B Production share by d° of competition in FBC

Competition is 'strong' if many firms compete on prices and 'limited' when 2 or 3 firms with large market shares exert price leadership. 'Regulation' implies that firms operate as regional monopsonies or that supply is administratively allocated.

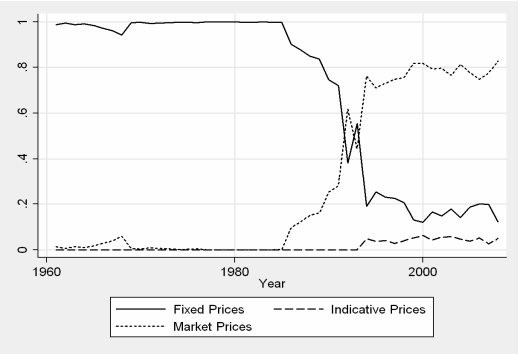
5-C Nb of countries by d° of ownership in FBC



5-D Production share by d° of ownership in FBC



5-E Nb of countries by price system in FBC

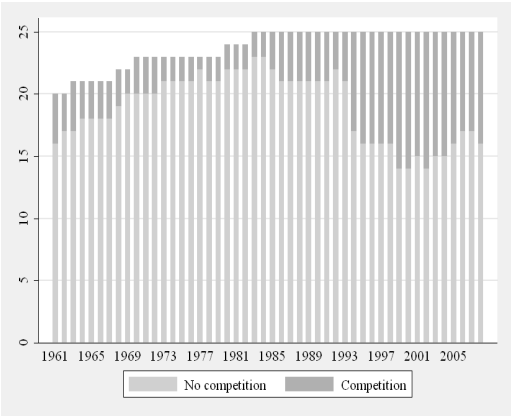


5-F Production share by price system in FBC

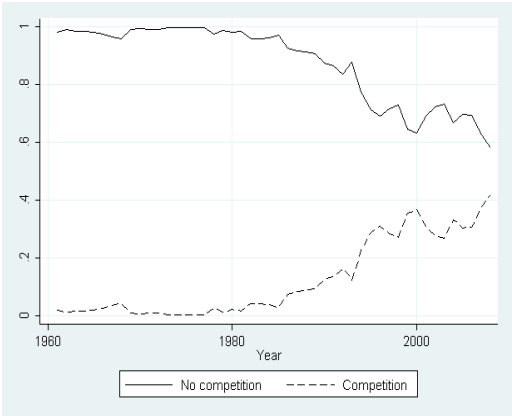
Former British colonies include The Gambia, Ghana, Kenya, Malawi, Nigeria, Sudan, Uganda, United Republic of Tanzania, Zambia and Zimbabwe.

Source: compilation by the authors

Figure 1.5: Market organisation in Former British Colonies (FBC) (1961-2008).

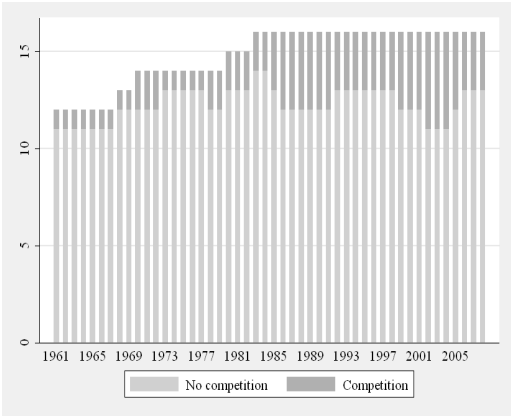


6-A Nb of competitive countries in SSA

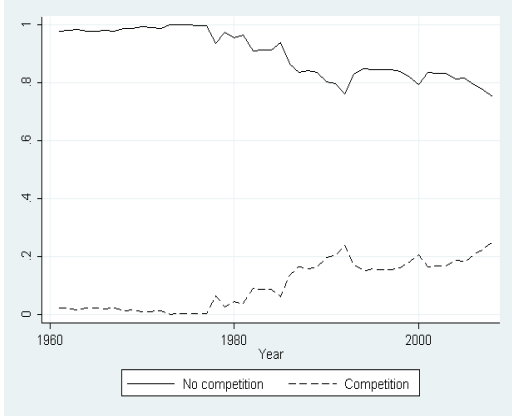


6-B Production share of competitive countries in SSA

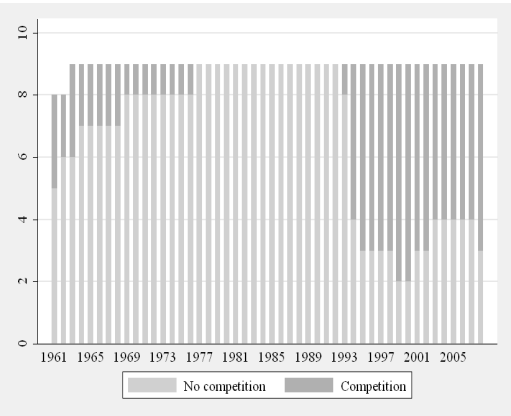
Countries are considered competitive if markets have achieved 'strong' or 'limited' competition



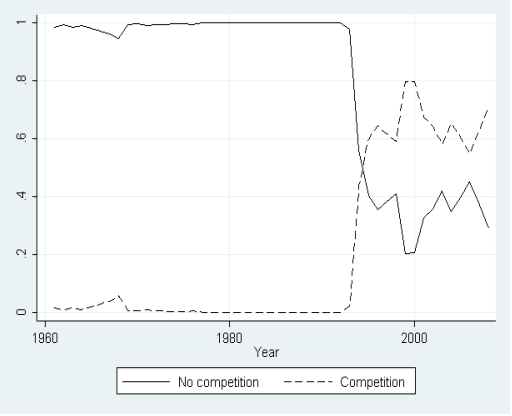
6-C Nb of competitive countries in WCA



6-D Production share of competitive countries in WCA



6-E Nb of competitive countries in ESA



6-F Production share of competitive countries in ESA

Source: compilation by the authors

Figure 1.6: Competition in African cotton markets (1961-2008).

CHAPTER 2

COTTON NATIONAL REFORMS IN SUB-SAHARAN AFRICA

This chapter is based on the following article: Claire Delpeuch and Antoine Leblois, The Elusive Quest for Supply Response to Cash-crop Market Reforms in sub-Saharan Africa: The Case of Cotton, under review at the *World Bank Economic Review*.

Abstract

Little cross-cutting conclusions emerge from comparative studies on the impact of structural adjustment on Sub-Saharan African agricultural performance. This paper illuminates this long-standing debate by exploiting the particularly interesting institutional history of Sub-Saharan African cotton markets to estimate the impact of market structure on acreage and productivity. We adopt a novel quantitative strategy, which controls for potential sources of supply response variation by incorporating detailed information on the pace and depth of reforms, the nature of pre-reform policies and weather conditions at the cultivation zone level. We found an overall positive impact of reforms on yield but such impact is associated with a decrease in area cultivated with cotton in strongly regulated markets.

2.1 Introduction

While there is widespread agreement that cash-crop markets in Sub-Saharan Africa (SSA) have been significantly liberalized since the early 1990s (Anderson and Masters, 2009; Delpeuch and Poulton, 2011), the effects of such reforms largely remain elusive. The impact of structural adjustment on agricultural performance has been widely researched. Positive supply and productivity responses have been identified in Asia (e.g. Rozelle and Swinnen, 2004) as well as, to a lesser extent and with a lag, in some of the European transition countries (e.g. Swinnen and Vranken, 2010). In contrast, in SSA, if any, the impact of reforms is found to have varied in direction and magnitude. Little cross-cutting conclusions thus emerge from comparative studies in SSA, except for the timidity of impacts (e.g. Kheralla et al., 2002; Akiyama et al., 2003).

Reviewing the literature on agricultural transition in developing countries (DCs) and on agricultural productivity in Africa, we identified four potential sources of supply and productivity response variation, which could conceal overarching trends: the depth of reforms and resulting post-reform market structure, the nature of pre-reform intervention, the institutional requirements of production processes and external forces such as climate or conflict.

The relatively limited scope of reforms, or their imperfect implementation, has long been identified as one potential explanation for their overall timid impact in DCs (Krueger et al., 1988). Delpeuch and Leblois (forthcoming, cf. Chap. 1) however offer evidence on the fact that reforms in the cotton sectors of SSA have not all been of limited scope and that they have instead brought about changes in market structure that vary widely in scope both across countries and over time. A long-term perspective and precise knowledge of the nature of post-reform market structure hence seem to be necessary to capture the effects of reforms.

Second, there is growing evidence that pre-reform state control of cash crop markets also varied in nature across countries and crops as well as over time, with policies ranging from direct support to taxation, depending on governments'

objectives and on the level of the world price for different commodities (Kasara, 2007; Anderson and Masters, 2009; Delpeuch and Poulton, 2011). The nature of pre-reform agricultural policies has been identified as a key determinant of supply response in Asia (Rozelle and Swinnen, 2004). There are thus reasons to expect the impact of reforms in SSA to be crop- and country-specific and to have varied depending on the time of their introduction.

Third, the imperfect nature of inputs and credit markets in Africa and the difficulty to enforce contracts, imply that the impact of reforms could vary depending on the size of input requirements for different crops. Indeed, when production requires the use of costly inputs and interlocking of input and output markets is necessary, introducing competition not only affects the prices received by farmers, but also the sustainability of input-credit schemes (Dorward et al., 2004; Delpeuch and Vandeplas, forthcoming).

Finally, many external factors interact with the reform of specific agricultural markets, among which, variations in world market conditions, domestic macroeconomic policies, conflicts and, most importantly, weather conditions (Meerman, 1997) [1]. With a few exceptions (e.g. Brambilla and Porto, 2011 and Kaminski et al., 2011), these external factors - in particular weather conditions - are rarely formally accounted for in studies of agricultural transition in SSA.

This paper thus aims to illuminate long-standing debates about the impact of structural adjustment in SSA agriculture by adopting a novel quantitative, sectoral and long-term approach, in which we consider all of the above-mentioned sources of potential supply response variation.

The cotton sector is the focus of this paper because of its particularly interesting institutional history. A large number of countries in SSA have had very similar cotton market structures for decades (a legacy of colonial policies) but have cho-

1. Differences in the legal and economic environment and enabling institutions have also been identified as a determinant of supply response (Jayne et al., 1997; Kherallah et al., 2002). However, this factor is more likely to explain broad differences in outcome between developing regions than within SSA, where the legal and economic environment and enabling institutions are relatively homogeneously low.

sen reform options that differ in several dimensions. This situation thus offers a privileged testing set-up for examining variations in post-reform performance and identifying the reasons for such divergence. Besides, the policy implications of our results should be of widespread interest in SSA: cotton remains at the core of vivid policy debates as it is the main source of cash revenue for more than two millions rural households and a major source of foreign exchange for about fifteen countries on the continent (Tschirley et al., 2009).

Our estimation strategy was made possible by two new datasets. First, we use the market structure indices compiled in a companion paper (Delpeuch and Leblois, forthcoming, cf. Chap. 1) to inform the timing of reforms and characterize the nature of post-reform market structure and pre-reform policies. Second, we construct precise indices of weather conditions at the level of cotton cultivation zones based on the dataset provided by the Climatic Research Unit of the University of East Anglia (2011).

We first show the necessity of a disaggregation of reforms into different types and to distinguish countries that had different pre-reform policies. Without such a distinction the only impact found is a positive impact on yield. However, when distinguishing regulated markets (and Western and Central Africa (WCA) and Eastern and Souther Africa (ESA) within those regulated markets) from the countries that undergone privatisations (characterized by low and strong competition), the conclusions are different. First, regulated markets seem to show significantly higher yields than before the reforms and, second, countries with cotton markets ruled by strong competition seem to have decreased their area cultivated with cotton. Depending on the specification, some other results arise, and seem to be in accordance with the hypothesis of a selection effect. Such effect, put into light by Brambilla and Porto (2011), is the idea that the increase of yields may be a consequence of a shrinking in areas under cotton cultivation. Interlinked agreement and transactions that take place under a monopsony structure, are indeed weakened by the introduction of competition, leading to an exit of less productive

farmers and to a concentration of cotton production on the most fertile lands.

The remaining of this paper is organized as follows. In section 2 we describe the reforms undertaken in SSA cotton sectors (2.2.1) and briefly outline the expected relation between market structure and performance (2.2.2). We also provide descriptive statistics on the empirical relation between market structure and performance (2.2.3). In 2.2.4 we describe the theoretical framework which motivates our estimation strategy and the estimation strategy itself and the dataset in 2.2.5. In section 3 we display and discuss the results as well as validity and robustness checks.

2.2 Reforms and performance

2.2.1 Reforms in SSA cotton sectors

Traditionally, most African cotton sectors have been organized around state-owned enterprises enjoying both a monopsony for seed cotton purchase and a monopoly for cotton input sale [2]. In addition, prices were fixed by governments or administrative bodies, and sales were guaranteed for producers. Following recommendations by the World Bank and the International Monetary Fund, SSA cotton sectors have however seen their share of reforms starting in the late 1980s and increasingly since the mid-1990s. The nature of the changes in market structure brought about by these reforms has widely varied across regions, ranging from the introduction of strong competition following far-reaching market and price liberalizations, to only marginal adjustments. While an increasing number of markets have become competitive, 50 percent of production in SSA still originates from markets with fixed prices (Delpeuch and Leblois, forthcoming, cf. Chap. 1). Schematically, former British colonies in ESA (plus Nigeria in WCA) have implemented far-reaching reforms up to the mid-1990s and former French

2. In some countries, these 'parastatals' or 'boards' also supplied services related to production and marketing including research dissemination, transport, ginning and exporting. Notably in ex-French colonies, these companies sometimes even provided public services in the rural cotton areas.

colonies in WCA have introduced much more modest reforms, if any, in the course of the 2000s.

Markets were thoroughly liberalized in Nigeria in 1986; Kenya in 1993; Malawi; Uganda, Zambia, Zimbabwe in 1994 and Tanzania in 1995. However, the degree of competition has also fluctuated, among these countries and over time, as a result of different private sector responses to reform and public and private introduction of new regulations. In Zambia, for example, the level of competition is said to have declined during the first half of the 2000s when the two biggest ginning companies began to cooperate in an attempt to fight side-selling (Brambilla and Porto, 2011). In Zimbabwe and in Uganda, limits to the degree of competition were imposed by the state with the aim of containing the detrimental effect of competition on the provision of inputs and extension: in Zimbabwe legal requirements with respect to inputs provision by cotton ginners were enforced in 2006 and, in Uganda, regional monopsony rights were established between 2003 and 2008.

Resistance to market reforms has been much stronger in French speaking WCA. The reforms implemented in Benin (1995), Burkina Faso (2004) and Ivory Coast (1994) have not given rise to competitive but 'hybrid' markets characterized by regulation and mixed private-public ownership. Where private companies are allowed to operate in addition to, or in lieu of the parastatals, they have been granted regional monopsony rights. Alternatively, ginning firms are administratively attributed purchasing quotas (with indications on where to source). What is more, prices remain administratively fixed everywhere. The price fixation method has however been revised in some countries. Instead of being decided unilaterally by the state or the parastatals, prices are increasingly determined by inter-professional bodies, which include representatives of farmers, ginners, transporters and input providers.

2.2.2 Expected relation

Market structure and institutional arrangements are believed to influence performance through a number of linkages. Some of these linkages are common to any sector: competition should improve the share of the world price received by farmers, and, in turn, positively impact the area under cultivation and the amount of effort and inputs that farmers put into cotton cultivation. In addition, if economies of scale are not suppressed and new transaction costs not introduced, competition should create cost minimization incentives and increase the benefits to be shared with farmers. As underlined by Baffes (2007), privatization should also minimize soft budget constraints, excessive employment or political interference in management.

The relation between market structure and performance, however, is likely to be affected by the conjunction of three characteristics of cotton cultivation in Africa: input requirements, credit constraints and limited contract enforcement. Cotton cultivation indeed requires costly inputs (fertilizers and pesticides). Farmers however face strong cash constraints as credit markets are quasi non-existent in rural areas. As a result, most production in SSA occurs through interlinked transactions, whereby ginning societies lend inputs to farmers in return for supplies of primary produce [3].

In this context, the capacity of a country to produce and export cotton is highly dependent on the capacity of farmers and ginning companies to enforce interlinking contracts (Dorward et al., 2004). Delpeuch and Vandeplas (forthcoming) formally show that because contract enforcement mechanisms are at best imperfect in many African countries, the sustainability of interlinking is highly influenced by market structure. The higher the degree of competition, the more farmers have the possibility to 'side-sell', that is, to sell their cotton to other higher-bidding buyers at harvest, instead of to the company that has pre-

3. Among the main producing countries in SSA, Tanzania is the only where this is not the case at all.

financed their inputs - unless sufficiently high reputation costs can be imposed on defaulting farmers. On the one hand, this magnifies the effect of competition on producer prices, but on the other, it reduces the sustainability of contracts if the company that has pre-financed the inputs cannot afford to pay a premium discouraging side-selling. The major advantage of a monopolistic or moderately competitive market structure is thus to facilitate the sustainability of input provision on credit [4]. The link between the scale of input-credit availability and productivity is however ambivalent. Indeed, as noted by Brambilla and Porto (2011), while inputs allow farmers to increase their productivity; as the scale of farmers who receive inputs increases (hence boosting production), more marginal land and less experienced farmers are dragged into production, hence potentially driving down average yields.

In addition, as price liberalization removes government intervention in price-setting, the nature of pre-reform intervention greatly matters: if farmers were taxed before reforms, liberalizing prices will improve production incentives while if they were being subsidized, production incentives will be weakened. There is widespread agreement that, on average, African governments have largely taxed exportable cash crops (e.g. Krueger, et al., 1988; Anderson and Masters, 2009; Bates and Block, 2009). The magnitude and the direction of state price intervention in cotton markets, however, have varied according to the world price and the objectives of governments (Delpeuch and Poulton, 2011). The countercyclical nature of support to the agricultural sector is indeed believed to be a common feature of agricultural policies (e.g. Gawande and Krishna, 2003; Swinnen, 2010). One explanation is rent maximization: if cotton is governments' major source of income, it is rational for them to subsidize their cotton sectors at times of low

4. Other characteristics of state monopolies have been discussed. Their system of pan-territorial and pan-seasonal price fixation has, for example, been heralded as a risk mitigation and spatial redistribution instrument (Araujo Bonjean et al., 2003) and criticized as an ineffective tool of rural development promotion (Baghdadli et al., 2007). It is however beyond the scope of this paper to discuss such issues.

world prices to avoid production disruption [5]. In line with such predictions, Baffes (2007) reports that cotton companies in WCA have received budget support between 1985 and 1993 and again since 1998, at times when they faced financial difficulties.

In summary, competition is expected to influence production incentives positively unless input-credit schemes collapse and/or the effect of competition is offset by the elimination of state support. The expected relation between market structure and yields is even more ambivalent as, if research and extension services are not scaled up; increasing production could ultimately result in declining average yields.

2.2.3 Model and identification strategy

Nerlovian expectation models enable analysing the speed and the level of acreage and yields adjustments following prices changes [6]. The basic relation between production in period t, production in period t-1 and producer prices in period t-1 is typically expanded to include substitute products and input prices, as well as various controls for weather conditions, agricultural policies or technological change, which is often proxied by a linear time trend.

Given our ambition to examine the link between market organization and performance, we adapt this framework to examine the impact of various sources of price changes, including market organisation, instead of estimating directly the impact of prices. The particularity of our approach therefore rests in the way we indirectly account for the local prices of inputs and output. This approach is particularly adapted to our choice to explore the relation between market structure and performance in a long-run and comparative perspective which reduces data availability in terms of input and output prices.

5. Another possible explanation is that government preferences exhibit loss aversion (Tovar, 2009) and therefore tend to protect especially the sectors where profitability is on the decline.

6. See Sadoulet and de Janvry (1995) for a thorough review of supply response analysis models.

The central element of our strategy is the inclusion of precise market structure indicators taken from Delpeuch and Leblois (forthcoming, cf. Chap.1), which characterize the nature of market organisation. Additional determinants of price changes are also included: the international prices of cotton and inputs or national are accounted for by year fixed-effects and national exchange rates are introduced. The fluctuation of the dollar value of local currencies indeed plays a key role in the profitability of cotton production, as exchange rate fluctuations have been of far greater magnitude, in some countries, than the fluctuations of the world price of cotton or inputs in dollars. We also include an interaction term between the exchange rate and a dummy variable denoting the CFA Franc (CFAF) zone after 1994 to account for the lasting effect of the 1994 devaluation of the CFAF, which boosted cotton in the region by improving producer prices, although all the price rise was not passed on to farmers [7]. In addition, we add a dummy variable coming from Swinnen et al. (2010) indicating that the country already has undergone structural adjustment procees. This is explained in greater detail in the Appendix A.

Lastly, we also control for the effect of weather shocks with year- and country-specific indices of weather conditions and for the effect of conflicts, which have been found to significantly disrupt production (e.g. Kaminski et al., 2011, on the implications of the recent Ivorian crisis for cotton production).

To account for the impact of past yields and acreage as cultivated area is knowingly influenced by past decisions; we take advantage of the long time series dimension of our panel to exploit its dynamic dimension. Following Kanwar and Sadoulet (2008), we estimate our model in an auto-regressive framework, which takes potential autocorrelation into account. We do so using the difference generalized method of moments (GMM, Arellano and Bond, 1991 and Blundell

7. We also include the nominal rates of assistance (NRAs, taken from Delpeuch and Poulton, 2011) and their lagged value to control more specifically for subsidies or taxation in the cotton sector. However, as the results are not affected by the inclusion of this variable and because NRAs are not available for all the period we otherwise cover, we do not show results with such control variables. The lack of incidence of NRAs on supply response is in line with Onal (2012).

and Bond, 1995) [8], avoiding issues related to the potential absence of stationarity for some time series.

The estimated equations can be written as follows (let us note $dY_t = Y_{i,t} - Y_{i,t-1}$ and $dLog(Y_t) = Log(Y_{i,t}) - Log(Y_{i,t-1})$):

$$dLog(Y_{i,t}) = \beta_0 + \alpha.dLog(Y_{i,t-1}) + \gamma.dLog(A_{i,t-1}) + \beta_1.dI_{i,t} + \beta_2.dX_{i,t} + dy_t + d\epsilon_{i,t} \tag{2.1}$$

$$dA_{i,t} = \beta_0 + \alpha.dLog(A_{i,t-1} + \gamma.dLog(A_{i,t-1} + \beta_1.dI_{i,t} + \beta_2.dX_{i,t} + dy_t + d\epsilon_{i,t} \tag{2.2}$$

where Y_{it} is performance (yields), A the area or area sown with cotton in country i and year t, the β's are parameters to be estimated; the terms I stands for vectors of institutional variables (the market structure indices) and and X additional time- and country-specific controls; Ws are the seasonal weather conditions indices and Wps the weather conditions before sowing; y_t, and c_i are the country and year fixed effects and ϵ_{it} is the error term. Including year fixed effects allow to control for international price shocks, including cotton and input prices.

Alternatively, we also run the model in a difference-in difference framework using ordinary least squares (OLS). The key drawbacks of this second estimation procedure are the existence of potential non-parallel trends before the reforms and the fact that the impact of past decisions is not so well accounted for and issues related to potential auto-correlation. We will test the presence of heterogeneous trends in the section 2.3.4.1. Moreover to limit the non-stationarity issues and

8. The Hansen J test proposed by Arellano and Bond (1991) recommends the use of an AR(2) specification in the case of yields and an AR(1) in the case of area under cultivation. The presence of heteroskedasticity is tested using the panel heteroskedasticity test described by Greene (2000), which produces a modified Wald statistic testing the null hypothesis of group wise homoskedasticity. It shows that heteroskedasticity is not an issue. Based on the Westerlund ECM panel cointegration test, we also rule out cointegration.

heterogeneous evolution between countries we reduce our sample to the period 1979-2008 for that second estimation, that is, after all countries gained independence.

The key advantage of this method, on the other hand, is that it allows to assess the long run impact of reform whereas difference GMM do not. First-differencing lead to only assess the dynamic impact of the one year jump after the reform but not to consider the long halting impacts of it. We also interpret the different impact the reform assessed over time in the two specifications: decreasing impacts on productivity with lags in the GMM framework vs. increasing one in the OLS one, to be the consequence of such difference. However, we think that reforms take time to be rightfully implemented and the institutions as well as the farmers take time to incorporate the modification of the institutional frame in their decisions. A recent working paper of Kaminsky (2012) indeed shows that accounting for the locust of control, the impact of the reform goes through a personality-induced appropriation of the effects of the policy change. The model includes the same variables as with the GMM estimation - the only difference being that, as the model in not differenced anymore, country-fixed effects (denoted c_i) are included to account for supply response determinants which only vary only on a geographical basis, such as the intrinsic quality of soil for cotton cultivation, climate or the fact to be a landlocked country. The regression on yields includes the lag of the area under cultivation because there is a negative relation between area and yield (since marginal lands are less productive, we however consider the lag area, for endogeneity issues, as it is strongly correlated to the current area) and conversely (high yields will probably lead to an increase in expected profit and thus to higher area cultivated).

For the OLS estimation, we follow Bertrand et al. (2004) in "ignoring time series information" as they show that serial correlation causes difference-in-difference standard errors to understate the standard deviation of the estimated treatment effects thus leading to overestimation of t-statistics and significance levels. To en-

sure that our results do not suffer from such bias, we start by regressing log (Y_{it}) on fixed effects (y_t, and c_i) and on time- and country-specific controls (X_{it}). We then obtain the effects of the market structure variables and their standard errors from a second OLS regression on the residuals, which now form a two-period panel (with pre-reform being characterized by Monopoly, the default category, and post-reform corresponding to either *Post Reform* or *Regulation*, *Low competition* and *Strong competition*):

$$Log(Y_{i,t}) = \beta_0 + \gamma Log(A_{i,t-1}) + \beta_2.X_{i,t} + y_t + c_i + Y\epsilon_{i,t} \tag{2.3}$$

$$Y\epsilon_{i,t} = \beta_0 + \beta_1.I_{i,t} + \epsilon_{i,t} \tag{2.4}$$

$$Log(A_{i,t}) = \beta_0 + \gamma Log(Y_{i,t-1}) + \beta_2.X_{i,t} + y_t + c_i + A\epsilon_{i,t} \tag{2.5}$$

$$A\epsilon_{i,t} = \beta_0 + \beta_1.I_{i,t} + \epsilon_{i,t} \tag{2.6}$$

2.2.4 Variable description and data sources

2.2.4.1 Dependant variables

We explore the link between market structure and performance both in terms of productivity, the typical indicator of performance, and in terms of cultivated area, as the size of the sector is politically of interest given the strong dependence of a number of SSA economies on cotton production and export.

We exploit a panel of 16 SSA countries between 1961 and 2008. These countries correspond to the 13 biggest producers of rain-fed cotton in SSA between 1998 and 2008 (Benin, Burkina Faso, Cameroon, Chad, Ivory Coast, Mali, Mozambique, Nigeria, Tanzania, Togo, Uganda, Zambia and Zimbabwe), plus

Malawi, Kenya, and Senegal[9].

Data for acreage (Ha) and yields (Kg/Ha) is available from the Food and Agriculture Organization of the United Nations (FAO) as well as from the International Cotton Advisory Committee (ICAC) since 1961. The FAO reports yields of seed cotton (the raw product) whereas the ICAC reports yields of cotton lint, that is, one of the semi-transformed product obtained through the ginning process that separates the lint it from the cotton seed and waste. As the impact of weather conditions is likely to be more directly perceivable in seed cotton terms, we primarily use the FAO data. The ICAC data is however used to perform data quality robustness checks (regression outputs using ICAC data are available upon request to the authors). Yields and acreages are log-transformed, to improve the distribution of the dependant variables.

2.2.4.2 Institutional variables

We characterize cotton markets, on a country and year basis, building on four types of market structure rather than simply differentiating between pre- and post-reform periods. *Monopoly* describes a situation where a parastatal or a marketing board (at least partly public) has a monopsony on the purchases of raw cotton from farmers at a fixed price and a monopoly on selling cotton on the international market. *Regulation* implies that a small number of firms operate as regional monopsonies or that supply is administratively allocated among firms. *Low Competition* involves that a small number of firms with large market shares exert price leadership exert price leadership. *Strong Competition* indicates that many firms compete on prices. These variables are exclusive: at one point in time, only one of these four variables is equal to one in a given country. *Post Reform*, which is sometimes used alternatively to the above variables, indicates

9. The panel is unbalanced in that the times series start at a later date for a couple of countries where independence was gained after 1961 and for which we did not have reliable information to construct the market organization indices before the independences. However, there are no gaps within each country-specific times series. We also run robustness checks on a shorter but balanced panel, which confirm results.

that *Monopoly* is abandoned for one of the three other market structure types we have identified. Cameroon, Chad, Mali and Senegal, which retained monopolistic cotton markets until 2008 constitute the control group in the most recent years when all other countries introduced reforms. Togo is also included in that control group since the privatisation process of Sotoco did not lead to put into question its place as a national monopsonic buyer of seed cotton, from the end of the 90's.

Given evidence that the impact of reforms might only show up with delays because of slow reform implementation, we also test the impact of these institutional variables with a lag of one and two periods.

In addition, is important to control for the nature of pre-reform state intervention as it will influence the impact of the elimination of such intervention, through liberalization. The nature of pre-reform intervention is captured by differentiating between former French colonies and other countries. While an imperfect policy measure, this controls for the fact that cotton was given a special role in former French colonies where governments invested more in research and extension than their counterparts. Such investment is believed to have enduring effects even in more recent periods when the difference in terms of investment is less clear (Tschirley et al., 2009).

2.2.4.3 Control variables

To control for the impact of weather, we construct three indices: the length of the cotton growing season (in months), a measure of cumulative rainfall during this growing season in the cotton cultivation areas and average and maximum monthly temperatures during the growing season. Rainfall and temperatures are known to be determinant of cotton growth (Blanc, 2008; Sultan, 2010). We use the length of the rainy season length since total precipitations are less of a limiting factor but the timing of precipitation greatly matters (WMO, 2011; Sultan et al., 2010) To control for the heterogeneity of impact of these weather conditions in different climatic zones, we interact them with climatic zone dummy variables.

The construction of these indices uses data at the cultivation zone level produced by the Climatic Research Unit of the University of East Anglia (2011) and land use data from Monfreda et al. (2008). Greater details about weather variables and cultivation zones are given in Appendix A.

The exchange rate data is taken from the Penn World Tables (Heston et al., 2011). It is expressed as national currency units per one thousand US dollars, averaged annually.

Dummy variables denoting different types of conflicts are taken from the UCDP/PRIO Armed Conflict Dataset (2009); they are described in Appendix A.

2.3 Results

2.3.1 Graphical evidence

Figures 2.1 to 2.6 show the evolution of area under cotton cultivation and yields across different groups of countries before and after the reforms, vertical lines representing the reform dates. Figure 2.1 suggests that countries where reforms were introduced in WCA increased the area cultivated with cotton, on average, compared to countries where no reforms were introduced. The impact of reforms on yields in this region is also pointing a potential positive impact. (Figure 2.2).

In ESA, it appears the introduction of competition had a positive impact on yields, particularly in countries where strong competition was introduced (Figure 2.3). Conversely, while hardly anything can be said, by such graphical analysis, about the impact of reforms that lead to strong competition on the area cultivated, there seem to be a positive response on the area in countries where low competition was implemented. Figures 2.5 and 2.6 shows that in strongly liberalized markets, the yield jump after the reform date seem to be much higher than in those where reforms lead to low competition.

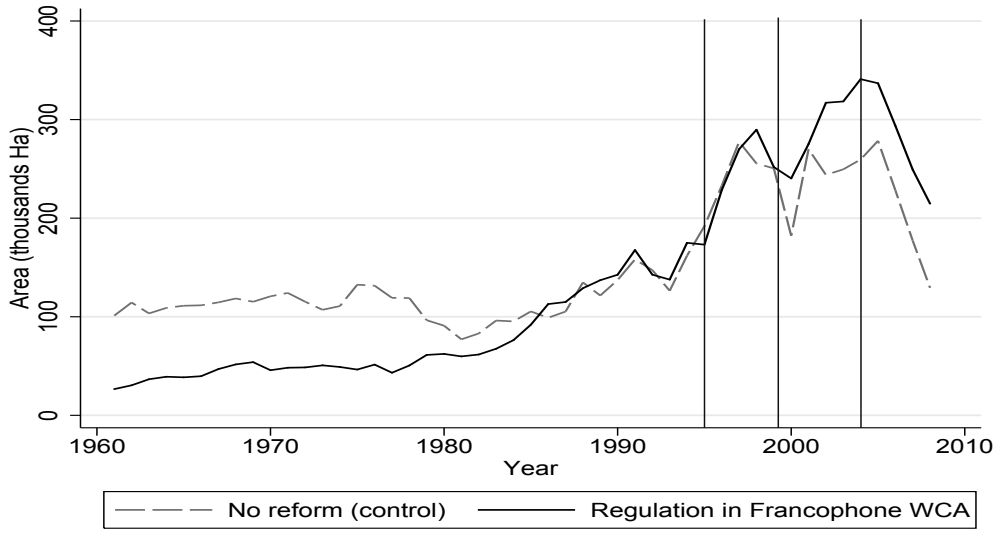


Figure 2.1: Average cotton area (thousand Ha) in countries where the cotton sector was regulated in WCA as compared to the average of the four not reformed countries.

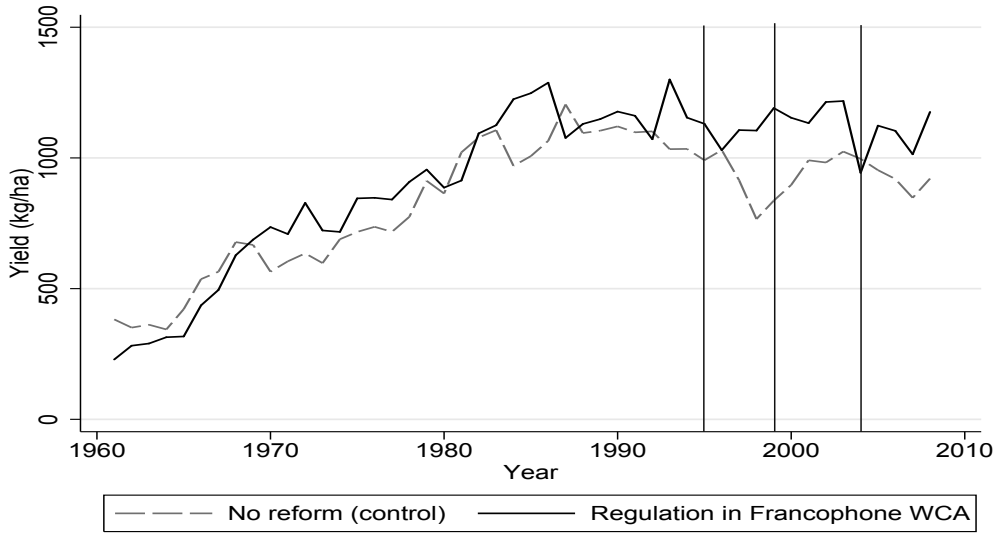


Figure 2.2: Average cotton yield (kg per Ha) in countries where the cotton sector was regulated in WCA as compared to the average of the four not reformed countries.

Figure 2.3: Average cotton area (thousand Ha) and yield (kg per Ha) in countries (Malawi, Uganda, Zimbabwe and Zambia) where the cotton sector was under low competition after the reform.

Figure 2.4: Average cotton area (thousand Ha) and yield (kg per Ha) in countries (Kenya, Nigeria and Tanzania) where the cotton sector was under strong competition after the reform.

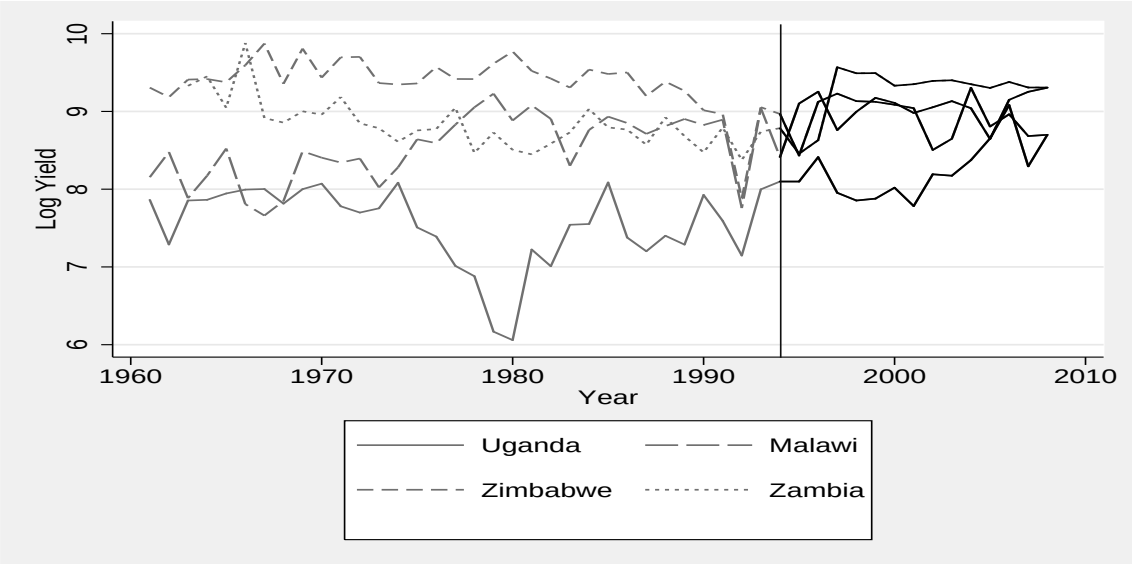


Figure 2.5: Log cotton yield evolution in markets where reforms lead to low competition.

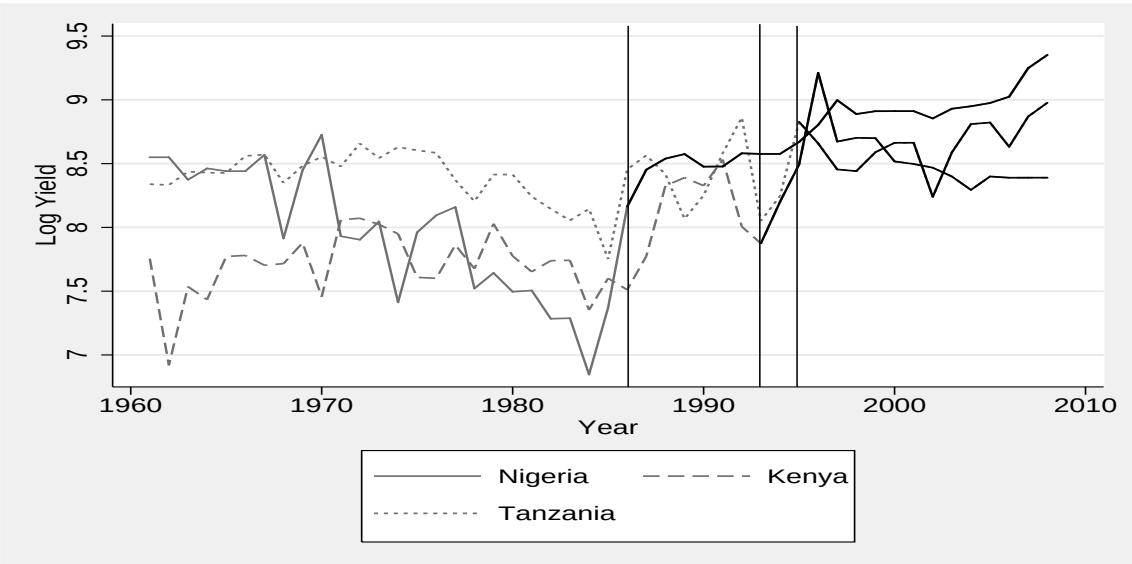


Figure 2.6: Log cotton yield evolution in markets where reforms lead to strong competition.

2.3.2 GMM and OLS results

Looking only at differences between monopolistic and any type of reformed markets, we find that, *ceteris paribus*, reforms do not seem to have had a significant impact on area (Table 2.I and 2.III) but that yields were higher in reformed markets than in monopolistic markets (by about 8 percent - column 1 to 3 Table 2.II in GMM and 5 in OLS).

If we enrich the institutional vector with an interaction term between *Post Reform* and a dummy for former French colonies (*Ex-French Col.*), however, this first finding is nuanced (Columns 4 to 6 of Tables 2.II and 2.IV). Concerning productivity, impacts of reforms significantly differ in French speaking WCA and other countries. Pre-reform policies seem to shape reform's impacts. In the regulated markets of French speaking WCA, yields were not significantly affected. On the contrary, the positive productivity response was greater than previously estimated in ESA and non-French speaking WCA countries. Reforms were thus more interesting in countries where interlinked transactions where weak. This result is in accordance with those from the theoretical paper of Delpeuch and Vandeplas (forthcoming) showing that introducing strong competition could harm the interlinking transactions that took place before decolonisation process. It also suggests that disaggregating the impact of reform is necessary to capture the complexity of the relation between market structure and performance.

Table 2.I: Cotton market structure and area (GMM, year fixed effects)

	(1) log_area	(2) log_area	(3) log_area	(4) log_area	(5) log_area	(6) log_area	(7) log_area	(8) log_area	(9) log_area
L.log_area	0.850***	0.850***	0.855***	0.836***	0.840***	0.849***	0.838***	0.833***	0.839***
	(0.0205)	(0.0182)	(0.0241)	(0.0223)	(0.0233)	(0.0251)	(0.0199)	(0.0197)	(0.0203)
L.log_y	0.144***	0.144***	0.146***	0.152***	0.152***	0.151***	0.152***	0.156***	0.157***
	(0.0419)	(0.0312)	(0.0362)	(0.0453)	(0.0432)	(0.0370)	(0.0313)	(0.0316)	(0.0321)
post_reform	−0.0186			−0.0929					
	(0.0835)			(0.129)					
L.post_reform		−0.0232			−0.0794				
		(0.0485)			(0.0866)				
L2.post_reform			−0.0610			−0.0933*			
			(0.0412)			(0.0486)			
post_reform_(Ex. French Col.)				0.171					
				(0.135)					
L.post_reform_(Ex. French Col.)					0.140				
					(0.0953)				
L2.post_reform_(Ex. French Col.)						0.0883			
						(0.0562)			
Regulation							0.0597		
							(0.102)		
L.Regulation								−0.0644	
								(0.0986)	
L2.Regulation									−0.153
									(0.0987)
Regulation_(Ex. French Col.)							0.0174		
							(0.124)		
L.Regulation_(Ex. French Col.)								0.125	
								(0.122)	
L2.Regulation_(Ex. French Col.)									0.154
									(0.124)
Low Competition							−0.0696		
							(0.0821)		
L.Low Competition								0.0149	
								(0.0810)	
L2.Low Competition									0.0463
									(0.0800)
Strong Competition							−0.126*		
							(0.0661)		
L.Strong Competition								−0.110*	
								(0.0652)	
L2.Strong Competition									−0.123*
									(0.0644)
Observations	704	704	691	704	704	691	704	704	691
P-value of AR(1)	0.0103	0.0101	0.0077	0.0102	0.0099	0.0075	0.0099	0.0105	0.0076
P-value of AR(2)	0.7551	0.7634	0.7777	0.7421	0.7922	0.7874	0.6862	0.7928	0.9886
P-value of Sargan test	0.9474	0.9520	0.8869	0.2889	0.9466	0.8788	0.9376	0.9473	0.8577
P-value of Wald test				0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Standard errors (AB robust est.) in parentheses
* $p < .1$, ** $p < .05$, *** $p < .01$

Table 2.II: Cotton market structure and productivity (GMM, year fixed effects)

	(1) log_y	(2) log_y	(3) log_y	(4) log_y	(5) log_y	(6) log_y	(7) log_y	(8) log_y	(9) log_y
L.log_y	0.527***	0.530***	0.530***	0.525***	0.529***	0.529***	0.524***	0.528***	0.528***
	(0.0329)	(0.0332)	(0.0344)	(0.0323)	(0.0331)	(0.0346)	(0.0337)	(0.0343)	(0.0362)
L2.log_y	0.203***	0.198***	0.197***	0.203***	0.196***	0.195***	0.204***	0.198***	0.199***
	(0.0317)	(0.0304)	(0.0305)	(0.0321)	(0.0303)	(0.0306)	(0.0321)	(0.0299)	(0.0293)
L.log_area	−0.115***	−0.117***	−0.117***	−0.110***	−0.114***	−0.115***	−0.107***	−0.117***	−0.120***
	(0.0310)	(0.0319)	(0.0313)	(0.0292)	(0.0313)	(0.0308)	(0.0293)	(0.0300)	(0.0293)
L2.log_area	0.0485**	0.0506**	0.0507***	0.0512**	0.0536**	0.0534***	0.0517***	0.0587***	0.0519***
	(0.0191)	(0.0197)	(0.0183)	(0.0203)	(0.0217)	(0.0194)	(0.0199)	(0.0219)	(0.0201)
post_reform	0.0811**			0.120*					
	(0.0367)			(0.0653)					
L.post_reform		0.0796**			0.108*				
		(0.0393)			(0.0620)				
L2.post_reform			0.0836**			0.107*			
			(0.0395)			(0.0547)			
post_reform_(Ex. French Col.)				−0.0874					
				(0.0759)					
L.post_reform_(Ex. French Col.)					−0.0684				
					(0.0727)				
L2.post_reform_(Ex. French Col.)						−0.0640			
						(0.0564)			
Regulation							0.189***		
							(0.0700)		
L.Regulation								0.206***	
								(0.0629)	
L2.Regulation									0.158**
									(0.0771)
Regulation_(Ex. French Col.)							−0.158**		
							(0.0758)		
L.Regulation_(Ex. French Col.)								−0.168**	
								(0.0736)	
L2.Regulation_(Ex. French Col.)									−0.114
									(0.0784)
Low Competition							0.109**		
							(0.0510)		
L.Low Competition								0.104**	
								(0.0492)	
L2.Low Competition									0.189***
									(0.0553)
Strong Competition							0.111		
							(0.0733)		
L.Strong Competition								0.0902	
								(0.0696)	
L2.Strong Competition									0.0700
									(0.0650)
Observations	691	691	691	691	691	691	691	691	691
P-value of AR(1)	0.0005	0.0005	0.0004	0.0005	0.0005	0.0004	0.0004	0.0005	0.0005
P-value of AR(2)	0.1116	0.0877	0.1416	0.1168	0.0877	0.1416	0.1223	0.0915	0.0895
P-value of AR(3)	.0607	.0536	0.0708	0.0700	0.0536	0.0708	0.0741	0.0547	0.0725
P-value of Sargan test	0.3696	0.3580	0.3623	0.3720	0.3580	0.3623	0.3813	0.3671	0.2889
P-value of Wald test	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Standard errors (AB robust est.) in parentheses

* $p < .1$, ** $p < .05$, *** $p < .01$

We further refine these results by considering the full set of disaggregated institutional indices. With the previous findings in mind, we again couple *Regulation* with the dummy for ex-French colonies. Similar distinctions are not necessary for *Low Competition* and *Strong Competition* as none of the French speaking WCA countries have introduced any kind of direct competition.

This new refinement of the institutional vector, shows that, in ESA and non-French speaking WCA, where a variety of reform options have been adopted, the effect of reforms on yields and area cultivated has varied in magnitude with the type of reform (as resumed in Table 2.V).

It also allows to compare different degree of competition. We can see that, according to both specifications, regulated countries show higher yields after the reforms. The amplitude of the impact found is however quite different: from 12 in OLS to 20% in GMM. The difference in the yield jump between regulations in French speaking Africa and elsewhere is a reflection of the different nature of the types of regulations adopted. As underlined by Tschirley et al. (2009 and 2010), in Mozambique and in Uganda, regulation never prevented input credit default crises and disturbances in input provision, whereas interlinked transactions have never been challenged in French speaking WCA where private operators are strictly forbidden to compete for the purchase of raw cotton. While implementing low competition does not seem to impact significantly the area cultivated with cotton, it lowers by about 8 percents in strongly competitive markets. This last effect is of comparable magnitude to the one identified, in Zambia, by Brambilla and Porto (2011).

Table 2.III: Cotton market structure and cotton area after 1979 (OLS, year and country fixed effects)

	(1) Residuals area	(2) Residuals area	(3) Residuals area	(4) Residuals area	(5) Residuals area	(6) Residuals area	(7) Residuals area	(8) Residuals area	(9) Residuals area
post_reform	−0.00669			−0.0519					
	(0.0337)			(0.0355)					
L.post_reform		0.00264			−0.0396				
		(0.0343)			(0.0361)				
L2.post_reform			−0.00328			−0.0383			
			(0.0349)			(0.0369)			
post_reform_(Ex. French Col.)				0.257***					
				(0.0701)					
L.post_reform_(Ex. French Col.)					0.250***				
					(0.0739)				
L2.post_reform_(Ex. French Col.)						0.218***			
						(0.0785)			
Regulation							−0.0919		
							(0.0698)		
L.Regulation								−0.0984	
								(0.0710)	
L2.Regulation									−0.123*
									(0.0736)
Regulation_(Ex. French Col.)							0.297***		
							(0.0922)		
L.Regulation_(Ex. French Col.)								0.309***	
								(0.0957)	
L2.Regulation_(Ex. French Col.)									0.302***
									(0.101)
Low Competition							0.0456		
							(0.0541)		
L.Low Competition								0.0728	
								(0.0550)	
L2.Low Competition									0.111**
									(0.0554)
Strong Competition							−0.106**		
							(0.0470)		
L.Strong Competition								−0.0984**	
								(0.0485)	
L2.Strong Competition									−0.121**
									(0.0502)
Observations	464	464	464	464	464	464	464	464	464

Standard errors (robust to clustering) in parentheses
* $p < .1$, ** $p < .05$, *** $p < .01$

Table 2.IV: Cotton market structure and productivity after 1979 (OLS, year and country fixed effects)

	(1) Residuals yield	(2) Residuals yield	(3) Residuals yield	(4) Residuals yield	(5) Residuals yield	(6) Residuals yield	(7) Residuals yield	(8) Residuals yield	(9) Residuals yield
post_reform	0.0519*			0.0487*					
	(0.0274)			(0.0293)					
L.post_reform		0.0619**			0.0620**				
		(0.0278)			(0.0297)				
L2.post_reform			0.0759***			0.0793***			
			(0.0283)			(0.0302)			
post_reform_(Ex. French Col.)				0.0183					
				(0.0579)					
L.post_reform_(Ex. French Col.)					−0.000224				
					(0.0608)				
L2.post_reform_(Ex. French Col.)						−0.0210			
						(0.0641)			
Regulation							0.115**		
							(0.0576)		
L.Regulation								0.145**	
								(0.0584)	
L2.Regulation									0.160***
									(0.0607)
Regulation_(Ex. French Col.)							−0.0484		
							(0.0761)		
L.Regulation_(Ex. French Col.)								−0.0832	
								(0.0787)	
L2.Regulation_(Ex. French Col.)									−0.102
									(0.0829)
Low Competition							−0.0335		
							(0.0446)		
L.Low Competition								−0.0259	
								(0.0453)	
L2.Low Competition									0.0179
									(0.0457)
Strong Competition							0.0806**		
							(0.0388)		
L.Strong Competition								0.0924**	
								(0.0399)	
L2.Strong Competition									0.0938**
									(0.0414)
Observations	464	464	464	464	464	464	464	464	464

Standard errors (robust to clustering) in parentheses
* $p < .1$, ** $p < .05$, *** $p < .01$

2.3.3 Results on production

We computed the overall impact on production on all market structure categories (cf. Table 2.V). This is obtained by multiplying the elasticities of each of the categories to their respective average levels of acreage and yield. The overall impact of regulation and low competition on production is not of the same sign in the different specifications while we obtain a positive impact of regulation in WCA countries and a negative production impact of strong competition in both specifications.

Areas under cultivation were lower in those strongly liberalized and regulated markets, leading a rather lower production level. This is contrary to expectations of price-induced production incentives boosts. Such results, however, can be explained by the context of cotton production in SSA.

First, as explained above, it is likely that competition reduces the sustainability of input credit schemes. If, post-reform, input access on credit is reduced, farmers will likely exit cotton production or produce with lower yields. We interpret the fact that productivity has been higher in all types of sectors post-reform compared to monopolistic markets as an indication that farmers quit cotton production when input availability declines rather than continue producing with lower yields. Higher productivity in post-reform markets in ESA is therefore likely to be partially a side-effect of market exit, or, put otherwise, the result of a selection process. Alternatively, in moderately competitive markets where input credit systems were maintained, productivity may also have been improved thanks to better input provision by private ginners to targeted farmers as opposed to larger-scale, but not well targeted, distribution of inputs by poorly efficient marketing boards (Brambilla and Porto, 2011).

Second, it is not surprising that the price-induced supply response of farmers who continued to produce cotton did not significantly exceed the negative effect of market exit on production in cotton sectors under strong competition, as the price effect of reforms is known to be relatively limited (Delpeuch and Vande-

Table 2.V: Elasticities of cotton area, productivity and production to reforms

		GMM	OLS post 1979
Area	Regulation	5.60%	-9.00%
	Regulation in WCA	6.57%	25.04% ***
	Low competition	-7.04%	4.51%
	Strong competition	-11.99% *	-10.13%**
Yield	Regulation	20.52%***	12.04% **
	Regulation in WCA	5.68%**	7.04%
	Low competition	11.41% **	-3.39%
	Strong competition	11.49%	8.31%**
Production*	Regulation	5.82%	-4.08%
	Regulation in WCA	4.69%	16.48%
	Low competition	-0.47%	1.28%
	Strong competition	-7.52%	-6.63%

* Authors calculations.

plas, forthcoming). Indeed, Poulton and Delpeuch (2011) show that taxation in monopolistic cotton markets of ESA began to be reduced before cotton reforms were introduced, through other structural adjustment policies (mainly through the moderation of exchange rate distortions). In addition, even before these reforms were introduced, monopolistic markets have not always resulted in heavy taxation.

For other types of reforms, the picture is entirely different. The rather higer acreage and yield could suggests that the entry of private ginners and the reorganization of markets have contributed to improve production incentives. This possibly occurred, in regulated markets, through the creation of a pressure to increase producer prices as producers entered the regulation bodies; through greater credibility over prompt payment; and/or easier access to input credit (Kaminski et al., 2011; Tschirley et al., 2009).

2.3.4 Validity and robustness checks

2.3.4.1 Endogeneity

It could be argued that selection into reform (and thus market structure) was not random and that poorly performing countries were compelled to introduce reforms when performance deteriorated. This raises concerns over the existence of potential endogeneity issues. A number of prima facie evidence elements however

suggest that reform implementation has not been directly linked to market performance. Figure 2.1 plots acreage (in WCA), and Figures 2.4 and 2.5 yields (in ESA) against market structure. Figure 2.1 shows that average area sown with cotton are very similar in regulated markets (reform dates are symbolized by vertical lignes) than in the control sample where no reform occured before the reforms [10]. Figure 2.4 (low competition) and 2.5 (strong competition) show that reforms took place in very different performance contexts and countries with relatively similar performance have/have not adopted reforms (e.g. Burkina Faso and Mali in the early 2000s). It is to be expected that reforms have rather been influenced by the macroeconomic and political situation of countries and, most importantly, by the way in which international financial institutions (IFI) promoted structural adjustment plans. Additional evidence that reforms were driven by IFI specific determinants rather than country and cotton sector-specific determinants, can be seen from the fact that reforms happened almost at the same time (1994 or 1995) in most countries of ESA. Conversely, in WCA, competition has been seldom introduced, partly because the French co-operation agency (the Agence Française de Développement) played an important role in the reform process - or rather, in the non-reform process - as it opposed the reform agenda pushed forward by the World Bank and promoted or supported regulatory systems instead (Bourdet, 2004).

The fact that reforms were more ideological than market-driven however suggests another potential endogeneity problem: what we capture as being the effect of cotton market reforms could reflect the impact of structural adjustment more generally. To deal with this potential endogeneity and address formally the reverse causality issue, one would ideally like to instrument the reforms. To our knowledge, there is, yet, no suitable instrument to do so. Instead, (i) we try to include structural adjustment as an additional explanatory variable and (ii) we test whether mean reversion processes could explain some of our results.

10. Since the beginning of the 80s, when the gap with Chad, a historically large producer, is reduced.

First, we add as an extra control in our regressions: a dummy variable that takes on the value one after a structural adjustment plan has been adopted (cf. section 2.2.3). The variable is based on a dataset displayed in Swinnen et al. (2010, Table A1) and starts with the year the country received its first structural adjustment loan from the World Bank. However, the fact of having adopted a structural adjustment plan is neither meaningful nor significant in explaining yield, whatever the definition of the variable used. With respect to area, a positive and significant impact is found. The inclusion of this variable does not affect the signs and the significance of the coefficients of the institutional variables vector. Overall, controlling for structural adjustment plans suggests that the effect of cotton reforms is not a by-product of structural adjustment. The inclusion of the exchange rate also contributes to controlling for the more general influence of macro-economic reforms.

Second, we try to test whether mean reversion processes could explain some of our results, that is, whether reform is endogenous and our estimation thus not valid due to pre-existing differences in level of average acreage or yield before the reform. Following Chay et al. (2005), we test for such possible effects by applying a false treatment (reforms leads by 15, 12, 10, 5 and 2 years) and estimating how it impacts performance before the reforms (Table 2.VII and 2.VIII). We find no impact, except for a significant negative impact on yields of the two-years lead in the case of yields, when using OLS. This effect is however of the opposite sign of what we find when looking at the impact of reforms on yields (Table 2.II and 2.IV, columns 1 to 3).

We also tested for the effect of implementing some reforms in the future on performance outcome, only in the case of OLS since a country specific dummy would be dropped in the GMM framework. We construct a dummy for any country that would reform in the period considered and regressed acreage and yield it on for the whole period without any reform. This second robustness check also lead to validate the absence of mean reversion process (Table 2.VII,

first line). As showed in Table 2.VII, applying a false treatment on the sample before the reforms on countries that will reform, lead to no significant effect; implying the absence of such heterogeneous trends.

Table 2.VI: Endogeneity bias on acreage and productivity (GMM, year fixed effects), one-step robust estimator: Endogeneity bias on acreage and productivity: false pre-treatment before the reforms

	(1) log_area	(2) log_area	(3) log_area	(4) log_area	(5) log_area	(6) log_y	(7) log_y	(8) log_y	(9) log_y	(10) log_y
L.log_area	0.837***	0.835***	0.835***	0.836***	0.836***	−0.0939*	−0.0978**	−0.0979**	−0.102**	−0.109**
	(0.0174)	(0.0170)	(0.0178)	(0.0207)	(0.0204)	(0.0522)	(0.0494)	(0.0483)	(0.0478)	(0.0478)
L2.log_area						0.00201	0.00685	0.0101	0.0204	0.0228
						(0.0470)	(0.0435)	(0.0434)	(0.0400)	(0.0413)
L.log_y	0.179***	0.178***	0.186***	0.194***	0.197***	0.490***	0.495***	0.501***	0.496***	0.488***
	(0.0478)	(0.0483)	(0.0479)	(0.0541)	(0.0544)	(0.0307)	(0.0291)	(0.0280)	(0.0254)	(0.0289)
L2.log_y						0.259***	0.265***	0.261***	0.254***	0.259***
						(0.0455)	(0.0449)	(0.0408)	(0.0426)	(0.0426)
F15.post_reform_sstog	0.0431					−0.0329				
	(0.0482)					(0.0453)				
F12.post_reform_sstog		0.0703					−0.0110			
		(0.0707)					(0.0481)			
F10.post_reform_sstog			0.0637					−0.0192		
			(0.0416)					(0.0265)		
F5.post_reform_sstog				−0.0178					−0.0623	
				(0.0409)					(0.0592)	
F2.post_reform_sstog										−0.139
										(0.0862)
Observations	434	457	471	501	516	423	446	460	490	505
P-value of AR(1)	0.0525	0.0418	0.0427	0.0409	0.0399	0.0004	0.0004	0.0004	0.0004	0.0003
P-value of AR(2)	0.4146	0.2776	0.2916	0.3269	0.3248	0.1648	0.1855	0.2103	0.2396	0.1868
P-value of AR(3)	.	.	.	.	.	0.5857	0.8665	0.6576	0.7238	0.6851
P-value of Sargan test	0.8904	0.9153	0.9143	0.9142	0.9187	0.1533	0.2041	0.2102	0.1954	0.1697
P-value of Wald test	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Standard errors in parentheses
* $p < .1$, ** $p < .05$, *** $p < .01$

Table 2.VII: Endogeneity bias on acreage and productivity (OLS, year and country fixed effects): false pre-treatment before the reforms

	(1) Residuals area	(2) Res. area	(3) Res. area	(4) Res. area	(5) Residuals area	(6) Res. area	(7) Residuals yield	(8) Res. yield	(9) Res. yield	(10) Res. yield	(11) Res. yield	(12) Res. yield
dum_reform	0.00389						−0.0301					
	(0.0437)						(0.0450)					
F15.post_reform_sstog		0.00634						−0.101				
		(0.0899)						(0.0691)				
F12.post_reform_sstog			0.0339						−0.101			
			(0.0634)						(0.0585)			
F10.post_reform_sstog				0.0315						−0.0992		
				(0.0576)						(0.0602)		
F5.post_reform_sstog					−0.0212						−0.136	
					(0.0685)						(0.0935)	
F2.post_reform_sstog						−0.106						−0.220*
						(0.101)						(0.108)
Observations	299	207	230	244	274	289	299	207	230	244	274	289

Standard errors in parentheses
* $p < .1$, ** $p < .05$, *** $p < .01$

2.3.4.2 Data

Results are confirmed when expanding the OLS estimation to the full panel, instead of limiting it as we did to the post-1979 period because of non-parallel trend issues. Using ICAC data instead of FAOstat data also gives very similar results.

2.4 Concluding Remarks

This paper estimates the impact of market structure on the performance of cotton markets, both in terms of acreage and productivity. We find that market structure is a meaningful and significant determinant of market performance and that the impact of changes in market structure has been very different in French speaking WCA and in the rest of SSA. Regulated sectors increased their productivity, leading to an increase of the production in countries where pre-reform policies supporting the sector probably helped in maintaining and probably extending the area under cotton cultivation. Elsewhere in SSA, highly competitive markets suffered from a significant decrease in are under cotton cultivation. We believe that the main factor behind the differences in reform effects in French speaking WCA and elsewhere in SSA is the nature of reforms.

To our knowledge, quantitative estimations of the effects of cotton marketing reforms had never been done, except in two country case studies. Looking at the Zambian reform experience, Brambilla and Porto (2011), found that production and productivity both declined in the aftermath of reform, at a time of strong competition when the input-credit system was challenged. Both however recovered when cooperation between firms improved and the input-credit scheme was revived (albeit at the cost of lower competition).

The other case study, by Kaminski et al. (2011) looks at the Burkinabe reform experience. The authors find that the reform participated in boosting production, at the cost of state transfers needed to maintain high producer prices.

Overall, this paper clarifies what should be expected out of the introduction of increased competition. This paper suggests that too much competition is not likely to improve production, on the contrary. Introducing far-reaching reforms in French speaking WCA would thus likely have a detrimental effect the revenues of the least productive farmers and, hence, on poverty rates, given the significance of cotton as a source of income for rural populations in these countries. In a perspective of poverty-reduction and rural development, the balance remains to be found between producing more cotton and producing cotton more efficiently.

Finally, this paper illustrates the interest of looking at the impact of structural adjustment in African agriculture using precise institutional variables. Additional work on the effects of reforms in particular countries, building on household level data (for example along the lines of the study by Brambilla and Porto, 2011) would contribute to a better understanding of the mechanism underlying the trends identified in this paper which reflect average effects. In such a framework, instrumenting reforms might be easier and help control more formally for potential endogeneity problems.

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CHAPTER 3

AGRICULTURAL INSURANCES BASED ON WEATHER INDICES

This chapter is based on the following article: Antoine Leblois & Philippe Quirion, Agricultural insurances based on weather indices: realizations, methods and challenges, forthcoming in *Meteorological Applications*

Abstract

Low-income countries are mostly endowed with rainfed agriculture. Therefore yields mostly depend on climatic factors. Furthermore, farmers have little access to traditional crop insurance. Insurances based on meteorological indices could fill this gap if transparent, cheap and straightforward. However their implementation has been limited so far.

In this chapter, we first describe different projects that took place in developing countries using these types of insurances. We then review the underlying methodology that has been or should be used when designing and assessing the potential of such recent but numerous projects and empirical results of experimetal projects. We finally introduce future challenges to be addressed for supplying index insurances to farmers.

3.1 Index-based insurance in developing countries: a review

In traditional crop insurance, the insurer pays an indemnity to the farmer when crops are damaged, typically by drought, hail or frost (the so-called "multirisk" crop insurance). In that case, information asymmetry between farmers and the insurer about the actual effort put into production creates moral hasard issues. Moreover, information asymmetry about the veracity of the claims makes the insurer resort to a costly and transaction costs. As a consequence, such insurances exist only where they are largely subsidized by the government. We can quote as examples PROPAGRO in Brazil, INS in Costa Rica, CCIS in India, ANAGSA and the FONDEN program in Mexico, PCIC in the Philippines, Agroseguro in Spain, and FCIC in the USA, for which every respective government pays for more than half of the premiums (Miranda and Glauber, 1997, Molini et al., 2010, Mahul and Stutley, 2010, Fuchs and Wolff 2011b). Unfortunately, developing countries governments' do not have the financial resources to finance these subsidies at a large scale.

Weather index insurances (WII) may constitute an interesting alternative, especially for these countries. The difference with traditional crop insurance is that indemnification is not triggered by damage to the crop, but by the level of a meteorological index, which is itself assumed to be correlated to crop yield. WIIs are analogous to weather derivatives, which appeared in the 1990s in the energy sector. Those latter financial products reduce the impact of climatic shocks on firms whose margins widely depend on climate, such as energy suppliers.

The main advantage of WIIs over traditional insurance is that there is no need for damage assessment. Thanks to an easily observable index the principal (the insurer) does not have to check the agent's (the insured farmer) statement (Quiggin et al., 1993). Moreover, a transparent and fast transmission of information allows quick payouts.

As a consequence of their simplicity a so-called basis risk possibly lies in such policies, i.e. the fact that the correlation between crop yields and the meteorolog-

ical index cannot be perfect. Indeed the relationship between weather and yield is complex and depends on field-specific features such as the type of soil or the farmer practices. Moreover, many hazards independent of the weather do impact yields. Finally, a high spatial variability of the weather (section 3.2.5.2) also contributes to the basis risk, since it would be too costly to install a rain gauge, let alone a complete meteorological station, in every field. We will explain basis risk in greater detail in section 3.1.3.3. To minimize the basis risk, the chosen meteorological index must be a good predictor of yields, and especially of bad yields. One should finally balance advantages and impediments of WII compared to traditional insurances, that is what we will try to do in this chapter.

A few articles have investigated the impact of crop insurance based on weather index in developing or transition countries (Berg et al., 2009 in Burkina Faso, Breustedt et al., 2008 in Ukraine, Chantarat et al., 2008 in Kenya, Molini et al., 2010 and Muamba and Ulimwengu (2010) in Ghana, De Bock et al., 2010 in Mali and Zant, 2008 in India). Ex-post studies are developing very fast in recent years due to the recent development of such products (Cai et al., 2009 in China; Fuchs and Wolff 2011a and 2011b in Mexico; Hill and Viceisza, 2009 in Ethiopia; Karlan et al., 2012 in Ghana; Giné and Yang, 2009 in Malawi and Cole et al. 2011 and Giné et al., 2008 in India).

However mostly due to data scarcity, products that were launched were rarely based on a baseline study using long run weather and yield data. Ex-post studies mostly concentrate on demand (take up rates) and there is no empirical evidence of the actual gain interest of such products for farmers in developing countries. The occurrence of indemnification being low, running a randomized controlled trial (RCT, Duflo, 2004) on such program is quite expensive and takes a lot of time. Fuchs and Wolff (2011b) is an exception, they studied the impact of the mexican programme in a natural experiment study using variations in insurance supply during the launching phase (2003-2008). They find a positive impact on yield (7%) and on income (8%), with income gain concentrated in medium-income

counties. The authors however found the program cost-ineficient as a whole, especially due to high premium, representing twice the expected indemnity for the period 1990-2008, entirely subsidized by the mexican government.

3.1.1 Main experiments in developing countries to date

Most WIIs projects implemented in developing countries aim at insuring individual farmers. Although distinction between low income and middle income countries could be questioned, we will bound our analysis to developing countries, since we mostly care about replicability in West Africa. Malawi and India were the low-income countries with the biggest experience of index micro-insurance at the time this survey was written (in 2009 [1]) and thus represent a large part of this work. We also draw attention about a rather different type of WII that was implemented in Ethiopia on a 'macro' scale.

3.1.1.1 India

India introduced traditional crop insurance in 1965 and WIIs in 2003. It was the first country to introduce WIIs at a commercial scale and is still the one which covers the highest number of farmers. The first implementation in 2003 was initiated by the private sector; more precisely, it was a joint initiative of the insurance company ICICI Lombard and the microfinance institution BASIX, with the help of the Commodity Risk Management Group (CRMG) of the World Bank (Hazell, 2010). It began in Andhra Pradesh, covering groundnut and castor oil plant against drought on three phenological phases of the crop. This programme expanded over time and covered, in 2008-09, around 10,000 farmers over 8 states in India. On average, during the six years of operation, 15% of farmers received an indemnity and the loss ratio (ratio of the sum of indemnities to the sum of premiums) amounted to 62% in 2010 and 48% in 2011. Despite those levels the

1. More recent reviews now exist, for instance in the case of India, the unique large scale market of individual index insurance, two quality reviews were released since that time (Giné et al., 2010 and Clarke et al., 2012).

demand grew, reaching more than 9 millions insured farmer in 2011.

A second programme, a public one, covers a much higher number of farmers (1.6 million in 2009), it is called the Weather Based Crop Insurance Scheme (WBCIS). For the large majority of them (around 90%), insurance was compulsory since it was included in a package with a loan for agricultural inputs. Premiums are subsidized up to 80% by central and state governments, depending on the crop. As a consequence, the loss ratio amounts to 0.7 if calculated on the unsubsidised premium, versus 2.3 with the subsidised one, according to Chetaille et al. (2011).

Despite the low premiums actually paid by the farmers (less than US$ 5 per acre, Giné et al., 2007) there was a low observed subscription rate when premiums are not subsidised, especially when compared to Mexican entirely subsidies premiums (with 22% of the national maize production insured). This somewhat disappointing result led to statistical studies about insurance take up and especially its determining factors (Cole et al., 2011, Giné et al., 2007 and Giné et al., 2008, cf. section 1.3.2).

3.1.1.2 Malawi

In Malawi, two projects jointly offering a WII with a credit for certified seeds were run by the Insurance Association of Malawi in association with a cooperative of local growers. The initial objective was to limit loan default payment, which precludes the development of these credits. Indeed, when the rainy season is bad, so is the yield and farmers are unable to repay the credit for certified seeds. For this reason, the maximum payout corresponds to the total loan value. The pilot program (launched during the 2005-2006 season) concerned groundnut producers of some regions (Hess and Syroka, 2005). The second was spread out over the whole country and extended to corn producers (2006-2007). The first round concerned less than 900 farmers and the second one about 2500 (of which 1710 were groundnut farmers, Barnett and Mahul, 2007). In the pilot program, drought

was defined as less than 75 percent of the long-run average of cumulative rainfall over the rainy season. 13 of the 22 government-managed meteorological stations, showing satisfying quality standards in terms of missing values, were taken into account: they provided 40 years of rainfall data. Extensions in other South-East African countries (Tanzania, Uganda and Kenya) are considered (Osgood et al., 2007). Kenya is the most promising field in the close future due to availability and quality of meteorological data.

The impact of this program on income could not be estimated due to a good rainy season in 2006. The use of hybrid seeds rose compared to the previous years but, surprisingly, insurance had a negative impact on loan take up (Giné and Yang, 2009, cf. section 3.2.4.2). However farmers' limited collateral liability, their relatively high default rate as well as the complexity of the terms of the contract (bundled with credit) creating additional ambiguity for potential buyers, could have hindered adoption (cf. section 3.2.3.4). Less surprisingly, loan take up was higher for more educated and richer people in both the control and the treatment samples, a feature also found in many experiment on index insurance policies (cf. section 3.2.3.2).

3.1.1.3 Ethiopia

In Ethiopia, a pilot program was initiated by the World Food Program (WFP) during the 2006 and 2008 seasons, with a technical assistance from the Food and Agriculture Organization (FAO) and the World Bank. The premium was offered by the latter's major donors and the product was insured by AXA Re (now called PARIS Re). If any indemnity had been paid, the Ethiopian government would have redistributed the funding of the WFP, that holds the policy of this safety net, to about 60 000 households in 2006 (Barnett et al., 2008) that cultivate wheat, millet, cowpea and corn. The reinsurer and WFP used historical rainfall data from the Ethiopian National Meteorological Agency (NMA) and a crop-water balance model to develop the Ethiopia Agricultural Drought Index (EADI), which had a

correlation of about 80 percent with the number of food aid beneficiaries between 1994 and 2004. Analysis of the historical data revealed a one in 20 probability of catastrophic drought in Ethiopia, as occurred in 1965, 1984 and 2002.

The index was based on the cumulative rainfall, computed with a network of 26 meteorological stations across the country. Long run data required for risk assessment were computed from interpolation of satellite and elevation datasets along 43 years longitudinal data across 80 areas, produced by the FEWSNET program. The complex annual rainfall pattern in Ethiopia pointed out the necessity to go thoroughly into growing strategies. In some regions there are two distinct rainy seasons, which induce two possible farming strategies depending on the earliness of the first one. Farmers can either choose to sow a long-cycle crop and hope to benefit from spring's rains or two different short-cycle crops.

In 2009 individual WIIs pilot projects were run in Ethiopia where the insurance market is developing, currently composed of one public and 10 private firms. One such example is the Horn of Africa Risk Transfer for Adaptation (HARITA) project in the Tigray region, designed by the International Research Institute for Climate and Society (IRI, Earth Institute, Columbia University) and launched by Oxfam America, the Rockefeller foundation and SwissRe. It is based on satellite imagery data. A second one was undertaken in the Oromia region supported by the WFP. Both projects directly target growers.

3.1.1.4 Other pilot projects and related literature

Institutional index insurance, as the Ethiopian one, covering governments against major spatially covariant shocks, were also launched in developping countries. It was the case of 16 Caribbean countries (2007) covered against natural disasters (hurricanes and earthquakes), in Malawi (2009) were the governement contracted an insurance, at the national level contrarily to the above-mentionned individual insurance, based on a production index for maize based on weather stations data, in Mexico (2003) against major droughts and in Mongolia (2009)

against major livestock losses.

Small scale individual-level index insurances were also developed in China (2007), Ethiopia (2007), Rwanda (2009), Tanzania (2009) and Thailand (2007) and discontinued or only attained pilot stage in Kenya (2 launched in 2009), Indonesia (2009), Madagascar (2007), Nicaragua (2008), Philippines (2009), South Africa (2007) and Ukraine (2005). Updated exhaustive reviews of passed and present WII experiments can be found in Hellmuth et al., (2009), Hazell et al. (2010), DeJanvry et al. (2011).

3.1.2 Indices

3.1.2.1 Meteorological indices

Some products insure against cold temperatures or frost (South Africa), others insure against excess water during harvest (India, Nicaragua, Rwanda and Tanzania) or against floods (Indonesia and pilots in Vietnam and Thailand). Here, we focus on the most common dommageable phenomenon which is also the most relevant for the sudano-sahelian zone.

Basic rainfall indices

Cumulative rainfall during the growing season (which, in the tropics, typically corresponds to the rainy season) is the simplest quantifier of water availability. However, the impact of a lack of rain depends on the crop growth phase. Hence, in practice, the growing season is often split in several sub-periods and an indemnity is paid whenever a lack of rain occurs in one of these sub-periods. The amount of rainfall that triggers the payment of an indemnity (the strike) as well as the amount of indemnity differ across the sub-periods and are based on agro-meteorological knowledge. Moreover, very light daily rains (typically <1 mm/day) and daily rains exceeding a given cap (60 mm per day in most Indian insurance schemes) are generally not taken into account in the cumulated rainfall. Indeed, very light daily rains generally evaporate before being used by the plant,

while rains exceeding a given cap run off and cannot be used either. Such simple indices were applied in India and during the first Malawian experiment. Those indices were also used in the Ethiopian scheme where payments were triggered by a low cumulative rainfall from March to October, compared to the 30-years average. Crop specific indices were computed by weighting 10-days periods cumulative rainfalls according to their relative impact on yields.

The Available Water Resource Index (AWRI: Byun et al., 2002), based on effective precipitations of the previous days, is a slight improvement on the cumulative rainfall. It is roughly simulating reduction of soil water stocks due to runoff, evapotranspiration and infiltration. Reduction is represented as a weighted sum of previous rains on a defined period (often 10 days) with time-decreasing factors.

Water balance and water stress indices

Water balance is computed by subtracting water losses to gains for a specific location on which the potential evapotranspiration (PET) is defined. Precipitations provide water whereas losses are principally due to draining and crop evapotranspiration. PET calculation (Allen et al., 1998) is made through more or less direct methods using quite specific data [2] for a good evaluation, or can even be measured on the field with lysimeters. Water stress indices are based on the idea that crop yields are proportional to the satisfaction of crop needs for water resource.

The WRSI (Water Requirement Stress Index) is the reference water stress index. It is defined as the ratio of actual evapotranspiration (ETa) to maximum evapotranspiration (ETc). ETa corresponds to an estimation of the quantity of water actually evaporated while ETc corresponds to the quantity of water that would evaporate if the water requirements of the plant were fully satisfied. This index was developed by the FAO and used in different WII schemes in India and in Malawi, computed on a 10 days period. FEWSNET improved it by taking into

2. PET is more precise than available rainfall for crops but they requires a lot of data such as solar radiation, wind speed, daily minimum and maximum air temperatures, relative air humidity, latitude, longitude and altitude, and cloud cover once an hour if possible. Soil type has also to be checked once individually for each region considered.

account water excess.

Kellner and Musshof (2011) use water capacity indices and compare them to common precipitation-based indices in the purpose of sheltering Eastern Germany farms against drought risk by calibrating WII for different crops. They find that risk reduction is higher due to a reduction in basis risk when using such elaborated indices. However, as mentionned by Hill and Robles (2010) such models have been modeled and tested in temperate climates for crops grown under ideal conditions on large plots that are not intercropped (Allen, 1998).

Phase-specified policy and sowing date issues

Since crop sensibility to water stress depends on its growth phase, most of the insurance contracts consider those phases and take in account different references values of WRSI as triggers, corresponding to different levels of crop water needs depending on the phase considered. There is generally 3 to 7 depending on the crop: sowing and establishment, growth and flowering, yield transformation phases and harvest. For instance, it was the case of the Indian and the Malawian (for groundnut) individual insurance experiments (cf. 3.1.1.1 and 3.1.1.2) distinguishing 3 major crop growth phenological phases (growth, flowering and yield transformation). For tobacco, the growing period was divided in 17 blocks of two weeks in the case of the Malawian WII. Rainfall level of each block is compared to the crop requirement for this particular growth stage and included in the weighted sum in order to compute the index corresponding for the whole period.

The major impediment in such a design implementation is the need for a sowing date (or thin period often called sowing window) to trigger the beginning of growth cycle. All the previously mentionned indices would be better predictors of yields if they are calculated using the actual sowing date (or a sowing window) to trigger the beginning of the growth cycle. However, inquiring after actual sowing date can be very costly (as discussed in the case of cotton in Northern Cameroon, in the fifth chapter of this thesis). Farmer's statement would indeed

induce a transaction cost, limiting the scope of the product. Hence, in practice, especially in India and Malawi, the sowing date used to determine the crop growth phases is imposed by the insurer (a fixed period in Malawi and triggered by the occurrence of a precise cumulative rainfall level in India).

Imposing an arbitrary sowing date or window in the insurance policy increases the basis risk hence reduces the benefit of the WII. It is nevertheless efficient when dealing with homogenous and predictable growing practices. For instance, it was set between 1st November and 20th January in the Malawian experiment. In this case, providing an annual weather forecast (cf. section 3.2.4.3) and a precise analysis of farmers practices should ideally precede the design and supply of insurance

Finally it could be simulated (as in Mahul et al., 2009) or chosen by farmers for instance among a list periods specified by the contract. The issue of setting a sowing window is tightly linked with the determination of the beginning for the rainy season. We discuss the importance of acutely forecasting the onset of the rainy season for growers in section 3.2.4.3. Recent research in West Africa favors an indicator of spatial coherence of (in general two) rainy days in different places located nearby (Sivakumar 1988 and Marteau 2011). Such criterion could then be used to simulate ex post the farmers' sowing decision using rainfall data. Heterogeneity of growing practices and/or beginning of rainy season within the area could therefore be an obstacle.

Drought indices

Those indices use temperatures and rainfall to determine air and/or soil dryness. The Selyaninov drought index, also called Selyaninov Hydrothermal Ratio, and the Ped index only captures the air dryness. Both have been used by Breustedt et al. (2004) in an ex-ante WII scheme study designed for Kazakhstan. Their calculus has the convenience of only requiring rainfall and temperatures data. The Palmer Drought Severity Index (PDSI: Palmer, 1965) was used for the study of

an insurance scheme in Morocco (Skees, 2001). It requires temperature, latitude, water retention capacity of soils and precipitations data, usually on a ten day basis.

3.1.2.2 Satellite imagery data

Satellite imagery data allows the computing of leaf area index (LAI) or other vegetation indices such as the Normalized Difference Vegetation Index (NDVI). The latter evaluates crop canopy photosynthesis - more precisely light absorption - calculated from the difference between near infrared (NIR) and red beams (RED), divided by their sum: NDVI = (NIR-RED)/(NIR+RED).

The NDVI can barely discriminate between pastures and cultivated areas and it is calculated with a delay period because of the potential presence of clouds. It is quite well adapted to biomass assessment but not to yield assessment. This technique is thus being more and more frequently used for global food crisis early warning, livestock management, and forecast of forage production [3]. Besides improvements in such fields are very quick so that imagery resolution increases every year with freely available data recorded since the year 1981 (for a 8 km resolution). However, delays in processing, homogeneization from difference sattelites data source and validation from research scientists, of MODIS data (the main source for such indices) render them inadequate for real-time drought monitoring. However, there are some near-real-time access to processed products such as eMODIS from USGS EROS as underlined by Anyamba and Tucker (2012) and discussed in the chapter V.

3.1.2.3 Mechanistic crop models

Mechanistic and dynamic models simulate crop physiological growth depending on available environmental factors (cf. Akponikpe, 2008 for an exhaustive

3. Implemented by Agriculture Financial Services Corporation (AFSC) in Canada, Spain, and Mexico (Hartell et al., 2006), by the Word Bank in 2005 in Mongolia (Mahul and Skees, 2008) and for livestock insurance in Kenya described in Mude et al. (2010).

review). Their precision in yields estimation is greater, but they need very detailed input data, particularly time series at the plot level. Such data are rarely available for large areas, especially in developing countries.

The DSSAT model is used by Osgood et al. (2007) in East Africa and Diaz Nieto et al. (2005 and 2012) in Nicaragua. It is however difficult to use such complex models because of a high sensitivity to parameters calibration and relies on the implied theoretical relation between yield and water. On the other hand they can be used to assess the shortcomings of other methods such as an unfavourable simulation of water stress. They may allow for yield simulation under higher levels of inputs than actually used by the farmers, which may be useful since WIIs create an incentive for such intensification that is unobservable ex ante (as discussed in the cas of Niger in the Chapter II).

3.1.2.4 About the use of complex models

First of all, designing a marketable WII is a challenge because very complex trade offs are at stake: we want it to limit basis risk by choosing an adapted index and the shape and calibration of the contract but do not want to fine tune it which would make it to hard to understand and to assess.

As mentionned earlier in this section Kellner and Musshof (2011) argue that using water capacity indices improves the outcome of index insurance. They however do not mention overfitting issues (we will discuss in broader terms in the chapter 4), that are to be worsen in the case of a complex index, since optimization of index parameters could artificially increase insurance gains. Moreover, the calibration of area-specific parameters in the calculation of the index value leads to relative subsidization (taxation) of areas endowed with soil that are less (more) suitable to the cropping system or more (less) prone to drought. We show in the chapter 5 of this thesis that it is what happen when dealing with heterogeneous areas in term of the agrometeorological relation.

The use of mecanistic models also poses some problems if someone want to

use directly the forecasted yield as an index. It would indeed make the indemnity depend on farmers choice such as the varietar, the crop management techniques or on structural parameters such as the soil type and its retention capacity. It will then lead to moral hasard issues in the first case and to a subvention of plot that are badly endowed. Mecanistic models thus should only be used in order to extract the role of weather variable on yield, which is probably not such an easy task.

3.1.3 Insurance policy design and calibration

3.1.3.1 Typical indemnity schedule

Typically the average contract is a linear one. There is, however, no evidence for choosing such a contract (Kapphan, 2011), and a simple lump sum contract could be more efficient (Gelade 2012) when there is a fixed cost associated with each indemnification. The standard indemnity schedule is defined in the related literature by three parameters (λ,S,M), as brought forward by Vedenov and Barnett (2004). Insurance indemnities are triggered by low values of an underlying index that is supposed to explain yield variation. The indemnity is a step-wise linear function of the index with 3 parameters: the strike (S), i.e. the threshold triggering indemnity; the maximum indemnity (M) and λ, the slope-related parameter. When λ equals one, the indemnity is either M (when the index falls below the strike level) or 0, which correspond to a lump sum transfert.

In many WII experiments, the indemnity schedule is more complex. In particular, as explained above (section 3.1.2.1), partial payouts are calculated for each crop growth phase, and the total indemnity is the total of these partial payouts. This design is based on the hypothesis that investment returns could be annihilated at every growth phase. It is the case in Malawi (Osgood et al., 2007) and Senegal (Mahul et al., 2009) and many schemes in India. A maximum insurance payout is defined for each growth phase and the sum of insurance payouts can also be capped for the whole growing period. De Bock et al. (2010) introduced a

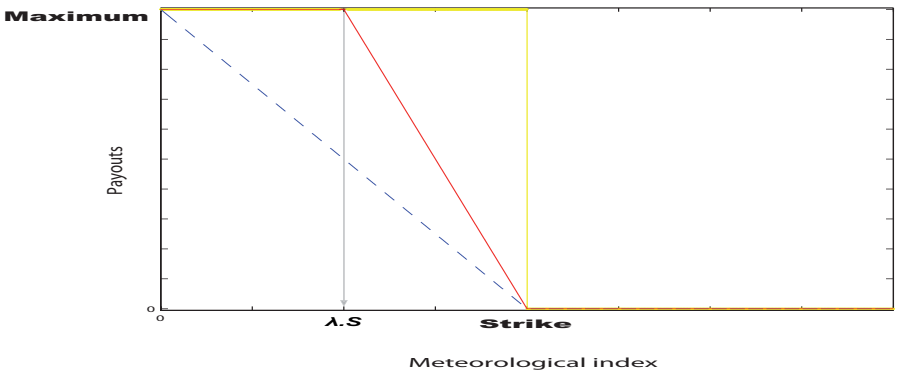

Figure 3.1: Usual shapes of WII policies.

second strike level in order to increase acceptance of the product by increasing the number of indemnified growers at low cost for the insurer. Insurance policies also could provide different hedging level for a given cultivated area, in the purpose of inciting farmers to reveal their level of investment. High intensification growing practices indeed relies on higher costs (and correspond to a higher level of risk taken) and thus need a higher level of coverage.

3.1.3.2 Optimization of policy parameters

We review here the methodology for designing the potential WII products under standard (Von-Neumann Morgerstern) expected utility [4].

In most cases, the indemnity schedule and the parameters are set without a formal optimization process, on the basis of expert knowledge. Typically, the strike will be set according to agronomists' views of under what level rainfall starts to be a limiting factor for crop yield, and the maximum payment may be set at the total value of inputs (fertilizers, seeds, pesticides...). In this case the strike is set according to a theoretical relation linking yields and water availability

4. The next section below is dedicated to the assessment methodologies and the case of subjective beliefs will be discussed in the third section of this chapter (section 3.2.3.4).

as in Vedenov and Barnett (2004).

In some cases, some of the parameters at least are set following an explicit optimization process. The function to optimize differs across authors. Some maximize an expected utility function with a given risk aversion, e.g. a Constant Relative Risk Aversion (CRRA) function in Berg et al. (2009). Others minimize the semi-variance [5] of insured income [6] as in Vedenov and Barnett (2004). Semi-standard deviation (also called Root Mean Square Loss, RMSL) can alternatively be considered if large losses are not to be overweighted compared to little losses. Finally Osgood et al., 2007 minimize the variance of basis risk i.e. the difference between payouts and expected losses, the latter being defined as an inferior quantile of the yield distribution simulated with the DSSAT crop model.

To wrap up there are 2 major categories of objective functions. A first type only ensure that the insurance scheme reaches the risk minimization objective and lowers the risk level (i.e. income downside variations). It includes semi-variance and its squared root, which minimize downside loss, only taking the lowest part of the outcome distribution into account. The second type (e.g. CRRA and mean-variance) take into account the cost in terms of average income. They allows to quantify and compare the reduction of risk to its cost in terms of average income, due to the presence of a positive loading factor.

3.1.3.3 Basis risk and index choice

Definition and causes of basis risk

The basis risk, *i.e.* the imperfect correlation between the index and yield, is a combination of two factors: first the spatial variability of weather (cf. section 3.2.5.2) that makes it to costly to assess in each precise point where the yield is observed and, second, the unperfectibility of weather indices.

5. Semi-variance is the squared difference of income inferior to the long-run average income, relatively to this long run level.
6. Income after insurance is the observed income plus indemnity minus premium

The word 'basis risk' comes from finance and more precisely from the options theory, used for the study of future markets including weather derivatives. The base is the difference between the future value in the central (terminal) market and the one observed in a remote area. This difference is composed of both a stochastic and a deterministic component. The latter is explained by the distance to the terminal market and the cost of crop storage, decreasing as the term get closer. The stochastic part of the base creates a risk called basis risk.

In the case of index insurance, basis risk has 3 different sources. First, the spatial basis risk comes from the the distance from where the observation of the index is done to the place where the crop is grown. Second, there is always a lack of correlation between the yield and the index, for instance due to non meteorological shocks (locust invasions, pests, diseases...) in the case of WIIs. Lastly, the idyosynchratic basis risk comes from the difference of productivity between heterogeneous farmers that do not put the same effort into production, do not use the same practices etc. We formulate better and apply such distinction in the chapter V.

Typology of basis risk

We can distinguish two kinds of particular basis risk in WII designs, with regard its effect on the insured ones. The first is the probability to give an indemnity to farmers that do not need it (false positive or 'false alarm', we will call it type I basis risk) is costly for the whole indemnified farmers (more precisely those paying premiums). It should be limited if the index is well designed, however in many case it remains.

The second type (type II basis risk, false negative) is a bad outcome without an alarm, also called missed crisis. The second type error is supposed to be worse regarding the demand of WII, especially when combined with the first type. As shown by Clarke (2011) index insurance with significant basis risk can indeed lower utility in the case of a concave utility function. In that case the premium

is paid when there is no signal for a bad situation, the exposure of the insured to risk could even increase since the outcome is worsen by the insurance (bad outcome minus a positive premium).

Minimizing the basis risk is the main criterion to compare those indices. The correlation between yields and index values is the simplest way to deal with such choice (as done in Carter, 2007), but more complex objective functions exist (cf. chapter V). In order to improve the attractiveness for farmers it is fundamental to choose a utility function in order to estimate the cost of a lack of correlation between yields and index values for low yields, i.e. for situations in which an indemnity should be paid (as discussed in the fifth chapter).

However, complexity limits the transparency and acceptability of WIIs and data availability is also often limited, especially in developing countries. Thus there is a trade-off between index transparency, readability for farmers, data availability and simplicity on the one hand, and the index ability to reflect low yields (or minimize the basis risk) on the other hand. If the insurance target is the farmer, simplicity is important, but if the target is a financial institution willing to insure its agricultural portfolio exposed to weather shocks, the product can be more complex.

3.1.3.4 Ex ante validation of index insurance policies design

As mentionned earlier, many ex post evaluation of WII experiments recently took place. It is however very coslty to implement those experiments and then run rigorous ex post impact analysis, especially when compared to ex ante analysis (Harrison, 2011). Moreover, designing an optimal insurance contract requires an assessment of farmers' interest and product accuracy before launching it, such necessary step is often spared, probably due to data, time and budget constraints. Ex ante assessment could even though avoid miscalibration and allow to fit better farmers need, which seem to be a critical necessity to convince farmers of WII relevance.

Testing the WII policy design may be done by computing the three parameters of the policy design and a premium level (total indemnification multiplied by the loading factor divided by the number of policies sold) on, potentially detrended, historical data. It might alternatively be done by fitting a statistical distribution function on the index time series and then run simulations to get an idea of future index realizations. Working on historical indices time series is called the Historical Burn Analysis (HBA) method and the simulation of meteorological index series is the Historical Distribution Analysis (HDA) also called index modeling method. Both methods are investigating different properties of the policy, the first one helps in parameterizing and assessing the contract pooling capacity on historical data while the second allows to test the robustness of a given contract over a long time span.

HBA method

Running policy on index and yield historical data is the only way to test a policy design a posteriori. Studying historical yield data however annihilates any endogenous impact of the policy such as the increase of average yields that could induce intensification (as shown by Hill and Viceisza, 2009) or other riskier strategies due to the pooling of risk among farmers (section 3.2.1.1).

The analysis of the distribution of moments of the index allows the future insurance payouts to be foreseen without making any assumptions on distribution function's parameters, as it is the case in HDA analysis (cf. next paragraph). Minimizing the difference between losses and payouts by a simple optimization technique is the best way to find an optimum value for any parameter. Such optimization should be done on a distinct sub-sample to avoid in-sample calibration leading to over-fit the sample data that artificially enhances the results.

Dealing with ex ante impacts, cross validation seem necessary because it is useful to test the stability of the calibration on different samples if data is sufficiently proficient. There exists different sampling techniques separating training

and validation data such as cross-validation, but they requires a minimum of spatial and temporal data. Among k-fold cross validation techniques a way to deal with over-fitting with short time series is to use a leave-one-out (Berg et al., 2009, also often called jackknife). In such method, calibration of parameters is done n times: on n-1 observations and tested on the nth observation left out of calibration sample.

HDA method

The quality of probability evaluation of indemnifications depends on the length of data series because high risk associated with low occurrence are very difficult to apprehend. Low probabilities / high risks (fat-tailed) distributions will thus be preferably treated with the HDA method.

Such method is worthwhile for testing the future prospects of a policy scheme. It is useful to test it in the long run, even if index data are not available on such time span for example checking for supplier solvability i.e. sustainability of the supply. Fitting a distribution function on a meteorological index allows the assessment of future WII outcomes through Monte-Carlo simulations (Hartell et al., 2006). Rare events, even if not present in the historical series, might be simulated and the specificity of the underlying density function can be better apprehended. Moreover outliers will have less of an impact on results than they do in the case of HBA and confidence intervals can be assessed by running bootstrap or other statistical methods on those large simulated series. Fitting the underlying distribution is its major advantage but also the major impediment. Simulated data are indeed very sensitive to parameter calibration (Jewson, 2004) and there is thus a need for large time series on index data. In practice designing an insurance scheme requires about 20 or 30 years of data (Jewson, 2004 and Woodward, 2011) depending on its quality and the presence of long-run trends (cf. section 3.2.5.1).

The only formal comparison of the accuracy of the two methods seems to be a working paper by Jewson (2004) who concludes that HDA is significantly better

than HBA when there is little uncertainty on the statistical distribution assumed in the HDA method. Both methods seem complementary and should ideally be run simultaneously for policy design, it has however never been the case in the existing literature.

3.1.3.5 Loading factor calibration

The insurance premium is higher than the expected indemnity (except if the insurance is subsidized) since it includes the administrative costs as well as the cost (load) of the risk taken by the insurer, *i.e.* the loading factor[7]. We only discuss the second aspect here.

The cost of the risk for the insurer decreases with the diversification of the portfolio of the insurer that could layer risk insuring different clients or regions (Meze-Hausken et al., 2009). It is also worth mentioning that reinsurance is able to cap the risk taken by national insurance companies who suffer from covariance within their portfolio. Finally a key element that affects the loading factor is the availability of historical data. For example, the loading factor for a policy which uses a new weather station will be higher than that for a policy with a long series of historical data. Aware of those limits two methods can be derived for evaluating the additional cost of risk taking (Henderson, 2002):

- The Sharpe ratio margin is proportional to cost standard deviation (σ(I), with I the indemnifications) for the insurer:

$$\alpha \times \sigma(I) \tag{3.1}$$

  Where σ is the Sharpe ratio. It is less adapted for HDA, in which standard deviation is a parameter.
- In the Value at Risk (VAR) this margin is proportional to a risk of defined occurrence probability. For example risk cost valuating at the VAR_{99} cost

7. Also known as gross-up factor or charging rate.

of events that occurs with a probability of less than 1%:

$$\beta \times [VAR_{99} - E(I)] \tag{3.2}$$

The latter method is more adapted to high risk with low probability (such as extreme weather or the occurrence of natural hazards) but cannot be applied with HBA (cf. the two previous paragraphs) since the number of events is too low. An ex-post statistical analysis on a case study in India conducted by Giné et al. (2007) showed that a large part of the payouts are due to extreme events: half of them in that case were due to the worse 2% climatic events. According to Hartell et al. (2006), α is chosen between 15% and 30% and β between 5% and 15% (and between 5% and 7% according to Hess and Syroka, 2005 and Osgood et al., 2007 who draw on WII case studies). For instance, in the case of Malawi, the VaR method applied with a factor β of 5% leads to an increase of 17.5% of the premium over the actuarial rate (no risk loading) and a final premium rate of 11% of total indemnifications (Hess and Syroka, 2005). However, due to sharp competition among private insurers, the actual rules for fixing the risk loading are very hard to assess.

3.2 Challenges and research questions

We will focus here on individual level WII schemes (as opposed to institutional ones as it was implemented in Ethiopia at the national level) which are concerned in the chapters IV and V. The recent but quite prolific academic literature on index-based insurance indeed raised several very interesting questions.

3.2.1 Low technology adoption under climate risk

We will try, in this section, to show the channels trough which risk could hinder farm capitalization leading to lower yields. It can also be seen as theoretical grounds that lead to think *a priori* that WII have high potential returns.

We will try to overcome the complexity of the topic coming from the interlinked relations bewteen the three main characteristics of smallholder farming on which we shed light in this essay: tied budget constraint and lack of access to markets, the presence of risk and a low intensification partly due to low technology adoption.

The existence of a yield gap in Africa is widely accepted by academics [8], however the question about the best mean to trigger intensification and productivity largely remains unsettled. There are indeed numerous hypotheses for explaining such gap with other developing and emerging countries. Risk is one among them and weather is only one of its sources (Fafchamps, 2010), it however gained great attention in the scientific community [9]. Such shocks are indeed known to have ex ante and ex post impacts on farming decisions. Poor level of wealth probably prevents farmers from implementing risky strategies that are more productive in average. Binswanger and Rosenzweig (1993) evaluate at 35% the average profit loss for the poorest quartile of Indian farmers undertaking low risk/low yields productive choices, partly due to risk aversion.

African smallholder farming shows very low intensification (excepting the cotton case discussed in broader details in the two firsts chapters): we will thus describe the two main recent potential explanations of this fact in the recent literature.

We will focus on subsistence constraint and timing in technology adoption. Both aspects are of primary importance for WII or other risk management strategies that reduces the risk before the cropping season without bringing distorsions. We will see that in spite of heterogeneous returns to technologies, they could play a great role in technology adoption.

8. See Udry, 2010 for a review.
9. See for instance Udry (1995) concerning savings, Dercon (2004a) concerning education and Maccini and Yang (2009) concerning health issues.

3.2.1.1 Subsistence constraint and poverty traps: the role of risks

Poor households face a double constraint constituted of a tied budget (limited access to credit market) and a subsistence imperative. In order to meet minimum nutritional needs, households often under-invest in productive capital, including in human capital through health and education expenditures (see Collins et al., 2009 for anecdotical evidence).

There is a large body of literature on poverty traps (Bowles, Durlauf and Hoff, 2006, and Dercon, 2003) and some exploring the potential role of heterogenous capital detention on the existence of poverty trap (for instance Eswaran and Kotwal, 1990 on risk averse behaviours and land detention and Rosenzweig and Wolpin, 1993 on oxen detention and consumption smoothing in India).

It has so far proved very difficult to find convincing empirical evidence of poverty traps (e.g., Jalan and Ravallion, 2005), except for the often quoten example of Rosenzeig and Binswanger (1993). A possible reason for that is the heterogeneity of threshold among households and the complexity of the assessment of a multidimensional vulnerability, showing some psychological as well as qualitative aspects.

Some evidences however seem to go in that direction. Reardon and Taylor (1996) found that droughts increase poverty for the poor disproportionately, as they rely more heavily on crop income. The resulting liquidation of assets makes them even more vulnerable to future droughts. Lybbert and Barrett (2007) showed the same type of consequences concerning herd management and stochastic shocks. They highlight the presence of a threshold effect due to multiple equilibria in herd size. Barnett et al. (2008) reviewed such mechanisms and their crucial role in designing index based risk transfer products.

Facing risk creates an incentive for poor households to stock non-productive subsistence assets (food) with low-return and low-risk (Zimmerman and Carter, 2003, cf. section 3.2.4.1 for a short review of the impact of other informal risk coping strategies). Zimerman and Carter (2003) show the substituability between

unproductive (stocks) and productive assets (land, livestocks) in a theoretical model and apply it to Burkina Faso. The first type of asset being more easy to sell in the case of a negative income shock and thus to play the (consumption smoothing) role of a buffer stock. This is to our knowledge the only theoretical model (with the one from Thorsen and Malchow-Möller, 2000, both using the graph theory) to consider states of the nature in which consumption (and thus utility) is zero for instance when it is below the subsistence level and thus able to deal with individual poverty trap dynamics. Hoddinott (2006) however put into question the accuity of the distinction between asset smoothing and consumption smoothing and finds that Zimbabwean households behave as if a pair of oxen represents an asset threshold below which they strive not to fall.

Concerning the dynamic of poverty trap, uninsured risk can affect the poor in two distinct ways: ex ante and ex post. Cai et al. (2010) find empirical evidence of an endogenous ex ante effect of insurance in China, where formal insurance increases farmer's tendency to invest in risky sow production. However the only framework developped to asses ex ante the impact of WII on such dynamics is the work of DeNicola (2011). It uses a mathematical programming model of a farm management with a WRSI insurance calibration design.

This academical debate also echoes in other spheres and one major point made by development practitioners concerns household farm management and intra-annual consumption smoothing or warrantage (harvest stocks in kind used as a collateral for cash credit). It allows to hedge farmers against intra-annual price variations. The first had an echo in the research area when mandatory or 'commitment' savings and warrantage has been proven to be quite efficient (for instance in a randomized experiment ran in Malawi for tobacco growers by Brune et al., 2010). Their great simplicity also argues in their favor.

3.2.1.2 Timing of shocks and investment opportunities

Most investments in agriculture has to be done before or during sowing (some fertilizers can still be applied during the growing cycle), period that follows the dry season, corresponding to the most critical period in terms of liquidity constraint. After the lean season, farmers are endowed with the lowest seasonal income stock: on-farm income comes from irrigated 'off-season' vegetables and/or legumes; and little rainy season crop harvest if there is two rainy season as it is the case in Ethiopia. It involves inherent difficulties for investing in that period, at least in absence of credit market or safe saving mechanisms: bank accounts, mandatory savings or warrantage.

The timing of shocks with regard to investment decisions seems crucial. Udry (2010) shows that household that face risk realized after input decision will invest under the optimal level 'sacrifying expected profits in exchange for more certain return'. Even though it is the case for most idiosyncratic shocks, such as weeds, pests and even some labor supply shocks, and covariant shocks, such as weather shocks and price fluctuations. This is coherent with the results of Duflo, Kremer and Robinson (2003) who run a randomized controlled trial (RCT) on the treatment by the Savings and Fertilizer Initiative (SAFI: a commitment device for farmers), finding that farmers take up this program when it is offered at harvest time, but not later.

3.2.2 Empirical evidence of a low weather index-based insurance take up in developping countries

Current research shows that the low (and price-elastic) demand for rainfall insurance raises doubts about the potential for this type of insurance as a general solution for all poor agricultural households to manage their risks (Macours 2012). The very low effective take up of weather index-based insurance by individual farmers indeed question the of theoretical estimation of a high return of such policies (cf. previous section 3.2.1).

Actual take up of WII experiments are very low: from 5% in 2004 analysed by Giné et al., 2008 in Gujarat, India to about 27% for the same sample of Indian farmers in 2006 as analyzed by Cole et al., 2011, in spite of a very high estimated potential. For instance an average gain of 17% of the income level in the long-run according to the calibration of DeNicola (2011) in the case of the Malawian experiment which was only purchased by 5% of farmers (Giné and Yang, 2009). Ex ante demand, estimated by willingness to pay for WII is also very high: Sarris et al. (2006) found that over 55% of all households surveyed would not purchase rainfall insurance with a positive premium in Tanzania. Sarris et al. (2012, ongoing) found that about 88% of Ethiopian household express interest in index insurance contracts and about 42% in a different study (Hill et al., 2011).

3.2.3 Potential determinants of the low weather index-based insurance take up

Rosenzweig and Wolpin already concluded in 1993 that the availability of weather insurance would have little effect on the well-being of Indian farmers. There are however two major limitations to that conclusion. First, the authors assume that even when households are hit by a large negative shock, they are guaranteed a minimum level of consumption. Second, the analysis focuses on understanding the process of accumulation of bullocks, which are considered as both production and saving assets. Since households own a maximum of two oxen and one water pump, Elbers et al. (2007) warn that the low level of heterogeneous variation in the farming inputs data may lead to an incorrect estimation of the structural parameters.

We will review here different mechanisms, raised by a much more recent literature, to explain the evidence of a low WII take up rate.

3.2.3.1 Price elasticity, budget constraint and time inconsistency

Only two recent experiments showed a relatively high take up level. The first is the Harita project (36% of buyers) where it was freely allocated with other products (Norton et al., 2011). The second, a recent experiment from Karlan et al. (2012) tests for different subsidization level, and find that at least half the acres were covered and even more, up to 100% for an insurance priced at the actuarially fair rate. Those results argue in favour of a high elasticity to insurance price (premium subsidization level) variations. However still some fair rate insurance experiments (the individual scheme in Malawi for instance) do not find enough buyer which suggest that there are also other reason for non buying those products. More generally, only a small proportion of farmers buy the insurance offered, the purchasers usually buy the smallest coverage offered and the poor farmers who would *a priori* benefit the most are not usually among the purchasers.

The most simple explanation for low take up rates could be the credit constraint. It was validated in the field by Cole et al. (2011) who found that households with randomly assigned endowments (about 80% or more of the insurance premium) are about 40 percentage points more likely to take up the insurance. Cole et al. (2011) argue that liquidity constraints do matter because they observe that the big endowment has a larger effect on poorer individuals, for whom liquidity constraints are more likely to be binding. Additionally, when asked about the main reason for not buying insurance, 'not enough funds to buy insurance' is the most common response. Likewise, Norton et al. (2011) found a significant decrease in the percentage of insurance buyers when they stopped distributing game endowments (from 99% to between 6 and 36% of insurance buyers). Measuring wealth in different ways, Gaurav et al. (2011) and Giné and Yang (2009) in India also found that the more wealthy are more likely to purchase insurance, although Dercon et al. (2011) do not.

Time inconsistency is also a potential explaination since it is difficult to ask

poor people to pay up front a service whose benefit wil not be realized immediately. Duflo, Kremer and Robinson (2010) indeed show that time inconsistency is a major problem in the demand for fertilizer, and Tanaka et al. (2010) also found evidence of such inconsistencies in rural households in Vietnam.

3.2.3.2 Financial literacy and peers effect

A large body of literature points out the need to increase financial literacy such as probability apprehension in such products and the potential improvements that trainings could bring. The first reason given by farmers explaining the low take up is indeed the misunderstanding of the product (Giné et al., 2008). There is also strong evidences that technology adoption depend on financial education and observed literacy in Gaurav et al. (2011) and Patt et al. (2010).

Patt et al. (2010) compared the impact of traditional communication tools such as oral or written presentations of indexed contracts relative to role-playing games on two groups of farmers, controlling for their respective educational level. The experiment was designed for this purpose and took place in two different sites in Ethiopia and one in Malawi. They found a high correlation between insurance understanding and the desire to take up but no evidence of any superiority of role-playing games compared to oral or written presentations. According to the authors, the misunderstanding of insurance policies after the training could be due to an insufficient educational background.

The quality of the training is at stake: short 15-minutes explanations do not seem to be effective, or at least not nearly as effective as longer training sessions. Cole et al. (2011) compare marketing treatments: a video and a simple flyer. They found a little but significant superiority of the video treatment. A personal marketing intervention also had a great impact on take up (about 20%), even if the product is available to all household, suggesting that the personal relationship helps in reducing the trust gap.

Khan (2011) measures both the impact of educational interventions on the un-

derstanding of the insurance product as well as the impact on demand. To do so, he offers interventions on health insurance to a group of workers in Bangladesh, consisting of three sessions of a few hours, spread over three weeks. One month later, the author assesses the households' willingness to pay (WTP) for the insurance product and observe an increase in knowledge between pre- and post-treatment periods as well as between treated and control groups. Moreover, an 33.8% increase in the WTP is found for the intervention group.

Then, it seems that one should differenciate between the instructions about the complexitiy of the index-based insurance schemes that often are quite technically grounded and explaining the objective and the scope of insurance to households that never used some. Hill and Robles (2010) laboratory experiment show the challenge behind the trade off between complexity and basis risk. They show that, even in a context where insurance understanding is high due to a high differenciation in products and the help of endogenously formed risk-sharing groups, the level of basis risk, especially stemming from the high heterogeneity of farmers, significantly limits the demand. Debock and Gelade (2012) analyse the existing literature and conclude that while it is unclear whether financial literacy training can achieve to higher take up. There is definitely scope for current training methods to focus less on the technicalities of the insurance product and more on a broader understanding of its concepts. We will see below that understanding is also a crucial factor in renewing: financial literacy trainings, possibly coupled with a good follow-up can also have substantial effects in the long run.

As any technology to be adopted for the first time, the product is associated with a substancial uncertainty, that could be overcomed faster by using learning and network and peers. As pointed out by Hill (2011) it is a conceptual rather than a physical product and do not beneficiate every year to farmers, which probably even reinforces the underlying ambiguity, especially for less educated farmers. The literature brought up the critical role of farmers' interest and trust in distribution organisations and thus the need for utilizing existing networks

among farmers (Cole et al. 2011; Patt et al., 2009 and Cai et al., 2009). The evidence also suggests that peers do have an important influence on the decision to adopt new technologies. By spreading information, buyers can increase the likelihood that a new technology will be purchased. Griliches seminal 1957 paper on the economics of agricultural technology adoption indeed suggests an s-shaped model of technological adoption where adoption begins with only a handful of people. Peers effects in technology adoption are a novel but prolific feature in the literature about technology adoption in developing countries (Conley and and Udry, 2010 and Duflo et al., 2009) and its impact on WII take up will probably be studied in deeper details along the coming years.

3.2.3.3 Basis risk and risk aversion and trust

It is generally held that farmers' aversion to risk affects the composition of their asset portfolio (see Rosenzweig and Binswanger 1993). It is therefore natural that we would expect demand to be increasing in risk aversion. Similarly, we expect demand to be declining with basis risk.

As a further extension, it is possible for farmer perceptions about the insured risk to differ from the information used to price the contract, in which case expected basis risk differs from the true basis risk. Mullally (2011) shows that such dissonance can negatively affect demand.

Strong and repeated empirical evidence from experimental studies reveals a result that seem quite odd at first sight: not only is demand for both indemnity and index-based insurance products low, but the likelihood of insurance purchases is negatively associated with measures of risk aversion in many contexts (Giné, Townsend, and Vickery 2008; Lybbert et al. 2010; Cole et al. 2011; Giné and Yang 2009; Galarza and Carter 2010 and Hill 2011). Cole et al. (2011) find that those who took the safest lotteries in a pre-survey are about 10 percentage points less likely to purchase insurance. Similarly, Giné et al. (2008) ascertain that risk-aversion decreases the probability to purchase the Indian rainfall index insurance

by 1.1 percentage point, from a baseline take up of about 5 percent. Galarza and Carter (2010), in a field experiment where subjects can choose between safe projects, uninsured loans and insured loans, find a non-monotonic relationship between risk aversion and insurance demand. In particular, they find that highly risk averse individuals have a higher demand for safer projects (including either an insured loan or no loan at all) but that this relation is decreasing, that is, those individuals with the highest risk aversion would prefer the riskier project or not to purchase the insurance.

There could be some interactions between different factors explaining low observed take up rates. Theoretically, in the case of a WII, basis risk could be a sufficient reason for poor and risk averse enough household not to buy insurance (as pointed out the model of Clarke, 2011). Risk averse farmers fear basis risk that could even accentuate their losses in a bad harvest year associated with a 'good' index level as low risk averse farmers get a lower gain in certain equivalent. Cole et al. (2011), however, measure basis risk as the distance between the farmer's village and the rainfall station, and do not find a significant correlation between basis risk and demand.

This unexpected relation between risk aversion and insurance demand could also be explained by a lack of definition of the underlying risk. First, the aversion to uncertain events (or ambiguous, i.e. that are not associated with objective probabilities) is quite different from pure risk aversion (cf. the next section, 3.2.3.4). A lack of trust in the insurance supplying institution also can be seen as an uncertainty as shown by Dercon et al. (2011). They apply a model of limited trust to health insurance take up and found that, controlling for trust [10], slightly increasing risk-aversion for risk-lovers individuals seems to have a positive effect on demand but a negative one on highly averse agents. Moreover, the effect of (random) price variations is stronger on the less trusting individuals.

10. Trust is defined here by the authors as a probability of default from the insurer as well as the unclear definition of what is covered by the contract. It is indeed important to differenciate between the trust in the product itself, the trust in the institution involved, and the degree of interpersonal trust of the individuals when considering insurances.

We shall mention that the great heterogeneity in the result found across different studies might be explained by the specific features of the field works. Trust is indeed a complex feeling with diverse potential determinants, the institutions at stake, the way people are approached, and the running of the field may also play a role in the take up. Lastly, the impacts found could also simply be some reciprocal actions of farmers participating to programmes characterized by the disbursement of an endowment grant or any other (monetary or not) transaction; there is thus still room for other factors limiting WII demand.

3.2.3.4 Beyond expected utility: uncertainty and ambiguity aversion

The literature about uncertainty, as opposed to risk that could be associated with a probability of occurrence (Knight, 1921 and Keynes, 1921), lead to the emergence of the notion of ambiguity. It stem from the initial approach of Ramsey (1926) and DeFinetti (1927) about probabilistic beliefs [11] that became recently popular because it allows to explain some individual behaviours that are challendging the expected utility theory (EUT) framework, such as the famous Allais (1953) or Ellsberg (1961) paradox.

Climate, partly due to the complexity of its underlying mechanisms is in the realm of ambiguity rather than risk; meaning that while there is some information about the relative likelihoods of different outcomes, this information does not constitute a probability density function. Index-based products are indeed particularly subject to ambiguity, i.e. uncertainty about underlying probabilities, for targetted farmers.

As seen for risk aversion, effect of ambiguity aversion on WII take up is not theoretically straightforward. One could first argue that ambiguity averse growers would like to reduce weather ambiguity by buing WII. However since the index insured is uncertain, some ambiguity still remains on the insurance contract out-

11. Individual subjectivity leads to a misapprehension of probabilities, often leading to an overestimation of low probability events. Delavande et al. (2011) offers a recent review of methods for empirical assessment of subjective probabilities in developing countries.

come, especially in the presence of basis risk that impede insurance to remove the risk completely. It is then difficult to distinguish the effect of uncertainty from the effect of trust, since beliefs will play a role on the perception of the insurance supplied (and thus on the level of basis risk). It is thus a potential lead for explaining divergence of take up in field experiments from the theoretically modelled gains of such products.

The effect of ambiguity aversion on technology adoption also depends on the effect of the technology on the perceived ambiguity. For instance, reducing ambiguity related to pest and disease, as in Barham et al. (2011), increase adoption if the technology reduces (more that it amplifies) ambiguity. Alary et al. (2011) show that ambiguity aversion should, in their framework, increase the level of self-insurance but lowers the level of self-protection, i.e. individual behaviours seen as risk mitigation measures (such as systematically using a seat-belt).

Ambiguity aversion impact on technology adoption and WII take up has been tested in a few studies. An experiment lead by Ross et al. (2010) in Lao republic showed that farmers' technology adoption seem to be hindered by ambiguity aversion more than simple risk aversion. This study is run in a very different region and considers many heterogeneous technologies. There are however other empirical evidence that point out the role of ambiguity aversion in risk management practices. Engle-Warnick et al. (2007) studied Peruvian farmers' decision to diversify and use new crops (assumed to be associated with unknown yield distributions) and found that ambiguity aversion is a factor for lower crop diversification and that risk aversion is not paying any role. The recentness of the fields and a lack of comparable studies however prevent from settling the question.

Alpizar et al. (2009) shows that farmers in Costa-Rica are more prone to take safer adaptation options (represented by insurance against natural hazards) when there is uncertainty rather than risk. Akay et al. (2009) found that Ehiopian farmers show the same ambiguity aversion that student samples and that poor health can play a role in such behavioural characteristic.

The only study that directly linked insurance take up to ambiguity aversion is the one from Bryan (2010). The author focused on index-insurance take up in Kenya and Malawi (using the data of Giné and Yang, 2009) and shows that ambiguity aversion lower the demand for WII even when controling for trust and risk aversion levels as revealed by farmers on a scale of 1 to 10.

3.2.3.5 Recency bias, hot-hand effect and subjective probabilities

Risk aversion also probably plays a role in technology adoption if considering that the Gollier and Pratt's (1996) theory - saying that households that endure losses due to one particular risk will update their beliefs and thus put higher probability on such events that those that did not - is true, as tested on an indonesian sample by Cameron and Shah (2011).

Rainfall patterns in the semi-arid tropics of West Africa exhibit no serial correlation (Nicholson 1993). Karlan et al. (2012) results are so far consistent with farmers who act otherwise. The results are consistent with salience, or recency bias, in which farmers who experienced a trigger event last year overestimate the probability of its reoccurrence this year and similarly farmers who did not experience a trigger event underestimate the probability of a payout this year. Galarza and Carter (2010) also found a 'hot-hand' [12] effect stemming from an minoration of the autocorrelation of the sequence of very bad years that could lead to take more risk after the occurrence of a 'bad' season. The authors make a distinction with the recency effect, this effect being the bias towards overweighting recent information and underweighting prior beliefs. Subjective probabilities thus could have an impact on insurance take up and put into question the expected utility approach. In the experiment of Kouame and Komenan (2011), Ivoiry Coast cocoa farmers' previous luck seems to interfere in the choices of the agents: those who had bad luck in previous lotteries tend to stick to the safer choice in the next

12. Hot-hand and gambler's fallacy are respectively the overestimation and minoration of autocorrelation of a random independant and identically distributed (iid) sequence, often observed in gambling.

round. This suggest the existence of path dependence and may be caused by the hot-hand effect discussed before.

One important policy implication of such idea is that the take up could increase in the long run due to learning effect or simple reduction of ambiguity by integrating probabilities with outcomes. There is indeed empirical evidence of a greater probability to chose ambiguous options in repeated games more than in single-options game (Liu and Colman, 2009). As showed by Papon (2008) historical events could also have a great impact on the willingness to pay for reinsurance. The occurrence of a drought in the first years or before WII implementation thus could increase the willingness to pay for it. Arun and Bendig (2010) support this idea and show that the experience of specific hazards in the past, in particular the death or a severe illness of a household member or the inability to sell agricultural products in the past five years, increases the probability to use financial services in Sri Lanka. In contrast, Cole et al. (2011) and Stein (2011) do not find any clear evidence that having experienced a weather shock increases the uptake of insurance services.

The prospect theory of Kahnman and Tversky (1979) first make the hypothesis that differential utility due to a marginal increase of income is not the same shape in the gain and in the loss domain (reflexion effect). This loss aversion is backed by many empirical studies on smallholders in developing countries: for instance Gheyssens and Günther (2011) in Benin and Tanaka et al. (2010) who show that loss aversion (and not risk aversion) is correlated with low income in Vietnam. In top of the reflection effect, prospect theory also implies a biased weighting of probabilities that leads to underestimate bad outcome associated with low probability. Underweighting low probablities also seem to be verified in the context of farmers in rich as well as in developing countries. Sherrick et al. (2000) explored the rational behind rainfall beliefs and show that they are very poor for Illinois farmers and that it leads to understate (overstate) the likelihood of favourable (unfavourable) events. It leads the author to claim that it could

lower the values of weather prediction found with common methods if recipients begin with less accurate prior beliefs.Liu (2008) studied the effect of risk attitudes on adoption of Bt cotton cultivar in China. She found that risk aversion prevents farmers to adopt early but that farmers overweighting small probability events tend to adopt earlier. It can be explained by the emphasize they put on low risk / high damages events that could have devastating effect on the production capacity.

However in the context of index insurance, the only study we found does not seem to validate that approach but the exact opposite. Clarke and Kalani (2011) actually find that insurance take up decisions in a game are better explained by the underweighting of extreme events, instead of the overweighting prescribed by prospect theory.

3.2.3.6 Heterogeneous returns

There are various reasons for explaining the very low actual demand for rainfall insurance in the pilots projects, one of them is the heterogeneity of risk aversion but it explains very little the observed heterogeneity in insurance demand. Spinnewijn (2012) proposes that heterogeneity in risk perception rather that direct aversion could complexify the current state of the framework.

There is a large, above-mentionned, body of literature exploring the potential role of heterogenous capital detention on the existence of poverty trap (for instance Eswaran and Kotwal, 1990 on risk aversion behaviours and Rosenzweig and Wolpin, 1993 on consumption smoothing). Recent articles focused on heterogeneity of farming conditions, in order to look deeper at individual factors for low technology adoption. Considering the average farmer can indeed lead to underestimate discrepancies between those that have large bufferstocks (such as livestocks), those that are more or less risk averse etc. Heterogeneity of agricultural practices (Zeitlin et al., 2010) could explain the high variation of yields observed in developing countries (the chapter IV of this thesis illustrates this

stylized fact).

Suri (2011) tries to show how much heterogeneity of input return can explain its adoption among households without calling irrationality. According to the author, adoption depend on technology return and farmers' individual comparative advantage in a given technology. Farmers with high return could have great disincentives from adopting due to high unobservable costs (low supply, infrastructure constraints) as compared to farmers with low return that are more prone to adopt the technology. A third category emerges in that study, that is the marginal farmers, with zero return to the technology that continuously switch in and out of use from period to period. Such feature could partly be due to the particularity of the technology considered (hybrid maize) that have decreasing returns in time, since replanting seeds will lead to lower probability of detaining the the desired crop modified genes each year.

If heterogeneity in observed yields is not explained by weather spatial discrepancies, index-insurance will probably not able to help farmers to get out of poverty traps if it is not supplied with a high flexibility on the contract that would fit heterogeneous farmers needs.

3.2.4 Interaction with other risk management tools

The literature dinstiguishes between risk management (or mitigation: ex ante) and risk coping (ex post: dealing with a given income) methods following Alderman and Paxson (1992) and Dercon (2004b). Since Besley (1995) and Fafchamps (2003) already reviewed the literature on those informal methods, we only mention them briefly below. There is many ways to manage (income diversification and informal insurance) or cope with risks among them insurance. The results of recent RCT's treating about such tools are reviewed in Macours (2012).

We will review potentially complementary and substitute ex ante hedging tools, with a focus on the way they could be combined with WII implementation and their potential impact on WII demand.

One could also argue that offering insurance with complementary products, i.e. bundle it with credit or weather forecasts. Economies of scale thus makes administration costs, largely composed of screening and monitoring, drop and lower the product price. Distribution costs also could be limited if different products are supplied in remote areas by the same distribution networks, i.e. same agents of a unique micro-finance institution (MFI).

But it could also be argued that WII are competing with other risk pooling tools as it is stressed by the literature (Hill, 2011). One has however to recall the substitutability with informal risk management strategies (such as diversification) or with risk mitigation strategies such as infrastructures investments: for example irrigation projects that could be crowded out by insurance providing is also able to limit the scope of such products. It could also be due to the desincentive due to the fact that insurance is only supplied to unirrigated lands, as mentionned in the Mexican case studied by Fuchs and Wolff (2011a), that revealed very instructive. The authors also pointed out that only insuring a few crops could lead to lowering over-specialization leading to a lack of diversification (the crop choice as well as intercropping are among the most common risk management tool) in various crops and off-farm income. Less diversification means a decrease in the scope of the risk taken as well as it can lead to environmental damage since the crop insured are often high yielding varieties, grown with many inputs under monoculture, potentially deteriorating soil fertility.

3.2.4.1 Informal hedging methods

Even if often very costly, informal credit, storage and other informal risk management strategies, could be a substitute to insurance products, by being accessible to all households. Complementarity between formal and informal insurance was discussed very early (Arnott and Stiglitz, 1991). Supplying formal insurance to the poor could break existing ties and informal transfers (Bloch et al., 2008), such as family or friends. More recent works examine the precise re-

lationship between those two aspects. Mobarak and Rosenzweig (2012) showed that indian farmers are less prone to use formal insurance due to the participation in informal networks, only if those networks are used to cope with agregate risks. It seem that, in that case, index-based insurance is a complement as well as a subsititute to informal insurance. We will thus try to investigate how supplying formal risk pooling tool could harm informal networks.

However, poor households are shown to be less able to use such informal networks (Thomas et al., 2011) and remain less able to increase their average outcome by adopting new technologies that often lead to implementing riskier production strategies. Moreover, informal insurance is incomplete, leading to a lower average income as a consequence of ex ante risk-mitigating behaviours (Rosenzweig and Binswanger, 1993 and Barett and Carter, 2006) at high costs (as reviewed by Hill, 2011).

Risk management

Insurance could also replace other previous strategies of self-insurance: build-up savings, livestock but also by diversifying incomes (crop or activities diversification) or risks (intercropping, fragmentation of fields, to grow a mix of crops that embody differing levels of susceptibility to climatic shocks, delaying planting until rainfall patterns are more certain). These ex ante actions often come at high cost: Bliss and Stern (1982) showed that a two-week delay in planting following the onset of seasonal rains is associated with a 20 percent reduction in rice yields. Consumption-smoothing strategies including the use of savings and borrowing, transfers within networks to spread risk, and accumulation and decumulation of physical assets are other examples of risk management.

Risk coping

Farmers are encouraged to pool the risks ex post, *i.e.* after its realization, by smoothing consumption over time (such as storing, saving and borrowing) or

across households (risk pooling) but also by migrating temporarily or adjusting stocks such as mortgage of personal goods as anecdotically described in Collin et al. (2009). Providing formal insurance could have a negative impact on informal risk coping networks, as noted by Alderman and Haque (2007). Transfers from migrants, neighbours, family or friends are well described in Fafchamps (2007), and their relation to risk transfert products has recently been analyzed by Barnett et al. (2008).

Empirical evidence of low informal pooling

Empirical studies point out the very low use of livestock as a buffer stock (Fafchamps et al., 1998; Lybbert et al., 2004; Lentz and Barrett, 2004 and Unruh, 2008). Farmers smooth consumption by adjusting stocks of stored grain, which is also very costly, depending on material, weather and crops. For instance stored grain undergoes very high depreciation rates associated with different degradation sources, such as moisture, rodents and insects.

Kazianga and Udry (2006) only found evidence of a very low risk sharing among households facing climatic shocks in Burkina Faso. Pan (2009) found evidence that transfers have a minor impact on risk pooling. A potential explanation is that having recourse to informal credit could also be very costly (Collins et al., 2009).

Finally it could be argued that the cost of informal practices limit their attractiveness, especially compared to formal insurance products. Dercon et al. (2008) reviewed the studies which evaluate these costs, highlighting the need for health and crop micro-insurances. However, their potential substitution by insurance and informal risk mitigation methods could lower their take up, especially when information about their relative costs is not easily available.

3.2.4.2 Credit

It seem that the complementarity with input credit could play a great role in increasing the potential of insurance interest: by lowering the default rate and then the price as put forward by Dercon and Christiaensen (2011); by crowding-in input supply and demand as in Carter et al. (2009) and Carter et al. (2011), input use (Hill and Viceisza, 2009) and technology adoption.

Mineral fertilizers are costly and their supply is quite limited (in quantity and in quality) in West Africa. Assuming that the inexistence of competitive loan markets is partly due to risk issues, the combination of WII with input credits presents a double interest. First, it allows the use of the distribution networks of micro-finance institutions. Second, it mitigates the default risk for lenders, and ceteris paribus lowers the credit interest rate. Lowering the default rate reduces the potential adverse selection induced by loans supplied for a given interest rate.

One could think that providing WII bundled with other more attractive products, such as fertilizer credit, could increase take up and be a possible justification of joining intensification loans. However, as already discussed above, Giné and Yang (2009) showed evidence of a very low take up rate even in such scheme. This study is a randomized control experiment ran in Malawi, where WII was supplied to farmers jointly with an input loan for high-yielding hybrid maize and groundnut seeds. Insurance supply did not increase the loan take up rate and may even possibly lower it contrarily to what is found in Peru in Carter et al. (2007). Another potential, and already mentionned, explanation is the very low collateral coupled with a high default rate of farmers that undertake the loans in Malawi.

3.2.4.3 Seasonal forecasts

Weather forecasts being necessarly imperfect, they create a room for insurance products, by increasing the risk taken by farmers in the case of a bad forecast. In this context insurance product seem to be a rather good complement at first

sight: Carriquiry and Osgood (2011) shows the potential synergies between both products in a theoretical framework. However including weather forecasts in an insurance model also induces information problems, stemming from differential information between the principal (insurer) and the agents (farmers) that could create adverse selection issues. Insurer should fix a closing date and be aware of all forecasts available to farmers to bound this ex post adverse selection. Experience from East Africa tend to show that herders seem to update their belief when external forecasts are about below normal rainfall but do not when above normal rainfalls are forecasted (Lybbert et al., 2011). Jewson and Caballero (2003) proposed two major methods, using different kinds of forecasts, for the pricing of weather derivatives.

Forecasts also allow growers to make a more accurate trade-off between different cultivars, for instance between improved (genetic selection or manipulation) and traditional ones. Certain well evolved crops, with short physiological cycles are more costly than traditional ones. Being more resistant to drought periods, they are more productive in average for the farmer that takes the risk to buy it. They also make robust weather forecasts very attractive as showed by Roudier et al. (2012) in the case of millet in Niger. Climatic forecasts are a mean to improve farm risk management and crop choices, increasing risk taking [13].

Weather forecasting can be implemented in the very short run or on longer periods as such as seasonal forecasting that generally predict the type of the rainy season about three month before its beginning. There are two major type of worthwhile seasonal weather forecasts in western Africa, the first concerns the date of onset of the rainy season (see next section below), the second the cumulative rainfall during crop cycle (cf. IRI, Agrhymet and Ensemble previsions integrated into the Pressao programme in West Africa).

Globally, the El Niño Southern Oscillation (ENSO defining El Niño/La Nina years) phenomenon, originally observed by Peruvian farmers, is often cited as an

13. See Meza et al. (2008) for a literature review about forecasts valuation.

interesting way of improving WII products (e.g. for East Africa Osgood et al., 2007) by inciting the intensification of production during forecasted good rainy seasons. Carriquiry and Osgood (2011) evoque the need for an interlocking frame of insurance and reinsurance for allowing insurance premium to adapt each year to the ENSO weather forescasts.

The case of the onset of the rainy season

Late onset of the rainy season decreases its length and thus the probable total rainfall that will be used by crops. It is especially the case for monsoon climates, such as the ones in part of sub-saharan Africa and India, comon in the tropics. Sowing too early due to a false start of the rainy season could indeed be costly since resowing is associated with significant labor and sometimes seed costs. The major role of the onset of the rainy season in western Africa explains the particular attention given to this type of forecast in the literature (e.g. Marteau et al, 2011).

Rozenzweig and Binswanger (1993) already found that the delay of the monsoon in semi-arid India can have considerable negative effects on agricultural yields and profit. If the onset moves back from one standard deviation the profit would experience a 35 percent reduction for farmers with wealth holdings below the 25th percentile,. Giné et al. (2009) emphasize the issue of planting decision, and its impact on yield. They estimate the cost of a bad forecast to about 8 or 9% of the harvest higher probability of replanting.

3.2.4.4 International food prices insurance

WIIs are not protecting against covariate risks such as international prices variations that are crucial in the case of cash crops. Rainfall data indeed often reflect on detrended price time-series of a food crop produced locally, generally with a one year lag. Molini et al. (2010) studied a non-parametric safety net protecting against rainfall and international price shocks within the Ghanaian context.

The literature on the topic only considers cash crop price insurance (i.e. Hill, 2010 or Karlan et al., 2011) because food crops prices have an undefined impact on poor household depending on the consumption and harvest i.e. if they are net buyers or sellers (in the chapter II discussing the case of millet growers in Niger is a good example of such situation). One could however argue that a safety net could be designed in order to protect against both type of shocks, simply reducing variance of the price.

The comparison of weather vs. price risk is the object of the third chapter of this essay, applied to the cotton sector in Cameroon.

3.2.5 Supply side issues

3.2.5.1 Robustness to climate change

Due to global warming, there is an upward trend in local temperatures in almost every region. If the index of an WII includes temperatures but does not account for this trend, the calculation of the expected indemnity is biased. The continuation of an upward trend in temperature is very likely over the next decades, but the magnitude of this trend is highly uncertain. First, according to the last IPCC (2007) synthesis report, global warming in 2100 could be between 1.4 °C and 5.8 °C, depending both on climate sensitivity and on greenhouse gas emissions. Second, uncertainty on local warming could be even higher than that on global warming.

In some regions (e.g. West Africa) rainfall data also exhibit trends, which may be due to global warming, natural climate variability and/or changes in land use. The difficulty is higher than for temperature since in many regions, such as West Africa again, climate models disagree on whether global warming will entail an increase or a decrease in rainfall. Not only the average, but also the inter-annual variability of the rainfall level may change due to global warming. Moreover, the evolution in average rainfall or temperature augur major change in extreme events. For example, it is shown in Siebert and Ward (2011) that a 10%

change in the mean rainfall can lead to a change of order times 2 in the number of threshold-crossing low seasonal rainfall totals, even without invoking any change in the characteristics of the interannual variability.

Trends formulation in designing WIIs and are becoming overriding issues (Collier et al., 2009) because the increasing impact and variability of weather-related losses are clearly visible in the long run (Mills, 2005). Simple detrending methods based on past data are routinely used in WII design (Jewson and Penzer, 2005). However, they cannot correctly account for complex non-stationarities, like the succession of humid and dry decades in the Sahel (Dai et al., 2004). Nor can they deal with the above-mentioned uncertainty with regard to future local climates. Hence, the presence of a trend in the data used to build the index can lead to private suppliers turning away from local markets. This was the case in Morocco (Skees et al., 2001) in spite of the twenty years of precipitation data and the provision promises made by the government.

Then, the duration of the service provision is dependent upon the long run solvability of the insurer and thus its ability to compensate for increasing risks. This point is even more crucial for insuring and re-insuring extreme events as such as catastrophe insurances (cat bonds or other weather derivatives) or for regions that are particularly hit by climate change. Hochrainer et al. (2007) tested the robustness of a WII in Malawi using climate forecasts generated by the MM5 and PRECIS regional climate models. They questioned its long run sustainability until 2080.

Finally it seems that renegociation of the contract to is the only way to get rid of trend issues. It is however associated with high transaction costs, a significant increase in contract complexity and related ambiguity for buyers. Such potential modification issues were also found during the Mexican experience, the threshold were not subjected to any modifications despite the substantial amount of research on drought resistant crop undertaken while the program was running, according to Fuchs and Wolff (2011a).

Yield distributions is approximated by normal distribution, or distribution bounded at zero (such as the lognormal, Beta or Weibull distributions as in De Bock et al., 2010), however the joint distribution of yield and weather is scarce in the literature, except for a recent contribution of Woodward (2011) who inquires Weibull distribution of yields conditional on weather events. Bokusheva (2011) studies the dependence in yield and weather joint distributions and shows that the relationship between weather and crop yields is not fixed and can change over time. Using regression analysis and copula approach, she reveals statistically significant temporal changes that put into question current methodology of the WII design.

3.2.5.2 Spatial variability of climate and the scaling of insurances

Covariate vs. idiosyncratic shocks

There exists different sources of risk: price fluctuations (covariant, at least when markets are integrated), climatic shocks (intermediate risk) and individual shocks (totally idiosyncratic). Covariant shock can only be assumed by a formal insurer that could use risk layering to pool highly (spatially) correlated risks as long as informal insurance is playing the role of smoothing indiosyncratic consumption shocks at a lower geographical scale. Weather insurance would in this case only be used for intermadiary risks (Mahul and Skees, 2007).

Optimal spatial scale

Risk covariance is a major source of insurance market failure in low income countries and explains the high subsidization rate of agricultural insurances (Barnett et al., 2008).

Spatial risk correlation is a major impediment of WII implementation. It increases income variance for the insurer, hence the insurance premium. The only ways to lower the variance of income for a given spatial variability of shocks are to insure a larger area, allowing a better pooling, and/or to transfer a part of the

risk to an international insurer or reinsurer through risk layering. For instance, reinsurance was needed for drought insurance in Ethiopia. In this Ethiopian context, Meze-Hausken et al. (2009) studied insurance provision on 30 years and 15 stations with an HDA and conclude that pooling over the country limits the need for capital requirement.

Spatial variability reduces this problem but increases what we called spatial basis risk at the end of section 3.1.3.2., for a given weather station density. There is thus a trade off between the cost of meteorological station installation and the level of the basis risk.

In practice the maximum distance to the nearest weather station is set at between 20 (in Senegal) and 30 km (in Malawi, in most cases in India and in Canada according to Hartell et al., 2006). Insurers indeed often use the 20km rule, meaning that the rain gauge or weather observation should not be situated at more than 20km from the individual agricultural plot.

However there are many arguments contradicting this rule. For instance, in some regions the spatial variability of weather is significant even at 10 km or less. Gommes (2012) shows that in Ethiopia, depending on the period and the region considered, the distance between neighbouring stations and the one considered should be reduced to between 0 and 0.77 km in order to account for 90% of the variance of rainfall estimates. It is also probable that horizontal and vertical gradient magnitude are different under many climates (Greatex, 2012). This calls for increasing the density of rain gauges, which would however substantially raise WII management costs (installation, operation and maintenance).

In most WIIs, only the closest weather station ('closest station' rule) is taken into account to calculate the indemnity. However, interpolation methods can also be used to infer the meteorological index realization over a geo-referenced grid (Paulson and Hart, 2006). Method complexity differs from simple and deterministic ones: simple linear weighting, decreasing with distance of stations around or squared weighting like the Inverse Distance Weighted Averaging (IDWA), to

stochastic ones: Kriging based on Gaussian multivariate statistical distributions.

3.2.5.3 Institutional aspects

There are also many institutional barriers restraining WII implementation. In particular it is crucial that the country institutional framework and regulatory environment be adapted to private insurers, e.g. allowing contract enforcement at low cost (Carpenter and Skees, 2005 and Henderson, 2002). South Africa, India (Indian Insurance Regulatory and Development Authority, IRDA), Peru and the Philippines (Insurance Commission of the Philippines: Insurance Code of 1974) adapted their respective legislation to facilitate private micro-insurance initiatives (Wiedmaier-Pfister and Chatterjee, 2006). However, a total lack of contract law enforcement in Malawi - where contract farming is not particularly defined from a juridical point of view - did not prevent WII implementation. On the other hand, in West Africa index-based insurance was not allowed for a long time by the regulation authority[14] and local insurance companies are often not used to work with the agricultural sector.

Finally, a very important detail we did not mention is the securization of the meteorologcial station network, that simply could be covered by a simple sleave in order to increase the probability of indemnification...

3.3 Conclusion

The research agenda about insuring developing countries' households against climatic risk is about improving five principal points:

14. Western African countries have a two stage regulatory system for insurance: a Regional Regulator based in Gabon, responsible for regulating the insurance market for over 14 countries of West and Central Africa and the National Divisions of Insurance. At the regional level, insurance is entirely regulated by CIMA (Conférence Inter-africaine sur le Marché des Assurances) that is in charge of approving any new insurance company and insurance product in its member states. CIMA has representatives in each Member State. They are normally hosted in the Ministry of Finance or of Treasury. The National Division is in charge of pre-approving any insurance product and new licenses. The CIMA Code dedicates an entire chapter to Agricultural Risks (Livre I/Titre II/Chapitre IV).

- weather index design depending on the availability of underlying data and weather forecasts, including trends apprehension and downscaling methods.
- optimal geographical zone of WIIs and the relation with rain gauges network density.
- quantification of the gains for farmers, by estimating their risk aversion and the extent of modifications in cultivation practices.
- acuity of cultural and institutional matters in risk pooling products, that largely depends on field specificities, requiring close cooperation with local stakeholders.

We can ask ourselves whether such products are adapted to agent showing high risk and/or ambiguity aversion or to agents who may have intensive and creditworthy productions and thus could invest in costly inputs. Second, risk diversification being very low for poor farmers, their incentive to buy such products regarding their low solvency, could be substantially limited by a relatively high proportion of non-rain-related losses. Third, one has to recall that implementation issues of such programs still depends on its acceptability on the field that seems to be driven by psychological and educational factors facilitated by field study and communication programs.

Finally, a large set of possibilities emerged in the recent developement of such products in the design (index choice, indemnification rate, geographical cover and zoning, subsidization level), the implementation (institutional arrangement: supplying level [15] and distribution channels, bundled with input credit, mandatory or not) and the diversity of products. Those possibilities should be considered before implementing a WII scheme. It goes by considering the goals of the product in deeper terms. Establishing a safety net, offering subsidized insurance to help farmers escaping a poverty trap situation is very different from elaborating a programme protecting against catastrophic events, such as heavy droughts, occuring

15. Insuring producers' organization may be more easy, decreasing the fixed costs, entity with legal authority to contract with banks, easier than with smallholder farmers, thay can use their extensive relationship with primary cooperatives and farmers to serve as enforcers of the loan/insurance contracts, minimizing default risk. Ex: Malawi, EPIICA project in Ethiopia.

every 25 years.

CHAPTER 4

EX ANTE EVALUATION FOR MILLET GROWERS IN NIGER

This chapter is based on the following article: Antoine Leblois, Philippe Quirion, Agali Alhassane & Seydou Traoré, Weather index drought insurance: an ex ante evaluation for millet growers in Niger, under revision at *Environmental and Resource Economics*.

Abstract

In the Sudano-Sahelian region, which includes South Niger, the inter-annual variability of the rainy season is high and irrigation is scarce. As a consequence, bad rainy seasons have a massive impact on crop yield and regularly entail food crises. Traditional insurance policies based on crop damage assessment are not available because of asymmetric information and high transaction costs compared to the value of production. We assess the risk mitigation capacity of an alternative form of insurance which has been implemented at a large scale in India since 2003: insurance based on a weather index. We compare the capacity of various weather indices to increase the expected utility of a representative risk-averse farmer. We show the importance of using plot-level yield data rather than village averages, which bias results due to the presence of idiosyncratic shocks. We also illustrate the need for out-of-sample estimations in order to avoid overfitting. Even with the appropriate index and assuming substantial risk aversion, we find a limited gain of implementing insurance, roughly corresponding to, or slightly exceeding, the cost observed in India of implementing such insurance policies. However, when we treat the plots with and without fertilisers separately, we show that the benefit of insurance is slightly higher in the former case. This suggests that insurance

policies may increase, although to only a limited extent, the use of risk-increasing inputs like fertilisers and improved cultivars, hence average yields, which are very low in the region.

4.1 Introduction

Since the 1970s, the Sahel, including Niger, has suffered from severe food crises, partly because of droughts which occurred, particularly in 1973, 1984, 2004 and 2009. Moreover, because of the very high spatial variability of rainfall in the Sahel (Ali et al., 2005), many villages suffer from drought even in years which are not labeled as dry at the regional or national level. This situation contributes to recurrent malnutrition, especially in Niger (FEWSNET, 2010).

Food insecurity risks will probably increase over the coming decades because of population growth and climate change. On the latter point, although the impact of global warming on rainfall in this region is uncertain, the rise in temperature will most likely harm cereal yields (Roudier et al., 2011). Not only do droughts reduce yields when they occur, but they reduce the adoption of potentially yield-increasing agricultural practices (e.g. fertilisers, improved cultivars, etc.). Indeed, even if some of these practices may improve yields and farm income when averaged over several years, they may be detrimental in case of drought through increased input costs without significantly increased yields.

In this context, tools hedging farmers against droughts would be welcome. Unfortunately, traditional agricultural insurance policies cannot efficiently shelter farmers because they suffer from an information asymmetry between the farmer and the insurer, creating moral hazard situations and thus a need for costly damage assessment. An emerging alternative is insurance based on a weather index, which is used as a proxy for crop yield. In such a scheme, the farmer, in a given geographic area, pays an insurance premium every year, and receives

an indemnity if the weather index of this area falls below a determined level (the strike). Index-based insurance does not suffer from the above-mentioned shortcoming: the weather index provides an objective and relatively inexpensive proxy for crop damages. However, its weakness is the basis risk, i.e. the imperfect correlation between the weather index and the yields of farmers contracting the insurance. The basis risk can be considered as the sum of two risks: first, the risk resulting from the index not being a perfect predictor of yield in general (the model basis risk). Second, the spatial basis risk: the index may not capture the weather effectively experienced by the farmer, all the more so if the farmer is far from the weather station(s) that provide data on which the index is calculated.

A rapidly growing body of literature has investigated the impact of crop insurance based on weather indices in developing countries: Berg et al. (2009) in Burkina Faso, De Bock (2010) in Mali, Chantarat et al. (2008) in Kenya, Molini et al. (2010) in Ghana and Zant (2008) in India. See Leblois and Quirion (2012, cf. Chap. 3) for a survey. Ex-post studies (Fuchs and Wolff, 2011; Stein, 2011; Hill and Viceisza, 2010; Cole et al. 2009; Giné and Yang, 2009 and Giné, Townsend, and Vickery, 2008) are still limited due to the recent development of such products. However, many recent reports describe existing programs (e.g. Hellmut et al., 2009 and Hazell et al., 2010).

This article aims at quantifying the benefit of a rainfall index-based insurance. We take advantage of a recent database of plot-level yield observations matched with a high density rain gauge network. We show that using village average yield distribution induces an upward bias in the estimation of benefits. Ex-ante simulations of insurance contracts indeed show that the insurance gain is limited by intra-village yield variations. We also demonstrate, in this particular case, the necessity to run out-of-sample estimations of the insurance impact in order to control for overfitting when calibrating its parameters. Such estimations validate the use of the most simple index, i.e. the cumulative rainfall over the growing season. Lastly, the database allows us to test whether and how much index-

insurance may incite farmers to use more fertilisers by distinguishing between traditional technical itineraries and plots where intensification was encouraged. The best insurance contract however proved to have limited impact in terms of incentive towards intensification.

The rest of the article is organised as follows: we first describe the data and methods (section 4.2), then the results (section 4.3), and conclude with a last section. An annex provides additional results and robustness checks.

4.2 Data and method

4.2.1 Study area

Niger is the third producer of millet in the world, after India and Nigeria. Millet covers more than 70% of its cultivation surface dedicated to cereal (FAO, 2010) and is produced almost exclusively for internal consumption. In the context of rainfed agriculture and due to the dryness of the region, water availability is the major limiting factor of millet yields. The prevalence of millet, especially the traditional Haini Kiere, a photoperiodic and short cycle cultivar studied in this article, is due to its resistance to drought.

We study the Niamey squared degree area (Figure 4.1), because it is equipped with an exceptionally dense network of rainfall stations. Such infrastructure is needed in a region where spatial variability of rainfall is significantly high. We also dispose of seven years of yield observations (2004-2010) in ten villages. Yield observations have been collected by Agrhymet for a minimum of 30 farmers, randomly picked from each of the ten villages in 2004 and then annually surveyed in their plots until 2010. Yields were estimated using standard agronomic practices, i.e. using three distinct samples of plot production, weighting grains, counting the grains per ear of millet and the number of ears per surface unit. Every plot is situated at less than 2 kilometres from the nearest rainfall station, which is likely to limit the spatial basis risk mentioned above. Some additional informa-

tion about the database can be found in previously published articles using the same data (Marteau et al., 2011).

In 2004, all plots were cultivated under traditional technical itineraries. In particular, very few mineral fertilisers, chemical herbicides or pesticides were used. From 2005 onwards, farmers continued to follow this traditional technical itinerary on a first plot, labeled the 'regular' plot, but freely received mineral fertilisers [1] for application on a second plot together with agronomic and technical advice from interviewers. The second plot is always situated in the immediate vicinity (within 50 meters) of the first.

It has to be mentioned that given the fact farmers have been studied for 7 years, a so-called "Hawthorne effect" could arise: farmers might have changed their behaviour by virtue of the fact that they are being studied for several years. For instance, they might adopt the technical itineraries recommended by agronomists, more than other farmers. Unfortunately, little can be done to detect or mitigate this effect.

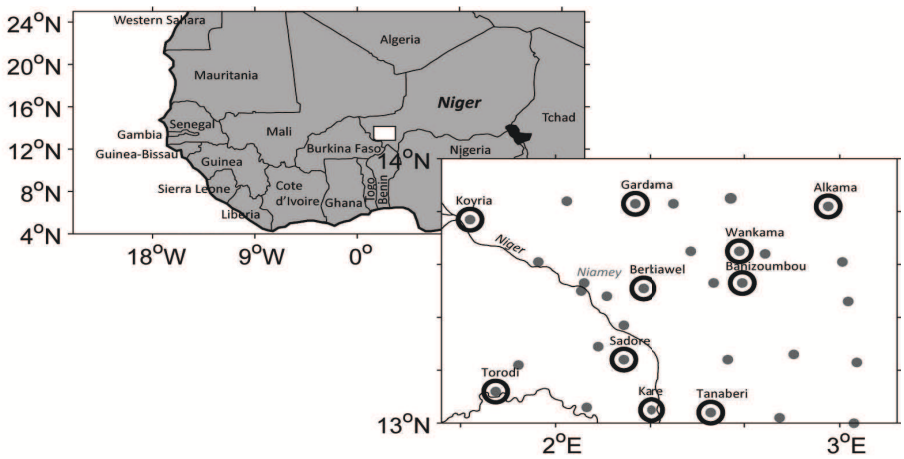

Figure 4.1: Rain gauges network and investigated villages (circled in black) across Niamey squared degree.

Table 4.I displays the summary statistics of the regular plot. There is a high

1. 50 kg per hectare (25 at hoeing and 25 when the plant runs to seed) i.e. more than the minimal level required (20 kg/ha) but less than the maximum (60 kg/ha) according to Abdoulaye and Sanders (2006).

annual variability of yields across villages, with a coefficient of variation [2] (CV) of .33. Intra-village annual yield variation is however even higher (average CV=.55 over the ten villages), inducing a likely basis risk. It is due to a significant occurrence of idiosyncratic shocks, partly explained by insect ravages [3] that take place in more than 40% of the whole surveyed farmers' sample.

Table 4.I: Summary statistics: regular plots (2004-2010)

Variable	Mean	Median	Std. Dev.	CV	Min.	Max.	N
Plot yields (kg/ha)	596	500	383	.64	0	3 100	1 780
Plot income (FCFA/ha)	108 176	91 392	68 075	.63	0	566 634	1 780
Other crops income (FCFA)*	3 873	0	8 557	2.21	0	81 886	1 780
Other farm and non-farm incomes (FCFA)*	4 705	2 632	6 821	1.45	0	5 8333	1 780
Livestock and capital stock (FCFA)*	75 317	27 111	154 580	2.05	0	1 359 674	1 780

* Per household member, only available for 2006.

We value production at the millet post-harvest consumer price in Niamey over the 7 years, using monthly data from the SIM network [4] in order to compute income for each plot (*Plot income*). Fertiliser prices are taken from the 'Centrale d'Approvisionnement de la République du Niger'.

We use a 2006 socio-economic survey to estimate the capital stock, as well as farm and non-farm incomes. *Other crops income* is the value of declared production from other plots cultivated in 2006. *Other farm and non-farm incomes* are the 2006 whole farm income plus other incomes from declared activities: e.g. derived from livestock (fattening), fisheries, hunting, craft or salary earned by the grower. Monthly livestock prices over the period considered are taken from SIM Bétail, Niger: *Système d'Information sur les Marchés à Bétail.* Farm capital is quite limited and mainly constituted of plough and carts. The two last variables of Table 4.I (*Other farm and non-farm incomes* and *Livestock and capital stock*) are computed per number of household members in order to estimate the actual share of income and stock available to the grower.

2. The CV is the standard deviation (std. dev.) divided by the mean.

3. We check that their occurrence is not significantly correlated with rainfall in the Annex B.3.3 (Table B.V).

4. Millet prices are the average prices of Katako market in Niamey, for the October-January period each year (94% of the sample has already been harvested at the end of October); the SIM network is an integrated information network across 6 countries in West Africa (resimao.org).

4.2.2 Indemnity schedule

Insurance indemnities are triggered by low values of an underlying index that is considered to explain yield variation. The indemnity is a step-wise linear function of the index with 3 parameters: the strike (S), i.e. the threshold triggering indemnity; the maximum indemnity (M) and λ, the slope-related parameter. When λ equals one, the indemnity is either M (when the index falls below the strike level) or 0. We thus have the following indemnification function depending on x, the meteorological index realisation:

$$I(S, M, \lambda, x) = \begin{cases} M, & \text{if } x \leq \lambda.S \\ \frac{S-x}{S-\lambda.S}, & \text{if } \lambda.S < x < S \\ 0, & \text{if } x \geq S \end{cases} \tag{4.1}$$

We took this functional form because, to our knowledge, almost all index-based insurance, presently implemented or studied ex ante, were based on this precise contract shape except two dual strike point contracts: the BASIX contract launched in Andhra-Pradesh (Giné et al., 2008) and the contract simulated in De Bock et al., 2010.

4.2.3 Index choice

We first reviewed different indices that could be used in a weather index insurance, from the simplest to more complex ones. We tested the number of big rains (defined as superior to 15 and 20 mm.) often quoted by farmers (Roncoli et al., 2002) as a good proxy of yields, the number of dry spell episodes in the season, the Effective Drought Index (EDI, Byun and Wilhite, 1999) computed on a decadal basis, the Available Water Resource Index (AWRI, Byun and Lee 2002) and the Antecedent Precipitation Index (API, Shinoda et al., 2000, Yamagushi and Shinoda, 2002). Those indices are not presented in this paper because they provide a lower gain than those we retained or no gain at all, expressed in certain

equivalent income.

The indices retained in the paper are listed below by increasing complexity. The first is the cumulative rainfall (CR) over the crop growth period, cutting off low daily precipitations ($<$ .85 mm following Odekunle, 2004) that probably evaporated entirely. Computing this index, as well as the next ones, necessitates determining the beginning of the crop growth period. Using the actual sowing date to determine the beginning of the crop growth period in an insurance contract is difficult because it cannot be observed costlessly by the insurer. Thus we compare two growth phase schedules: the one observed referred to as *obs* and the one simulated following Sivakumar (1988), referred to as *siva* in the paper. The onset of the simulated growing season is triggered by a cumulative rainfall of over 20 mm in two days followed by one month without seven consecutive days of dry spells (with no significant rainfall, i.e. superior to .85 mm) after 1 May. The offset is the day that follows 20 consecutive days without rainfall after 1 September.

We then consider a refinement (referred to as BCR) of each of these simple indices by bounding daily rainfall at 30 mm. corresponding to water that is not used by the crop due to excessive runoff (Baron et al., 2005).

A further refinement is to distinguish various phases during the crop growth period in the calculation of the index. Hence we use a weighted average of cumulative rainfall during these phases, following Alhassane (1999) and Dancette (1983). Weights of each period represent water needs as a share of available water, approximated by cumulative rainfall during the period, in order to represent the contribution of rainfall of each phase to crop growth. This index is thus very similar to the Water Requirement Satisfaction Index (WRSI), the most commonly used index in the literature. The indices are referred to as $WACR$ when daily rainfall is not bounded and $WABCR$ when it is. Table 4.II displays the descriptive statistics of the above-mentioned indices over the study period. The trade-off between accuracy and the simplicity of the index, brought up by emerging literature (Patt et al., 2009), suggests to use the most transparent index

among indices reaching similar outcomes.

Table 4.II: Summary statistics: growing season rainfall indices (2004-2010)

Variable	Mean	Std. Dev.	Min.	Max.	N
CR_{obs} (mm)	452.754	120.359	61.469	685.199	1 780
BCR_{obs} (mm)	397.417	99.95	61.469	565.468	1 780
CR_{siva} (mm)	475.072	95.432	263.816	735.89	1 780
BCR_{siva} (mm)	417.058	73.524	262.199	574.062	1 780
$WACR_{siva}$ (mm)	241.332	62.214	33.543	365.543	1 780
$WABCR_{siva}$ (mm)	275.767	75.026	33.543	453.566	1 780

4.2.4 Parameter optimization

The literature offers multiple different objective functions, such as the semi variance (or downside risk as used in Vedenov and Barnett, 2004) or the mean-variance criterion. The former only takes risk (variance minimization) into account, without considering the trade-off with a reduction of average consumption level (as emphasized by Osgood and Shirley, 2010). The mean-variance criterion accounts for both the consumption level and the risk, but it weights risk with an ad-hoc parameter. We finally retained the power or Constant Relative Risk Aversion (CRRA) utility function in order to compute the variation of certain equivalent income (CEI). Power utility functions have the advantage of facilitating the comparison of results for different risk aversions and of using a parameter that has been estimated in many contexts, in particular in many developing countries. CRRA appears appropriate to describe farmers' behaviours according to Chavas and Holt (1996) or Pope and Just (1991). Moreover, Andreoni and Harbaugh (2009) who tested the robustness of 5 of the most often used hypotheses in the field of utility, found that "the expected utility model does unexpectedly well" and that "if a researcher would like to impose the simplification of CRRA utility, this likely comes at a small cost on average". We thus consider the following utility function:

$$U(Y_i) = \frac{(W_0 + Y_i)^{(1-\rho)}}{(1-\rho)} \tag{4.2}$$

Where Y_i is a individual-year income observation, the individual being the plot or the village depending on the simulation under consideration, W_0 is the non-millet related income and ρ is the relative risk aversion parameter. In sections 4.3.1 and 4.3.2, we use yields, in kg per hectare, as a proxy for income. This neglects the use of purchased inputs such as mineral fertilisers but their use is very limited[5]. It also neglects the inter-annual variations of prices, the impact of which on insurance gain is negligible, as shown in Table B.III in the Annex B.3.1. Section 4.3.3 is devoted to the introduction of millet and input prices in the analysis. Hence in this section, Y_i is the income in monetary units. The certain equivalent income corresponds to:

$$CEI(\tilde{Y}) = \left((1-\rho) \times EU(\tilde{Y})\right)^{\frac{1}{1-\rho}} - W_0, \qquad \tilde{Y} = \{Y_1, ..., Y_N\} \tag{4.3}$$

With $EU(\tilde{Y})$ the expected utility of the vector of income realizations ($\tilde{Y}$). The non-millet related income (W_0) is considered as certain, following Gray et al. (2004). It lowers insurance gains in terms of certain equivalent income by increasing the certain part of total income (cf. Table B.IV in the Annex). It also allows the premium to be superior to the lowest yield observation. The 2006 socio-economic survey shows that the average for capital detention, *Other farm and non-farm incomes*, is more than half the average income for one hectare of production (as displayed in Table 4.1). This is consistent with Abdoulaye and Sanders (2006) who found millet representing about 40 to 60% of total revenues. Nevertheless, there is pronounced heterogeneity among such incomes (CV of about 2[6]), half the farmers having less than 27 000 FCFA of livestock (and 75% of them having less than the average level), which leaves them without any buffer stock for facing weather and production shocks. Looking at the median

5. Plots with encouragement to fertilise will be considered in section 4.3.3.

6. Due to the large number of livestock Fulani or Tuareg people (representing 12% of the sample) often own.

of these variables to get the situation of an average millet grower, other incomes represent about 32.5% of the income for one hectare of millet. We thus set W_0 at a third of the average yield (about 200 kg of millet) multiplied by the average millet price over the period considered. However, when running robustness checks to the calibration of this parameter, the scope of the results does not change dramatically and the order of indices remains the same (as displayed in Table IV in section B.3.2 in the Appendix). We tested a range of values for the relative risk aversion parameter from .5 to 4. This range encompasses the values usually used in development economics literature (Coble et al., 2004; Wang et al., 2004; Carter et al., 2007 and Fafchamps, 2003; see Cardenas and Carpenter, 2008 for a review of econometric studies that estimate this parameter). A relative risk aversion of 4 may seem high but empirical estimates of relative risk aversion indicate a wide variation across individuals. If, therefore, insurance is not compulsory, only the most risk-averse farmers are likely to be insured (Gollier, 2004).

The insurance contract parameters S, M and λ are optimized in order to maximize the certain equivalent income of risk averse farmers given by equation (3) with the following income after insurance:

$$Y^I = Y(x) - P(S^*, M^*, \lambda^*, x) + I(S^*, M^*, \lambda^*, x) \tag{4.4}$$

Y^I is the income after indemnification, Y the income before insurance, P the premium, I the indemnity and x the rainfall index realisations associated with each plot. We used a grid optimization process to maximize the objective function and bounded the premium to the minimum endowments. The loading factor is a percentage of total indemnifications over the whole period (β, fixed at 10% following a private experiment that took place in India, cf. section 4.3.4), plus a transaction cost (C) for each indemnification, fixed to one day of rural labor wage.

$$P = \frac{1}{N}\big[(1+\beta) \times \sum_{i=1}^{N} I_i\big(S^*, M^*, \lambda^*, x_i\big) + C \times \sum_{i=1}^{N} F_i\big], \text{ with } F_i = \begin{cases} 1 \text{ if } I_i > 0 \\ 0 \text{ if } I_i = 0 \end{cases} \tag{4.5}$$

4.3 Results

For the first two parts of this section we will consider only regular plots (1780 observations), on which traditional technical itineraries are followed (for the period 2004-2010). The last part will compare different technical itineraries for the 2005-2010 sub-period for which data for both plots (regular and 'encouragement' plots, 2952 observations) are available.

4.3.1 Plot-level vs. aggregated data

We show that calibrating insurance parameters on village average yield can have undesired consequences due to high intra-village yield variations. Calibration on plot-level data allows taking intra-village yield variations and idiosyncratic shocks into consideration, which is rarely the case due to a lack of such plot-level data.

In tables 4.III, 4.IV, and 4.V we present the average farmer's gain from insurance in certain equivalent income for each index, respectively calibrated for the whole sample (using the entire vector with N=1780), then each village's average yields (N=60) and lastly testing this latter calibration on the whole sample. This is done to test whether the calibration of parameters significantly differs when considering intra-village yield variations. This CEI gain when insured (CEI^I) is expressed in percent of the CEI without insurance. The CEI gain in percent is:

$$\frac{CEI^I - CEI}{CEI} \tag{4.6}$$

The indemnity schedules of the CR_{siva} contract and the parameter calibrations for all indices are respectively displayed in Figure 1 and Tables 1 and 2 of Appendix B. The premium level goes from 16.8 ($\rho = .5$) to 24.2 kg ($\rho = 4$) of millet that represents about 5% of average yield, which seems affordable but is significant when compared to insurance gain.

Table 4.III: Average income gain of index insurance *calibrated on the whole sample* (N=1780)

	$\rho = .5$	$\rho = 1$	$\rho = 2$	$\rho = 3$	$\rho = 4$
CEI gain of CR_{obs}-based insurance	.00%	.24%	.94%	1.93%	3.08%
CEI gain of BCR_{obs}-based insurance	.00%	.28%	1.27%	2.40%	3.68%
CEI gain of CR_{siva}-based insurance	.00%	**.31**%	1.27%	2.62%	4.65%
CEI gain of BCR_{siva}-based insurance	.00%	.29%	**1.52**%	**3.13**%	**5.21**%
CEI gain of $WACR_{siva}$-based insurance	.00%	.16%	.95%	2.06%	3.52%
CEI gain of $WABCR_{siva}$-based insurance	.00%	.23%	1.38%	2.92%	4.95%

Table 4.IV: Average income gain of index insurance *calibrated on village average yields values* (N=60)

	$\rho = .5$	$\rho = 1$	$\rho = 2$	$\rho = 3$	$\rho = 4$
CEI gain of CR_{obs}-based insurance	.00%	**.27**%	1.20%	2.64%	4.48%
CEI gain of BCR_{obs}-based insurance	.00%	.23%	1.06%	1.96%	2.87%
CEI gain of CR_{siva}-based insurance	.00%	**.27**%	1.15%	2.57%	4.41%
CEI gain of BCR_{siva}-based insurance	.00%	.26%	**1.44**%	**2.95**%	**4.81**%
CEI gain of $WACR_{siva}$-based insurance	.00%	.11%	1.00%	2.27%	3.91%
CEI gain of $WABCR_{siva}$-based insurance	.00%	.13%	.85%	1.76%	2.91%

Table 4.V: Average income gain of index insurance *calibrated on village average yields values and tested on the whole sample (N=1780)*

	$\rho = .5$	$\rho = 1$	$\rho = 2$	$\rho = 3$	$\rho = 4$
CEI gain of CR_{obs}-based insurance	.00%	.24%	.91%	1.71%	2.48%
CEI gain of CR_{obs}-based insurance	.00%	.08%	1.26%	2.32%	3.36%
CEI gain of CR_{siva}-based insurance	.00%	**.31**%	1.25%	2.54%	4.30%
CEI gain of CR_{siva}-based insurance	.00%	.29%	**1.52**%	**3.04**%	**4.92**%
CEI gain of CR_{siva}-based insurance	.00%	.16%	.93%	1.80%	2.61%
CEI gain of CR_{siva}-based insurance	.00%	.12%	1.06%	2.38%	4.16%
Variations in CEI gain compared to calibration on plot-level sample					
CR_{obs}-based insurance	n.a.	-2.55%	-2.93%	-11.41%	-19.68%
BCR_{obs}-based insurance	n.a.	-71.26%	-.72%	-3.19%	-8.58%
CR_{siva}-based insurance	n.a.	-.06%	-1.14%	-2.76%	-7.50%
BCR_{siva}-based insurance	n.a.	-.39%	-.18%	-2.90%	-5.41%
$WACR_{siva}$-based insurance	n.a.	.02%	-1.34%	-12.56%	-26.08%
$WABCR_{siva}$-based insurance	n.a.	-46.02%	-22.87%	-18.23%	-15.99%

n.a.: not applicable.

The main results are the following. Firstly, none of the tested insurance contracts are found to increase CEI when assuming the lowest level of risk aversion

(.5). The explanation is that with such a low risk aversion, the potential benefit of insurance is too low to compensate the loading factor plus the transaction cost. With higher levels of risk aversion, CEI does increase but by a very modest margin (+5.21% at most).

Secondly, more complex indices do not always lead to a larger gain: bounding daily rainfall to a maximum of 30 mm (BCR) performs better than simple cumulative rainfall but taking the weighted averages does not increase relative CEI gains.

Thirdly, the insurance gain is higher when dealing with simulated crop growth cycles than with observed ones. Such a peculiar result could be explained by the use of water reserves constituted before the actual sowing date and that are available in the soil. As shown by Marteau et al. (2001) the observed sowing date occurs, in most cases, after the onset of the rainy season. This result also shows that costly observation of sowing date does not seem to be needed [7].

As shown by the comparison of Tables 4.III and 4.V, taking the average value for each village leads to a miscalculation of insurance parameters with a concave utility function that also depends on intra-village income distribution. In our case the misapprehension of village yield distribution leads to an over-insurance situation, i.e. a higher indemnity M and thus a premium 25% higher on an average: cf. Tables I and II in the Appendix B. The presence of yield heterogeneity within villages modifies the effective gain of an insurance calibrated on village averages. The average loss from average yield calibration is significant (12%) but its size depends on the index. It stresses the usefulness to calibrate insurance parameters on observed yields at the plot level.

7. The emergeance of new information technology can make the collection of such information easier. Cell phones could, for instance, be used for reporting sowing dates with high frequency and accuracy at low cost. Those technologies, even if very cheap, would rely on the availability of cell phones in each community, and were only available to 4% of the population of Niger in 2006 according to Aker (2008). Moreover, even when technologies are cheap, their price can still be significant in regards to the low area cultivated and the budget constraints of smallholders that are studied in this article

4.3.2 Need for cross-validation

In the previous section, we optimized the parameters and evaluated the insurance contracts on the same data. This creates a risk of overfitting due to the fact that parameters will not be calibrated and applied to the same data in an actual insurance implementation. We can identify such a phenomenon by running a cross-validation analysis (as do Vedenov and Barnett, 2004 and Berg et al., 2009). We thus run a 'leave one (village) out' method, optimizing the 3 parameters of the insurance contract for each village using data from the 9 other villages. We apply this method for each of the three different indices and on the whole sample of farmers' regular plots. As shown by Figures B.2 to B.7 in the Appendix, the strike level is relatively robust across out-of-sample estimations and comparable to the in-sample case. However the maximum indemnity M is less robust and we will show later that this causes severe reductions in CEI gain.

In the out-of-sample estimations the insurer can be better off or worse off than in the corresponding contract optimized with the in-sample method [8]. Table 4.VI shows the gain in CEI when the insurer can either endure losses or obtain benefits, due to the bad calibration that arises from the fact that insurance is assessed and calibrated on different datasets. It is thus important to keep in mind that in a real insurance project, either the insurer or the farmers would suffer from this (partly unavoidable) bad calibration. In our case study, calibrating insurance parameters on the nine other villages leads to heightening the variation of the insurer's benefit across different calibrations.

8. This is also the case in Berg et al. (2009, Fig. 4)

Table 4.VI: Average CEI gain of leave-one-(village)-out calibration index insurance, with insurer gain or losses.

	$\rho = .5$	$\rho = 1$	$\rho = 2$	$\rho = 3$	$\rho = 4$
CEI gain of CR_{obs}-based insurance for farmers	-0.175%	-.02%	-.23%	-.28%	-.33%
Insurer gain (kg/ha) with CR_{obs}-based insurance	1.34	2.48	3.47	3.71	2.72
Insurer gain (perc. of total indem.) with CR_{obs}-based insurance	16.29%	17.69%	20.15%	23.79%	18.90%
CEI gain of BCR_{obs}-based insurance for farmers	-0.177%	-.41%	.28%	.80%	1.31%
Insurer gain (kg/ha) with BCR_{obs}-based insurance	0.44	4.10	3.95	3.20	3.01
Insurer gain (perc. of total indem.) with BCR_{obs}-based insurance	10.28%	21.95%	19.20%	16.76%	17.78%
CEI gain of CR_{siva}-based insurance for farmers	.57%	-.10%	1.06%	1.66%	2.77%
Insurer gain (kg/ha) with CR_{siva}-based insurance	-2.81	2.16	0.55	2.03	3.54
Insurer gain (perc. of total indem.) with BCR_{obs}-based insurance	-54.33%	14.63%	2.93%	9.99%	18.18%
CEI gain of BCR_{siva}-based insurance for farmers	-0.336%	.43%	.78%	1.43%	2.47%
Insurer gain (kg/ha) with BCR_{siva}-based insurance	1.27	0.13	2.44	2.26	2.01
Insurer gain (perc. of total indem.) with BCR_{obs}-based insurance	69.02%	.58%	9.93%	9.76%	9.31%
CEI gain of $WACR_{siva}$-based insurance for farmers	-0.080%	1.51%	2.63%	3.49%	5.85%
Insurer gain (kg/ha) with $WACR_{siva}$-based insurance	0.03	-4.13	-4.59	-3.85	-4.86
Insurer gain (perc. of total indem.) with BCR_{obs}-based insurance	1.84%	-18.14%	-18.21%	-16.35%	-21.70%
CEI gain of $WABCR_{siva}$-based insurance for farmers	-0.300%	.69%	.94%	1.71%	3.31%
Insurer gain (kg/ha) with $WABCR_{siva}$-based insurance	1.15	-1.22	1.31	1.17	-0.14
Insurer gain (perc. of total indem.) with BCR_{obs}-based insurance	69.92%	-5.73%	5.53%	5.28%	-.65%

Table 4.VII shows the insurance gain in out-of-sample when redistributing to farmers of insurer profits (losses) that are superior (inferior) to the 10% charging rate we fixed in the previous sections. This artificially keeps the insurer out-of-sample gain equal to the in-sample case and thus allows comparison with in-sample calibration estimates. The insurance benefit for farmers drops by an average of 71% .

The ranking of the indices also changes compared to the in-sample calibration: while simulated crop cycles still perform better than observed ones, the preceding result that bounding daily rainfall to 30 mm makes the index more accurate no longer holds for simulated crop cycles: under out-of-sample calibration, for $\rho \geq 3$, the simplest index, cumulated rainfall (CR_{siva}), brings the best outcome.

4.3.3 Potential intensification due to insurance

As pointed out by Zant (2008), our ex ante approach does not take into account the potential intensification due to insurance supply. Indeed, many agricultural inputs, especially fertilisers, increase the average yield but also the risk. If the rainy season is bad, the farmer still has to pay for the fertilisers even though the increase in yield will be very limited or even nil. The literature on micro-insurance

Table 4.VII: Average income gain of leave one (village) out calibration index insurance, with equal redistribution across farmers of residual gains or losses from the charging rate (10% of total indemnification) by the insurer.

	$\rho = .5$	$\rho = 1$	$\rho = 2$	$\rho = 3$	$\rho = 4$
CEI gain of CR_{obs}-based insurance	-.07%	.20%	.22%	.40%	.17%
CEI gain of BCR_{obs}-based insurance	-.17%	.06%	.76%	1.20%	1.81%
CEI gain of CR_{siva}-based insurance	**-.05**%	.04%	.72%	**1.66**%	**3.36**%
CEI gain of BCR_{siva}-based insurance	-.13%	-.01%	**.78**%	1.41%	2.42%
CEI gain of $WACR_{siva}$-based insurance	-.11%	**.17**%	.81%	1.56%	3.21%
CEI gain of $WABCR_{siva}$-based insurance	-.11%	.00%	.67%	1.38%	2.46%
Loss in CEI gain (compared to the in-sample calibration)					
CR_{obs}-based insurance	n.a.	-16.95%	-76.19%	-79.28%	-94.48%
BCR_{obs} -based insurance	n.a.	-79.92%	-39.97%	-49.88%	-50.89%
CR_{siva}-based insurance	n.a.	-86.38%	-43.21%	-36.51%	-27.73%
BCR_{siva}-based insurance	n.a.	-103.97%	-49.01%	-54.95%	-53.55%
$WACR_{siva}$-based insurance	n.a.	7.73%	-14.23%	-24.11%	-8.93%
$WABCR_{siva}$-based insurance	n.a.	-102.12%	-51.52%	-52.54%	-50.38%

n.a.: not applicable.

suggests that the supply of risk-mitigating products could increase the incentive to use more yield-increasing and risk-increasing inputs (Hill, 2010). It could also foster input credit demand thanks to lower default rates, as tested by Giné and Yang (2009).

To address the first point we use additional data concerning 'encouragement' plots, where inputs (following a micro-dose fertilisation process) are systematically used because they are freely allocated by survey officers. Each farmer has a 'regular' plot and an 'encouragement' plot, the latter being available for only the 2005-2010 period. Our hypothesis is the following: since the cost of a bad rainy season is, in most cases, higher for intensified production, the insurance gain should also be higher. In such a case insurance should foster intensification and therefore bring a higher gain.

Table 4.VIII displays the summary statistics of the indices over the sub-period considered in this section. Observed yields are 15.1% higher in the plots where fertilisation was encouraged. On-farm income of plots where mineral or both organic and mineral fertilisers were used is about 4.4% superior in average [9] but with higher risk compared to regular plots that were grown under traditional technical

9. In this calculation, we assume that farmers have to buy the fertilisers (in the 'encouragement plots', they receive them for free).

itineraries. The CV of on-farm income is 6% higher in the encouragements plots than in the regular plots. This may explain why fertilisers are seldom used in this area when they must be purchased.

Table 4.VIII: Summary statistics: all plots (2005-2010)

Variable	Mean	Std. Dev.	CV	Min.	Max.	N
Farm yields (kg/ha)	579.19	368.53	.64	0	3300	2 952
Plot income (FCFA/ha)	101 637.70	68 154.46	.67	-5 001.62	593 692	2 952
Other crops income (FCFA)*	42 317.23	98 015.53	2.32	0	1 080 833.13	2 952
Other farm and non-farm incomes (FCFA)*	4 743.83	6 872.70	1.45	0	5 8333.33	2 952
Livestock and capital stock (FCFA)*	78 643.36	159 825.72	2.03	0	1 359 674.13	2 952
CR_{obs} (mm)	471.28	99.29	.21	293.37	735.89	2 952
BCR_{obs} (mm)	412.68	74.98	.18	266.68	574.06	2 952
CR_{siva} (mm)	451.28	125.74	.28	61.47	685.20	2 952
BCR_{siva} (mm)	393.94	102.53	.26	61.47	565.47	2 952
$WACR_{siva}$ (mm)	277.79	80.00	.29	33.54	453.57	2 952
$WABCR_{siva}$ (mm)	241.31	65.63	.27	33.54	365.54	2 952
Among which						
Regular plots:						
Farm Yields (kg/ha)	538.55	347.61	.65	0	3 100	1 476
On-farm income (FCFA)	99 439.26	65 003.70	.65	0	566 634.94	1 476
Encouragement plots:						
Farm Yields (kg/ha)	619.83	384.16	.62	31	3 300	1 476
On-farm income (FCFA)	103 836.15	71 120.02	.69	-5 001.62	593 692	1 476

* Per household member, in 2006.

Table 4.IX displays the in-sample gain from insurance, when dealing with plot income instead of raw yields, using the same objective function and the same optimization process. As shown in Table B.III in the Appendix, results are not altered by taking the income level for one hectare. The main differences between Table 4.III and Table 4.IX (considering only the part dedicated to regular plots in Table 9) are thus driven from the change in the sample (dropping the year 2004 in Table 4.IX).

Looking at the CEI gain to use fertilisers, we see that insurance is not a powerful incentive to use costly inputs. This is illustrated in Figure 4.2 which displays the CEI according to the risk aversion parameter, arrows showing the level under which growers will use fertilisers (augmenting risk and average income) without and with index-based insurance. The risk aversion threshold under which farmers have an interest in using fertilisers is a bit higher with insurance (dotted arrow) but only slightly. The area in light (dark) grey on the left (right) corresponds to the risk aversion levels for which farmers' certain equivalent of their expected

Table 4.IX: In-sample average gain of insurance depending on the index and risk aversion parameter.

	$\rho = .5$	$\rho = 1$	$\rho = 2$	$\rho = 3$	$\rho = 4$
All sample (N=2952)					
CEI gain of CR_{obs}-based insurance	.00%	.08%	.61%	1.25%	1.92%
CEI gain of BCR_{obs}-based insurance	.00%	.13%	1.13%	2.47%	4.12%
CEI gain of CR_{siva}-based insurance	.00%	.13%	1.08%	2.56%	4.49%
CEI gain of BCR_{siva}-based insurance	.00%	**.14%**	**1.14%**	**2.71%**	**4.78%**
CEI gain of $WACR_{siva}$-based insurance	.00%	.03%	.58%	1.43%	2.52%
CEI gain of $WABCR_{siva}$-based insurance	.00%	.03%	.44%	1.12%	1.96%
Regular plots (N=1476)					
CEI gain of CR_{obs}-based insurance	.00%	.10%	.51%	1.00%	1.48%
CEI gain of BCR_{obs}-based insurance	.00%	.12%	.96%	1.94%	3.05%
CEI gain of CR_{siva}-based insurance	.00%	.21%	1.00%	2.35%	4.15%
CEI gain of BCR_{siva}-based insurance	.00%	.22%	.99%	2.32%	4.06%
CEI gain of $WACR_{siva}$-based insurance	.00%	.01%	.67%	1.62%	2.90%
CEI gain of $WABCR_{siva}$-based insurance	.00%	.01%	.55%	1.38%	2.38%
Encouragement plots (N=1476)					
CEI gain of CR_{obs}-based insurance	.00%	.05%	.70%	1.49%	2.33%
CEI gain of BCR_{obs}-based insurance	.00%	.15%	1.30%	3.01%	5.16%
CEI gain of CR_{siva}-based insurance	.00%	.05%	1.16%	2.76%	4.82%
CEI gain of BCR_{siva}-based insurance	.00%	.05%	1.29%	3.09%	5.42%
CEI gain of $WACR_{siva}$-based insurance	.00%	.04%	.48%	1.25%	2.16%
CEI gain of $WABCR_{siva}$-based insurance	.00%	.04%	.33%	.87%	1.57%

income is higher without (with) fertilisation. The medium grey area in-between corresponds to the values of risk aversion for which farmers will use fertilisation only if a BCR-based insurance is supplied. Moreover, the size of the latter area that corresponds to the insurance intensification incentive shrinks with the level of certain wealth (W_0). We display identical figures, for the 5 other indices considered in the paper, in the Appendix B.

4.3.4 Comparison of cost and benefit of insurance

Up to this point we have used ad-hoc insurance costs. We now try to assess its level using a private experiment of weather index-based insurance, without subsidies, that has been taking place since 2003 in 8 districts in India (Chetaille, et al., 2010). The annual number of insurance contracts sold reached 10,000 in 2010. The average loss ratio (total claims divided by the sum of collected premiums) for the 6 years was 65%. The total cost was about US$ 7 000 per year (US$1.3 per policy sold), among which 30% is dedicated to design and implementation (ICICI Lombard), another 30% to reinsurance (SwissRe) and 40% to distribution

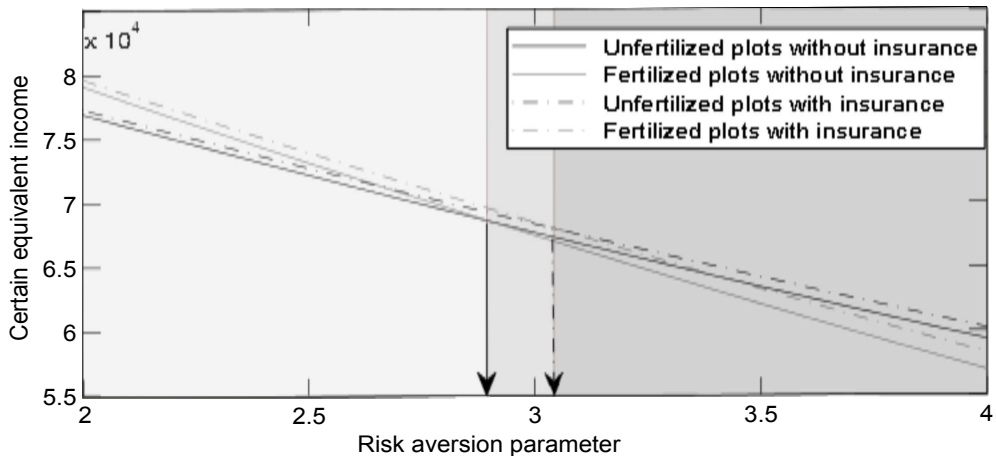

Figure 4.2: CEI (in FCFA) of encouraged and regular plots without (plain lines) and with CR_{obs}-based insurance (dotted lines), according to the risk aversion parameter, ρ and an initial wealth (W_0) of 1/3 of average income. The light grey area corresponds to the level of risk aversion for which no fertilisers are used, the dark grey one for which they are used with or without insurance and the medium grey area to the levels for which fertilisers are used only if CR_{obs}-based insurance is supplied.

(Basix). Each institution declared to make profits amounting to about 10% of its total sales.

In our case a 1% increase in CEI represents 4.9kg of millet for $\rho = 2$, which can be valued at about US$ 1.8 per hectare when millet is valued at the period average price (188 FCFA/kg) for the period considered. Given the distribution of income among regular plots, the insurance gain should exceed 0.7% of CEI in order to be profitable to the whole system composed of farmers and the insurer. 0.7% of CEI corresponds to US$1.3, the estimated cost of a weather index-based insurance policy in India. We found in section 4.3.2 that the gain from insurance is lower in out-of-sample than in in-sample estimations. For most indices, the insurance is thus worth implementing if farmers' risk aversion parameters are equal or superior to 2.

Moreover, in section 4.3.3 we show that the insurance impact on CEI could be higher when production is intensified but only a slightly larger part of farmers would use costly inputs. Finally, it seems that the performance of insurance could

hardly become significantly larger than its cost in our case, even when considering the potential incentive to intensification.

4.4 Conclusions

The article highlights four major conclusions for designing and assessing weather-index insurance policies for agriculture. Firstly, it underlines the need to use plot-level data to calibrate and get a robust estimation of the ex ante impact of insurance. This is particularly important in our case study (millet in South West Niger), where intra-village yield variations are high and the causes of low yields are numerous. Secondly, the outcomes of simple indices are comparable to those of more complex ones. More specifically, within an in-sample assessment, the best index is a simple cumulative rainfall over the growing period, with a cut-off for daily rains exceeding a certain threshold. Within an out-of-sample (leave-one-out) assessment, the best index is even simpler, i.e. the cumulative rainfall over the growing period. This second conclusion is welcome since a simple index is easier to understand for farmers. Our third conclusion is also welcome: indices based on a simulated sowing date perform at least as well as those based on observed sowing dates which would be costly to collect.

However, our final conclusions are more dismal: our out-of-sample estimations show that mis-calibration is a risk for both the insurer and farmers, and that for the benefit from index-based insurance to be higher than a very rough estimation of its implementation cost (based on evidence from India), a rather high risk aversion (typically superior to 2) is required.

Moreover, taking the potential fertilisation into account does not seem to change this conclusion, since insurance supply could hardly foster additional costly input use under our set of hypotheses. The last two results emphasize the need for more research in order to evaluate the potential of such products in the case of low intensification, shown by most food crop production systems in sub-Saharan Africa.

Acknowledgements: We thank two anonymous referees for their very useful comments, C. Baron, B. Muller and B. Sultan for initiating and supervising of the field work, J. Sanders and I. Abdoulaye for kindly providing input price series and R. Marteau for providing the Niamey Squared Degree map.

CHAPTER 5

THE CASE OF A CASH CROP: COTTON IN CAMEROON

Potential of weather index-based insurance for a cash crop regulated sector: An ex ante evaluation for cotton in Cameroon

Abstract

In the Sudano-sahelian zone, which includes Northern Cameroon, the inter-annual variability of the rainy season is high and irrigation is scarce. As a consequence, bad rainy seasons have a massive impact on crop yield. Traditional insurances based on crop damage assessment are not available because of asymmetric information and high transaction costs compared to the value of production. Moreover the important spatial variability of weather creates a room for pooling the impact of bad weather using index-based insurance products. We assess the risk mitigation capacity of weather index-based insurance for cotton growers. We compare the capacity of various indices coming from different sources to increase the expected utility of a representative risk-averse farmer. We consider weather indices, mainly based on daily rainfall.

We first give a tractable definition of basis risk and use it to show that weather index-based insurance is associated with large basis risk, no matter what the index or the expected utility function is chosen, and thus has limited potential for income smoothing (in accordance with previous results in Niger: Leblois et al., 2011). This last result is robust to the a change of the objective (utility) function. Using observed cotton sowing dates significantly decrease the basis risk of indices based on daily rainfall data. Second, in accordance with the existing agronomical literature we found that the length of the cotton growing cycle is the best performing index. Third, cutting the Cameroonian cotton zone into more

homogeneous rainfall zone seem necessary to limit subsidisation of the driest zones. As a conclusion, implementing an index insurance for cotton growers in Northern Cameroon would bring, at most, less than 1% of certain equivalent income gain. This seem particularly low, especially when compared to the implicit price insurance already offered by the cotton company by fixing purchasing price before the growing period.

5.1 Introduction

Seed-cotton is the major cash crop of Cameroon and represents the major income source, monetary income in particular, for growers of the two northern provinces: *Nord* and *Extrême Nord* according to Folefack et al. (2011). It is grown by smallholders with about .6 hectares dedicated to cotton production on average in the whole area (Gergerly, 2009). 346 661 growers cultivated 231 993 ha in 2005 reaching its peak, while, in 2010, the number of grower has dropped to 206 123 growers and the area cultivated with cotton shrinked to 142 912 ha.

Cotton is rainfed in almost all sub Saharan African (SSA) producing countries, and largely depends on rainfall availability. The impact of a potential modification of rainfall distribution during the season or the reduction of its length has been found as of particular importance (cf. section 5.3.2) and could even be higher with an increased variability of rainfall (ICAC, 2007 and 2009) that is supposed to occur under global warming (IPCC, 2007). Moreover the sector also suffers from several geographic and climatic challenges: isolation of the North of the country, decline in soil fertility due to increasing land pressure.

When growers are not able to reimburse their input credit at the harvest [1], they are not allowed to take a credit next year. Falling into a situation of unpaid

1. The standing crop is used as the only collateral and credit reimbursement is deducted from growers' revenue when the national company buys the cotton, cf. section 5.2.3 for further descriptions.

debt is thus very painful for those cotton growers (Folefack et al., 2011).

Traditional agricultural insurance, based on damage assessment cannot efficiently shelter farmers because they suffer from an information asymmetry between the farmer and the insurer, especially moral hazard, and from the cost of damage assessment. An emerging alternative is insurance based on a weather index, which is used as a proxy for crop yield (Berg et al., 2009). In such a scheme, the farmer, in a given geographic area, pays an insurance premium every year, and receives an indemnity if the weather index of this area falls below a determined level (the strike). Weather index-based insurance (WII) does not suffer from the two shortcomings mentioned above: the weather index provides an objective, and relatively inexpensive, proxy of crop damages. However, its weakness is the basis risk, i.e., the imperfect correlation between the weather index and the yields of farmers contracting the insurance. The basis risk can be considered as the sum of three risks: first, the risk resulting from the index not being a perfect predictor of yield in general (the model basis risk). Second, the spatial basis risk: the index may not capture the weather effectively experienced by the farmer; all the more that the farmer is far from the weather station(s) that provide data on which index is calculated. Third, the heterogeneities among farmers, for instance due to their practices or soil conditions are often high in developing countries.

This paper therefore aims at assessing WII contracts in order to shelter cotton growers against drought risk (either defined on the basis of rainfall, air temperature or satellite imagery). Insurance indemnities are triggered by low values of the index supposed to explain yield variation. Insurance allows to pool risk across time and space in order to limit the impact of meteorological (and only meteorological) shocks on producers income.

The first section describes the cotton sector in Cameroon while the second one is dedicated to describing the data and methods including agrometeorological methods used for index design and the insurance policy contract and model calibrations. In the last section we present the results before concluding.

5.2 Cameroonian cotton sector

5.2.1 National figures

Cotton sectors in French speaking Western and Central Africa (WCA) inherited of the institutions of the colonial era during which the cotton national 'filières' were developed by the *Compagnie Française des Textiles* (CFDT). National cotton companies - at least those that were not regulated or privatized in the 90's, i.e. in Cameroon and Mali - thus often follow the 'filière' model inherited from that time (Delpeuch and Leblois, forthcoming, cf. Chap. I). The model is characterized by its input distribution scheme. Cotton parastatals act as a monopsonic buyer, providing inputs on credit, with no other collateral than the cotton future harvest. They also supply infrastructures and extension services: construction and maintenance of roads, agronomical research and advices etc.

Cameroon national cotton company (Sodecoton, for *Société de Développement du Coton du Cameroun*) suffered from a decreasing trend in yields since the end of the 80's (Figure 5.1). A trend reversal, succeeding to the increase of cotton yield in the 60's and the 70's, can be observed in most of major African producing countries (Vitale et al., 2011). It could be due to fertility loss and/or soil erosion, often pointed out as a source of long run reduction in yield in Western and Central Africa (WCA). It was indeed accompanied, until 2005, with an increase of surface grown with cotton that led to exploit marginal and less productive arable lands, increasing the pressure on land use. The number of growers indeed continuously increased from 1983 to 2005. The decreasing trend could finally be linked to market entry by new less experienced farmers, using less fertile land, as pointed out by Delpeuch and Leblois (2012, cf. Chap. II) in WCA and Brambilla and Porto in the case of Zambia.

The development of cotton cultivation in WCA has been favored by that institutional frame, farmers being encouraged by the availability of quality fertilizer on credit. Stabilized purchasing price and the distribution of inputs on credit - for

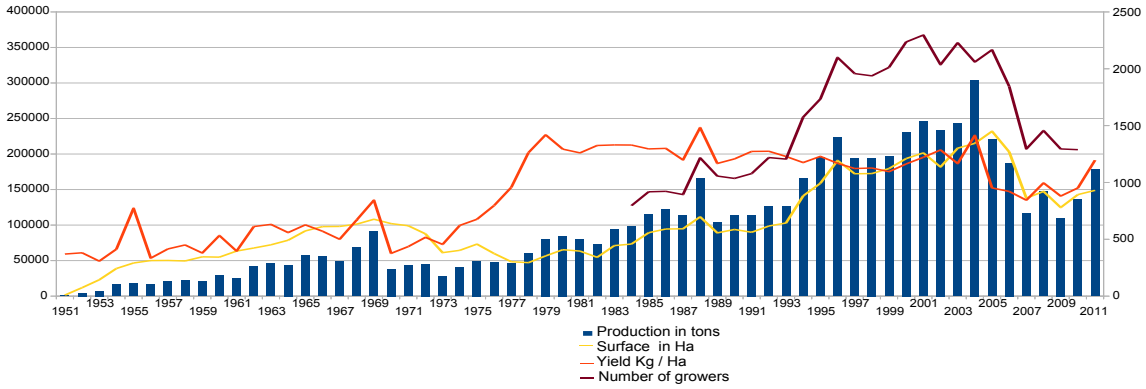

Figure 5.1: Evolution of Cameroon seed cotton yield, production, surface and number of growers. Source: Sodecoton.

cotton but also more recently for cereals in the case of Cameroon - at favorable prices are indeed strong incentives to growing cotton for risk averse smallholders. Cotton sales and production in the whole CFA zone were also boosted by the devaluation (1994).

This model has however been challenged in the recent years, especially in Cameroon, as mentioned by Mbetid-Bessane et al. (2009) and (2010). Profits in cotton growing activities are limited given the need for costly inputs use and thus highly depend on input and cotton prices. Inputs whose production is energy intensive, are bought at a price under constant upward pressure since the year 2000. On the other hand cotton prices are linked to euro/dollar exchange rate that dramatically increased since 2002. Those two combined factors could explain the drop in yield, surface and number of growers since the beginning of the century (cf. Figure 5.1).

The decrease in the number of growers in Cameroon can be attributed to the high fertilizer price (Crétenet, 2010), in spite of the national input subsidies. However, institutional issues and country specific sector management such as side-selling and credit default, also explain the decrease in cotton observed production. Side-selling occur in borderland areas to countries where price are higher, Nigeria in the case of Cameroon, or where the cotton sector has been liberalized, which

permit to avoid input credit reimbursement, cf. Araujo-Bonjean et al. (2003). A major part a the input credit is indeed reimbursed after harvest when the national cotton society buys cotton to producers. The purchasing prices in Nigeria could have reached three times as much as the Cameroonian price in recent years according to Kaminsky et al. (2011), and quality standards are even lower that those of the national company. The presence of textile industries in Nigeria also explain the high demand for cotton. Cotton smuggling, that particularly occurs in the North-West of the cotton zone, creates a potential loss of about 16% of the national production for the authors (according to Sodecoton). Side-selling always existed in Cameroon when looking at annual (for instance in 1989) Sodecoton's briefs reporting heavy leaks of cotton going to Nigeria. However, credit default in Cameroon did not exceed 5% until 2005 and have reached 10% after 2006.

5.2.2 Study area

The cotton administration counts 9 regions divided in 38 administrative sectors (Sadou et al., 2007, cf. Figure 5.2).

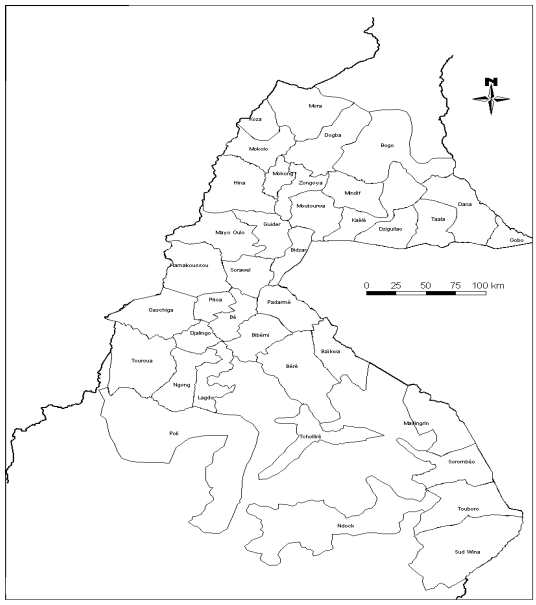

Figure 5.2: Sodecoton's administrative zoning: the sectors level.

5.2.3 Input credit scheme

The cotton society (Sodecoton) and its Malian (CMDT) counterpart, are still public monopsonies (Delpeuch and Leblois, forthcoming, Chap. I). Those parastatals are thus the only agent in each country to buy cotton from producers at pan-seasonally and -territorially fixed price.

The specificity of those institutional setting is also characterized by the input provision at the 'filière' level. Costly inputs are indeed provided on credit by the national companies at sowing, ensuring a minimum quality and their availability in spite of a great cash constraint that characterize the lean season in those remote areas: the so-called 'hunger gap'.

In that purpose collective guarantee circles (CGC, named *Groupe d'Initiative Commune* in French: *GIC*'s) were set up to control the risk of bad management in large groups. The group put up bond for each grower, hence creating a new associative layer within the village (Enam et al., 2011). However, in spite of a self-selection process to form those groups, the mechanism suffers from local elite pressure and influence from traditional power structures, as described in Kaminsky et al. (2011). GICs exist since 1992. The 2010 reform of the producers' organization (OPCC standing for *Organisation des Producteurs de Coton du Cameroun*) led to a pool of villages producers' groups (PGs) at the zone level (2000). There is about 2000 active PGs in 2011, which represent an average of about 55 PGs per sector. The reform also led to the creation of pools at an upper level: unions of GICs at the sector level (48 sector) and a federation of unions at the region level (9 regions).

5.2.4 Insurance potential institutional setting

Due to data availability constraint (see section below), we study an insurance mechanism at the sector level. This thus naturally lead to the unions of the producers' organization to be the insured entity.

Moreover, the the producers' organization (OPCC) already has recently played

part of a risk pooling role (or more precisely income smoothing) when reallocating the annual surplus of good years into a compensation found for bad years. Before that the surplus was simply distributed as a premium to producers for the next growing season (Gergely, 2009). Besides, the the producers' organisation also urge the villages to stock cereals in order to increase consumption smoothing and to lower the risk of decapitalization in case of a negative income shock (Kaminsky et al., 2011).

5.3 Data and methods

5.3.1 Data

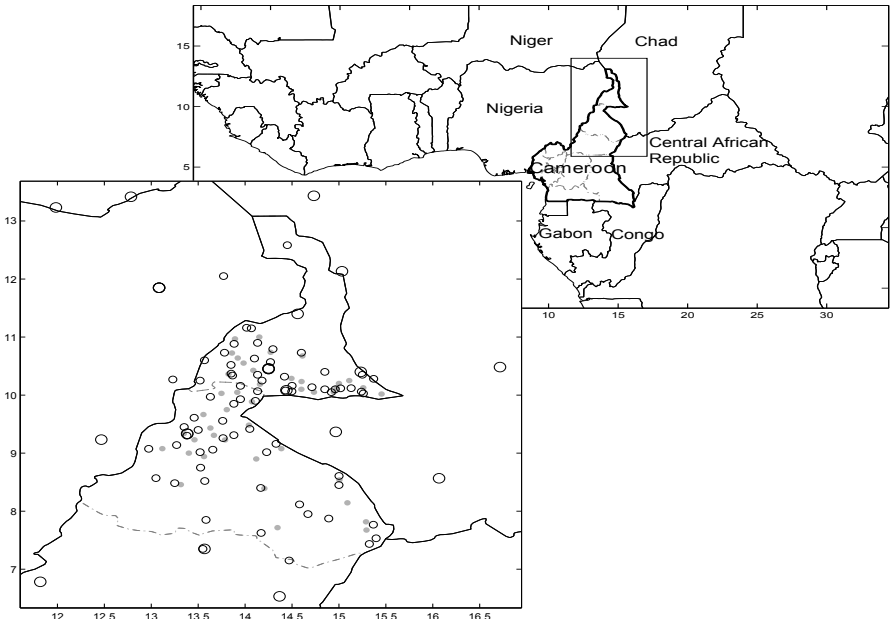

Figure 5.3: Meteorological (large black circles) and rainfall stations (small black circles) network of the region and barycentres of sectors (grey dots: average of PGs locations). Sources: Sodecoton, IRD and GHCN (NOAA).

We dispose of time series of yield and gross margin per hectare at the sector level from 1977 to 2010, provided by the Sodecoton. Gross margin is the difference between the value of cotton sold and the value of purchased inputs: fertilisers,

pesticides, but not labor since the vast majority of workers are self-employed. We will call it cotton profit thereafter.

The profit series suffer from a high attrition rate before 1991, with about one third of missing data, but limited between 1991 and 2010 (18%).

We matched this data to a unique meteorological dataset which we have build. It includes daily rainfall and temperatures (minimal, maximal and average) coming from different sources [2], with at least one rainfall station per sector (Figure 5.3). Sectors agronomical data are matched to rainfall data using the nearest station, that is, at an average of 10 km and a maximum of 20 km. Sectors location are the average GPS coordinates of every Sodecoton's producers group (PG) within the sector. A sector represents about 900 squared kilometres(cf. Figure 5.1).

We interpolated, for each sector, temperature data from ten IRD and Global Historical Climatology Network (GHCN) synoptic meteorological stations of the region: six in Cameroon and four in Chad and Nigeria [3]. We used a simple Inverse Distance Weighting interpolation technique [4], each station being weighted by the inverse of its squared distance to the sector considered applying a reduction proportional to 6.5 Celsius degree (°C) per 1000 meters altitude. The average annual cumulative rainfall over the whole producing zone is about 950 millimetres (mm) as showed in Table 5.I, hiding regional heterogeneities we explore in the next section.

Table 5.I: Yield and rainfall data summary statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
Annual cumulative rainfall (mm)	950	227	412	1790	849
Yield	1150.216	318	352	2352	849
Cotton profit* (CFA francs per Ha)	114847	50066	-7400	294900	849

* Profit for one hectare of cotton after input reimbursement, excluding labor.

We finally used the Normalized Difference Vegetation Index (NDVI), available

2. *Institut de la Recherche pour le Développement* (IRD) and Sodecoton's rain gauges high density network.

3. National Oceanic and Atmospheric Administration (NOAA), available at: www7.ncdc.noaa.gov

4. IDW method (Shephard 1968), with a power parameter of two.

for a 25 year period spanning from 1981 to 2006 at 8 km spatial resolution[5]. This vegetation index is a relative measure of the spectral difference between visible (red) and near-infrared regions and is thus directly related to green plants photosynthesis.

5.3.2 Weather and vegetation indices

5.3.2.1 Weather indices and cotton growing in Cameroon

The critical role of meteorological factors in cotton growing in WCA has been widely documented. For instance, Blanc et al. (2008) pointed out the impact of the distribution and schedule of precipitation during the cotton growing season on long run yield plot observations in Mali. In recent studies on this region of the world, length of the rainy season, and by extension late onset or premature end of the rainy season, are also seen as key elements determining cotton yields. The onset and duration of the rainy season were recently found to be the major drivers of year-to-year and spatial variability of yields in the Cameroonian cotton zone (Sultan et al., 2010).

Luo (2011) finally reports many results of the literature about the impact of temperatures on cotton growth that seem to depend on the cultivar: cotton is indeed grown in some very hot region of the world, such as in Ouzbekistan.

5.3.2.2 Designing rainfall indices

Rainfall indices

We first considered the cumulative rainfall (CR) over the whole rain season. We define and only consider significant daily rainfall, that will not be entirely evaporated, as superior to .85 mm following the meteorological analysis of Odekunle (2004). We then consider a refinement (referred to as BCR) of each of those simple indices by bounding daily rainfall at 30 mm, corresponding to water that

5. The NOAA (GIMMS-AVRHH) remote sensing data are available online at: www.glcf.umd.edu/data/gimms), Pinzon et al. (2005).

is not used by the crop due to excessive runoff (Baron et al., 2005). We will thus mainly study the length of the growing season (GS), cumulative (significant) rainfall (CR) and the bounded cumulative rainfall (BCR, described in the previous section) on the whole growing season and by growing phases.

Growing season schedule

Only considering critical rainfall used by the crop, requires the availability of growing cycle dates (typically the sowing or emergence date). Moreover, as shown by Marteau et al. (2011), a late sowing can have dramatical impact on harvest quantity. We used the informations about sowing date reported by the Sodecoton in their reports: the share of the acreage sowed with cotton at each of every 10 days between the 20 of may until the end July. We defined the beginning of the season (the emergence) as the date for which half the cotton area is already sown (has already emerged).

Since this information was not available for the whole sample, we also simulated a sowing date following a criterion of the onset of the rainfall season defined by Sivakumar (1988). It is based on the timing and of first rainfall's daily occurrence and validated by Sultan et al. (2010) and Bella-Medjo (2009) on the same data. We will test whether observing the date of the growing cycle, could be useful to weather insurance by using both the raw and approximated date of sowing and emergence. Simulated sowing date seemed to perform well in the case of millet in Niger as shown by Leblois et al. (2011).

We compare two growth phase schedules: the observed one is referred to as *obs* and the one simulated is referred to as *sim* in the paper. The onset of the simulated growing season is triggered by a rainfall zone specific threshold in cumulation of significant rainfall (50 mm during 5 days), the offset is the last day with observed significant rainfall.

Growing phases schedule

We then, try to distinguish different growing phases of the cotton crop, indices

based on that growing phases schedules will be referred as *sim gdd*. Cutting-in growing phases allows to determine a specific trigger for indemnifications in each growing phase. We do that by defining emergence, which occurs when reaching an accumulation of 15 mm of rain and 35 growing degree days (GDD) [6] after the sowing date. We then set the length of each of the 5 growing phases following emergence only according to the accumulation of GDD, as defined by the *Mémento de l'agronome* (2002), Crétenet et al. (2006) and Freeland et al. (2006). The end of each growing phases are triggered by the following thresholds of degree days accumulation after emergence: first square (400), first flower (850), first open boll (1350) and harvest (1600). The first phase begins with emergence and ends with the first square, the second ends with the first flower. The first and second phases are the vegetative phases, the third phase is the flowering phase (reproductive phase), the fourth is the opening of the bolls, the fifth is the maturation phase that ends with harvest.

The use of different cultivars, adapted to the specificity of the climate (with much shorter growing cycle in the drier areas) requires to make a distinction different seasonal schedule across time and space. For instance, recently, the IRMA D 742 and BLT-PF cultivars were replaced in 2007 by the L 484 cultivar in the Extreme North and IRMA A 1239 by the L 457 in 2008 in the North province. We simulated dates of harvest and critical growing phases [7] using Dessauw and Hau (2002) and Levrat (2010). The beginning and end of each phase were constraint to fit each cultivar's growing cycle (Table C.I in the Appendix review the critical growing phases for each cultivar).

The total need is 1600 GDD, corresponding to about an average of 120 days in the considered producing zone, the length of the cropping season thus seem to be a limiting factor, especially in the upper zones (Figure 5.5) given that an average of 150 needed for regular cotton cultivars, Crétenet et al. (2006).

6. Calculated upon a base temperature of 13 °C.
7. See Figure C.1 in the the Appendix for the spatial distribution of cultivars and Table C.I for the description of all cultivars and schedules.

5.3.2.3 Remote sensing indicators

According to Anyamba and Tucker (2012), MODIS derived products, such as NDVI, can not directly be used for drought monitoring or insurance since it requires huge delays in data processing, homogenization from difference satellites data source and validation from research scientists. However, they underline the existence of very similar near real-time (less than 3 hours from observation) products, such as eMODIS from USGS EROS used for drought monitoring by FEWS.

There is also a cost in terms of transparency to use such complex vegetation index that is not directly understandable for smallholders. There is thus a trade-off to be made between delays (minimized when using near real-time products), transparency and basis risk. In a similar study in Mali (De Bock et al., 2010) vegetation index is found to be more precise than rainfall indices following a criterion of basis risk (defined as the correlation between yield and the index).

We used the bi-monthly satellite imagery (above-mentioned NDVI) during the growing season: and considered annual series from the beginning of April to the end of October. We standardized the series, for dropping topographic and soil specificities, following Hayes and Decker (1996) and Maselli et al. (1993) in the case of the Sahel. There is 2 major ways of using NDVI: one can alternatively consider the maximum value or the sum of the periodical observation of the indicator (that is already a sum of hourly or daily data) for a given period (say the GS). As an example Meroni and Brown (2012) proxied biomass production by computing an integral of remote sensing indicators (in that particular case: FAPAR) during the growing period. Alternatively considering the maximum over the period is also possible since biomass (and thus dry weight) is not growing linearly with photosynthesis activity during the cropping season, but grows more rapidly when NDVI is high. Turvey (2011) for instance considers, in the case of index insurance, that the maximum represents the best vegetal cover attained during the GS and will better proxy yields. We thus tried indices using both

methods but also consider the bi-monthly observations of standardized NDVI.

5.3.3 Definition of rainfall zones

De Bock et al. (2010) justify the use of different zones across the Malian cotton sector in order to insure yields. Pooling yields across heterogeneous sectors in terms of average yields indeed leads to a subsidisation of sectors characterized by low yields. Moreover, considering different areas associated with heterogeneous climate would also lead to subsidise drier areas in the context of an drought index-based insurance framework.

Average annual cumulative rainfall varies between 600 and 1200 mm in the cotton producing area characterized by a Sudano-sahelian climate: sudanian in the Southern part and Sudano-sahelian in the Northern part.

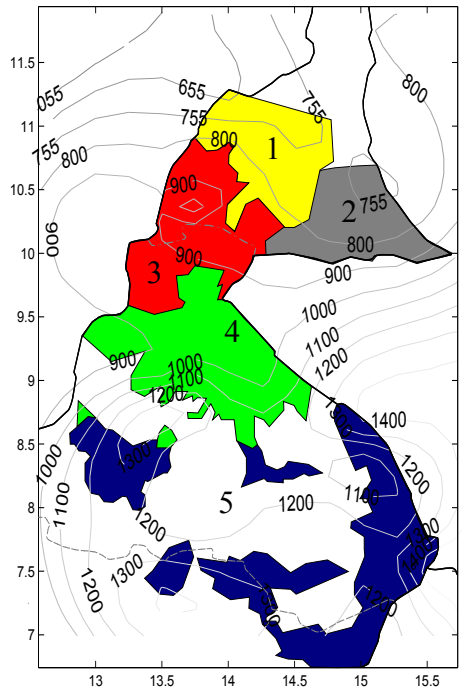

Figure 5.4: Zoning of cotton cultivation zone, based on meteorological (annual cumulative rainfall) classification (different areas are called North: 1, North East: 2, North West: 3, Centre: 4 and South: 5) and isohyets (in mm on the 1970-2010 period). Source: authors calculations.

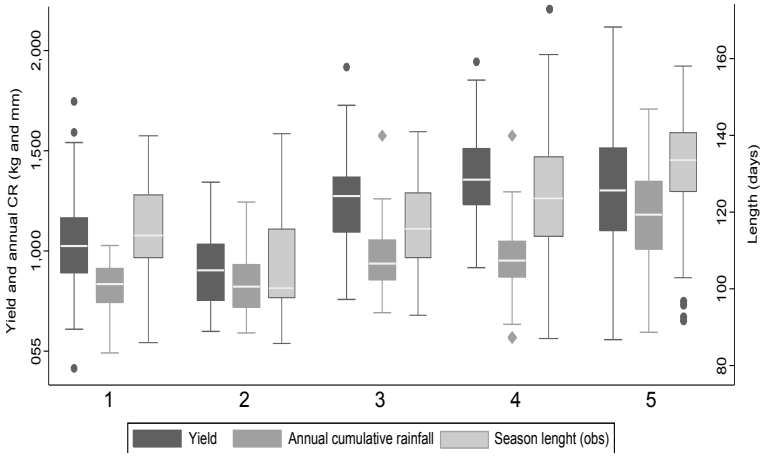

Figure 5.5: Boxplots of Yield, Annual rainfall and cotton growing season duration in different rainfall zones.

We defined 5 zones only following rainfall levels of each sector (referred as rainfall zones below), classing them by average annual cumulative rainfall on the whole period and grouping them in order to get a significant sample. The geographical zoning of the cotton cultivations area is displayed in Figure 5.5 and the distribution of yields, annual cumulative rainfall and length of the rainy season for each zones in Figure 5.4.

The rainfall zones have significantly (student, probability of error lower than 1%) different average yield, cumulative rainfall and cotton growing season length. As mentioned in the section 5.3.2.1, yield seem very sensitive to the sowing date. The two northern rainfall zones are sowed (and emerge) 10 to 15 days later; such feature could explain part of the discrepancies among yields, in spite of the development of adapted cultivars for each zone by the agronomic research services.

However, in our case, optimizing insurance in each of the rainfall zones lead to largely better pooling for each of them, but standardizing [8] indices by sector did not improved significantly the results.

8. Considering the ratio of the deviation of each observation to the sector average yield on its standard deviation.

5.3.4 Weather index-based insurance set up

5.3.4.1 Indemnity schedule

In this section we simulate the impact of an insurance based on weather indices used to pool yield risk across sectors. The indemnity is a step-wise linear function of the index with 3 parameters: the strike (S), i.e. the threshold triggering indemnity; the maximum indemnity (M) and λ, the slope-related parameter. When λ equals one, the indemnity is either M (when the index falls below the strike level) or 0. The strike represents the level at which the meteorological factor becomes limiting. We thus have the following indemnification function depending on x, the meteorological index realisation:

$$I(S, M, \lambda, x) = \begin{cases} M, & \text{if } x \leq \lambda.S \\ \frac{S-x}{S\times(1-\lambda)}, & \text{if } \lambda.S < x < S \\ 0, & \text{if } x \geq S \end{cases} \tag{5.1}$$

It is a standard contract scheme of the WII literature. The insurer reimburse the difference between the usual income level and the estimated loss in yield, yield being proxied by the meteorological index realization.

5.3.4.2 Insurance policy optimization

We use different objective function and show that our results are robust to such choice. We consider the three following objective function, respectively mean-absolute semi-deviation (MASD, Konno and Yamazaki, 1991; in the vein of Markovitz' mean-absolute deviation model but only considering downside risk, equation 5.2), a constant absolute risk aversion (CRRA) utility function (equation 5.3) and finally a negative exponential, i.e. constant relative risk aversion (CRRA) utility function (equation 5.4). Expected utility are expressed as follows:

$$U_{MASD}(\tilde{\Pi}) = E(\tilde{\Pi}) - \phi \times \frac{1}{N}\sum_{i=1}^{N}\Big(\max\big(E(\tilde{\Pi}) - \Pi_i, 0\big)\Big), \qquad \tilde{\Pi} = \{\Pi_1, ..., \Pi_N\} \tag{5.2}$$

$$U_{CARA}(\Pi_i) = \Big(1 - \exp\big(-\psi \times (\Pi_i + w)\big)\Big) \tag{5.3}$$

$$U_{CRRA}(\Pi_i) = \frac{(\Pi_i + w)^{(1-\rho)}}{(1-\rho)} \tag{5.4}$$

$\tilde{\Pi}$ is the vector of cotton profit within the period and among the sectors considered, N the number of observations, and w other farm and non-farm income. ϕ, ρ and ψ are respectively the risk aversion parameter in each objective function. Risk aversion is equivalent to inequality aversion in this context, since we consider the production function to be ergodic and assimilated spatial (sectoral) variations to time variations.

We maximised the expected utility of these three utility functions and computed the risk premium, i.e. the second term of the first objective function and the expected income minus its certainty equivalent in the two latter, for each of them. The first function is simply capturing the income 'downside' variability (i.e. variations are considered only when yield is inferior to the average yield considered to be particularly harmful). The second term represents the average downside loss, loss being defined as yield inferior to average of yield distribution among the calibration sample. It represents about 1/3 of average yield with very little change when considering different samples.

The second and third objective functions are quite standard in the economic literature; we added an initial income level, following Gray et al. (2004). Initial income is fixed to the average revenue of one hectare of cotton, after input reimbursement (cf. section, the fixed cost of indemnification is about one day of rural wage.

Given that we use the aversion to wealth in both case (as opposed to transitory income), we assume that $\psi = \rho/W$, with W the total wealth, according to Lien and Hardaker (2001). The insured profit (Π^I) is the observed profit minus premium plus the hypothetical indemnity:

$$\Pi_i^I = \Pi(x) - P(S^*, M^*, \lambda^*, x) + I(S^*, M^*, \lambda^*, x) \tag{5.5}$$

The loading factor is defined as a percentage of total indemnifications on the whole period (β, fixed at 10% of total indemnification), plus a transaction cost (C) for each indemnification, fixed exogenously to one percent of the average yield.

$$P = \frac{1}{N}\big[(1+\beta) \times \sum_{i=1}^{N} I_i\big(S^*, M^*, \lambda^*, x_i\big) + C \times \sum_{i=1}^{N} F_i\big], \text{ with } F_i = \begin{cases} 1 \text{ if } I_i > 0 \\ 0 \text{ if } I_i = 0 \end{cases} \tag{5.6}$$

We finally optimize the three insurance parameters in order to maximise utility and look at the reduction in the risk premium depending on the index and the calibration sample. The strike is bounded by a maximum indemnification rate of 25%.

5.3.5 Model calibration

5.3.5.1 Initial wealth

We use three surveys ran by Sodecoton in order to follow and evaluate growers' agronomical practices. They respectively cover the 2003-2004, 2006-2007 and 2009-2010 growing seasons. We also use recall data for the 2007 and 2008 growing season from the last survey. The localizations of surveyed clusters (as displayed in Figure C.2, in the Appendix) are distributed across the whole zone. We computed the share of cotton-related income in on-farm income for 5 growing seasons. Cotton is valorized at the average annual purchasing price of the Sodecoton and

the production of major crops (cotton, traditional and elaborated cultivars of sorghos, groundnut, maize, cowpea) at their annual sector level price observed at the end of the lean season period, corresponding to April of the next year. The lower level of observation (especially for recall data) is explained by the year by year crop rotation that make farmers with low surface grow cotton only one year each two years. We can however not exclude that recall is not perfect and that some missing data remains.

Table 5.II: On-farm and cotton income of cotton producers during the 2003-2010 period (in thousands of CFA francs)

Variable	Mean	Std. Dev.	Min.	Max.	N
2003					
On-farm income	545.493	539.744	.587	6049.995	1439
Cotton share of income (%)	**49.8**	1.80	.5	100	1439
2006					
On-farm income	493.395	496.589	43.111	3845.007	850
Cotton share of income (%)	**42.4**	17.1	4	100	850
2008*					
On-farm income	472.656	490.784	18.390	4050.643	811
Cotton share of income (%)	**65.8**	21.7	10.6	100	811
2009*					
On-farm income	802.533	866.899	22.932	9520.681	952
Cotton share of income (%)	**40.9**	20.6	4.6	100	952
2010					
On-farm income	699.728	759.979	34.451	9236.930	1138
Cotton share of income (%)	**31.7**	24	0.3	100	1138
Whole sample					
On-farm income	606.546	661.703	.587	9520.681	5190
Cotton income	246.064	278.751	.185	4525.1	5190
Cotton share of income (%)	**45.5**	23.1	.3	100	5190

Source: Sodecoton's surveys and author's calculations.
* Recall data from the 2010 survey.

As showed in Table 5.II the share of cotton in on-farm income of cotton growers is more than 45% in average. There are however some limits to that calibration, for instance the period is not representative from the period studied in the article since this period, as already mentioned, the cotton production collapsed after 2004, especially due to low incentive (high fertiliser prices). We finally fixed average on-farm income as the double of average cotton income of our sample. We also tested on-farm income increasing in function of cotton income[9] but it

9. For three major reasons it can be assumed that cotton yields and other incomes (mainly other crops yields) are being correlated. First, even if each crop has its own specific growing period, a good year for cotton in terms of rainfall is probably also a good rainy season for other

did not modify the results.

5.3.5.2 Risk aversion

We used a field work (Nov. and Dec. 2011) to calibrate the risk aversion parameter of the CRRA function. We assumed the CRRA preferences in that section because it is standard in such field work, but, as said previously, the two other parameters can be inferred from the level of the calibrated relative risk aversion.

A survey was implemented in 6 sodecoton groups of producers in 6 different locations, each in one region, out of the nine administrative regions of the Sodecoton, two in each agro-ecological areas [10], were about 15 cotton growers were randomly selected [11] to answer a survey concerning socio-economic variables, crop cultivated and yields, technical agronomic practices and agro-meteorological assessment, such as the sowing date choice and the criteria for this choice. Those producers were asked to come back at the end of the survey and lottery games were played. We use a typical Holt and Laury (2002) lottery, apart from the fact that we do not ask for a switching point but ask a choice between two lotteries (one risky and one safe) for a given probability of the bad outcome. It thus allows the respondent to show inconsistent choices, and if not, ensures that she/he understood the framework.

At each step (5 lottery choices displayed in Table 5.III) the farmers have to choose between a safe (I) and a risky (II) situation, both constituted of two options, represented by a schematic representation of realistic cotton production

crops growing during the rainy season. Second, a household that have a lot of farming capital is probably able to get better yields in average for all crops. Third, cotton being the main channel to get quality fertilisers, the higher is the cotton related input credit, the higher the collateral.

10. The localization of those six villages are displayed in Figure C.3 in the Appendix.

11. Randomly taken out of an exhaustive list of cotton growers detained by the Sodecoton operator in each village in order to manage input distribution each year. Those groups of producers are all about the same size because they are formed by the Sodecoton in order to meet management requirement. Villages are divide into 2 groups when there is too numerous producers in one single village and alternatively villages are put together in the same group when they are too small.

in good and bad years. The gains represent the approximative average yield (in kg) for 1/4 of an hectare, the unit historically used by all farmers and Sodecoton for input credit, plot management informal wages, etc. The gains were displayed in a very simple and schematic way in order to fit potentially low ability of some farmers to read and to understand a chart, given the low average educational attainment in the population. For each lottery, the options are associated with different average gains, probabilities were represented by a bucket and ten balls (red for a bad harvest and black for a good harvest). When all participants made their choice, the realization of the outcome (good vs. bad harvest) is randomly drawn by childrens of the village or a voluntary lottery player picking one ball out of the bucket.

The games were played and actual gains were offered at the end. Players were informed at the beginning of the play that they will earn between 500 and 1500 CFAF francs, 1000 CFAF representing one day of legal minimum wage. We began with the lotteries in which the safer option was more interesting. Each lottery was then increasing the relative interest of the risky option. We thus can compute the risk aversion level (ρ) using to the switching point (or the absence of switching point) from the safe to the risky option, assuming CRRA preferences. They are displayed in Table 5.III, BB goes for black balls and RB for red balls.

Table 5.III: Lotteries options

	I		**II**				
Number of BB (prob. of a good outcome)	RB	BB	RB	BB	Difference (II-I) of expected gains	CRRA risk aversion when switching from I to II	MASD risk aversion when switching from I to II
5/10	150	250	50	350	0	≤ 0	≤ 0
6/10	150	250	50	350	20	]0,0.3512]	]0,0.17]
7/10	150	250	50	350	40	]0.3512,0.7236]	]0.17,.29]
8/10	150	250	50	350	60	]0.7236,1.1643]	].29,.38]
9/10	150	250	50	350	80	]1.1643,1.7681]	].38,.44]
No risky option chosen						> 1.7681	>0.44

5.4 Results

5.4.1 Risk aversion distribution

We dropped each respondent that showed an inconsistent choice [12] among the set of independent lottery choices representing 20% of the sample: 16 individuals on 80. We choose the average of each interval extremities as an approximation for ρ, as it is done in the underlying literature. Table C.II in the Appendix shows the summary statistics of the obtained parameters in the whole sample and in each villages. We display the distribution of the individual relative risk aversion parameter across the 6 villages in Figure 5.6.

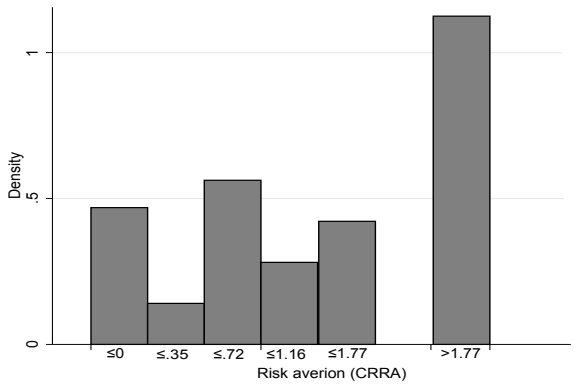

Figure 5.6: Distribution of relative risk aversion (CRRA) parameter density (N=64).

According to the previous methodology (described in section 5.3.5.2) 20% of our sample (N=64) show a risk aversion below or equal to .72, and 38% a risk aversion superior to 1.77 under CRRA hypothesis. Given that only the most risk averse agents will suscribe to an insurance and that 52% of our sample show a risk aversion superior to 1.16 we decided to test a range of values between 1 (the approximative median value) and 3 for the CRRA. The parameters of the CARA [13] objective function are set in accordance: $\psi = \rho/W$, with W the average

12. For instance a respondent that shows switching points indicating a risk aversion parameter superior to 1.7681 and inferior or equal to .3512 to is dropped.
13. Cf. section 5.3.4.2 above.

wealth (average cotton income plus initial wealth). Concerning the parameter of MASD objective function, i.e. the weight of the income semi-standard deviation relatively to the average income, we considered a set of parameter $\phi = [.25, .5, 1]$.

5.4.2 Basis risk and certain equivalent income

Let us suppose that the potential yield ($\bar{Y}$) depends on the (covariant or at least with spatial correlation) meteorological index (I) following a function ϕ:

$$\bar{Y_t} = \Phi(I_t) \tag{5.7}$$

The individual yield is composed of an idiosyncratic exogenous shock ($\epsilon_{i,t}$) and an individual fixed effect (u_i, that can alternatively be interpreted as the plot fertility as weel as the farmer's effort or experience):

$$y_{i,t} = \bar{Y_t} + \epsilon_{i,t} + u_i \tag{5.8}$$

The individual cotton profit of year t depends on the cotton price P_t, the quantity of inputs (F) and their price (P_t^F):

$$\Pi_{i,t} = (\phi(I_t) + \epsilon_{i,t} + u_i) \times P_t - F \times P_t^F \tag{5.9}$$

The individual farm income of year t depends on the non-cotton income (W_0):

$$R_{it} = W_0 + \Pi_{it} \tag{5.10}$$

Under such a function shape hypothesis, basis risk arises either from idiosynchratic and price shocks, from the modelisation of Φ (for instance by considering a linear relationship between the index and yield we called the model basis risk in the Chap. 3) or from the heterogeneity among individuals in terms of average yields and input use (studied in Chap. 4). We can consider that a differentia-

tion of insurance contracts could be used to discriminate among heterogeneous farmers. Offering different premium levels corresponding to different hedging rates indeed could make contractors reveal their intended level of input use and their average yield level. As we only have observed cotton profit at the sector level, the idiosyncratic shock cannot be assessed. However, in spite of the role of intra-village distribution in insurance calibration (Leblois et al., 2011) intra-village idiosyncratic shocks are often considered to be more easy to overcome at the village level, by private transfers through social networks (Fafchamps and Gubert, 2007). The hypothesis of income smoothing among communities and effectiveness of intra-village redistribution could be discussed, but it is not the purpose of this paper that does not have the appropriate data to address such question.

The remaining basis risk is thus the difference between the average yield at the sector level, and village average yield, we will call it spatial basis risk thereafter. This is resulting from two potential sources. First, spatial variability of the index, i.e. the difference between the level of the index, observed at the sector level and its realisation in each village. Second, it also results from exogenous shocks occurring at the meso or macro level, i.e. covariant exogenous shocks such as locust invasions etc.

There is not much theoretical work on the definition of basis risk in the context of index insurance calibration since Miranda (1991). The Pearson correlation coefficient between weather and yield time series is the only measure used for evaluating the basis risk since that time (see for instance Carter, 2007 and Smith and Myles, 2009). Such measure seems imperfect to us, because it does not depend on the contract shape and the utility function which will determine the capacity of insurance to improve resources allocation. We propose a tractable definition of basis risk, based on the computation of a perfect index that is the observation of the actual cotton profit at the same level for which both yield data and meteorological indices are available.

We thus consider the basis risk (BR) as the difference in percentage of utility gain obtained by smoothing income through time and space lowering the occurrence of bad cotton income through vegetation or weather index insurance (WII) as compared to an area-yield insurance (AYI) with the same contract type. We consider an insurance contract based on yield observed at the sector level. The contract has the exact same shape[14] and the same hypothesis[15] than the WII contracts, except from the index, that is the observed outcome. We will call it AYI thereafter, considering this is the best contract possible under those hypothesis. AYI probably shows higher transaction costs than WII because of the need to asses the yield level and prevent moral hazard, however, the same loading factor and transaction costs are considered for AYI and WII to ease the comparison beteween both type of insurance.

$$BR = 1 - \frac{CEI(\tilde{\Pi}_{WII})}{CEI(\tilde{\Pi}_{AYI})} \tag{5.11}$$

The certain equivalent is the expected utility, average utility of all situations(years and sector specific situations expressed in CFA francs), to which we apply the inverse of the utility function $U^{-1}(EU(\tilde{Y}))$.

5.4.2.1 Whole cotton area

We only show the results for the period 1991-2004 in Table 5.V, excluding strongly unbalanced panel data before 1991 and the period 2005-2010 characterized by a collapse of the Cameroonian cotton sector with a strong decrease in yield. This latter decrease is probably due to low input use, that could have been triggered by high input prices, in spite of the input credit and significant subsidization. In the context of high input prices, Sodecoton's inputs misappropriation, for instance to the benefit of food crops, such as maize, is also known to happen very often.

14. A stepwise linear indemnification function.
15. The premium equals the sum of payouts plus 10% of loading factor and a transaction cost.

Inter-annual variations in Sodecoton purchasing price and input costs contribute to the variations of cotton profit throughout the period. However we are not interested in computing such variations since the inter-annual variations of input and cotton prices are taken into account in crop choice as well as acreage and input use decisions. We thus value cotton and inputs at their average level over the period considered[16]. Figure C.5 in the Appendix shows that such modification does not modify the shape of the distribution of profits at the sector level. Alternatively, intra-annual prices variations matters, at least those occurring during the crop cycle. We address the issues related to intra-annual price variations in section 5.4.3.

Table 5.IV: Index description.

Index name	description
CR_{obs} after sowing	Cumulative rainfall from the observed sowing date to the last rainfall
BCR_{obs} after sowing	Cumulative rainfall, capped to 30 mm per day, from the obs. sowing date to the last rainfall
$Length_{obs}$ after sowing	Length of the growing cycle, from the observed sowing date to the last rainfall
Sowing $date_{obs}$	Observed sowing date, in days from the first of January

In Table 5.IV, we briefly recall the definition of each index. The first line of Table 5.V shows the maximum absolute gain in percent of CEI that a stepwise insurance policy contract could bring. The rest of the table shows the gains of other indices as a share of this maximum gain, corresponding to (1-BR). The index called "Sowing $date_{obs}$" is the observed sowing date, in days from the first of January. In that case, as opposed to rainfall and season length indices, insurance covers against high values of the index. We display in bold insurance contract simulation that reach at least 25%.

The first result is that the ranking among different indices performance is not modified when considering different utility functions. The MASD objective function always shows higher indemnification rate and CEI gains. It is due to the linearity of the objective function that leds to a reduced cost of basis risk. Concave utility functions (CRRA and CARA) indeed weight more low income

16. In addition, spurious correlation was found between fertiliser price and temperatures levels after 2000; and over the whole period between cotton price and NDVI (probably corresponding to a well known phenomenon, i.e. the greening of the Sahelian zone).

Table 5.V: CEI gain of index insurances relative to AYI absolute gain from 1991 to 2004.

	CRRA			CARA			MASD		
	$\rho = 1$	$\rho = 2$	$\rho = 3$	$\psi = 1/W$	$\psi = 2/W$	$\psi = 3/W$	$\phi = .25$	$\phi = .5$	$\phi = 1$
AYI CEI **absolute** gain	.19%	.92%	1.81%	.40%	1.16%	1.88%	1.42%	3.91%	10.11%
CEI gains relative to AYI									
CR_{obs} after sowing	N.A.	3.20%	4.22%	3.29%	4.94%	7.58%	**28.22%**	**34.03%**	**36.37%**
BCR_{obs} after sowing	N.A.	3.20%	5.97%	3.29%	6.94%	10.19%	**32.45%**	**32.57%**	**34.11%**
$Length_{obs}$ after sowing	**26.25%**	**33.66%**	**37.25%**	**32.04%**	**36.79%**	**39.95%**	**45.63%**	**47.51%**	**48.57%**
Sowing $date_{obs}$	**34.98%**	**50.69%**	**52.46%**	**46.43%**	**49.81%**	**52.49%**	**59.65%**	**58.57%**	**58.67%**

situations, which see their income level lowered by the premium payment in the case of type one basis risk (cf. Chap. 3) i.e. when there is no payout.

Second, we observe a very high basis risk level that is always superior to almost 50% for meteorological indices. The best performing index is the length of the cotton growing season. This result is coherent with the existing literature: Sultan et al. (2010) and Marteau et al. (2011) show that the length of the rainy season, and more particularly its onset, is a major determinant of yield in the region. It is mostly explained by the fact that the cotton bolls number and size are proportional to the tree growth and development, which itself, is proportional to the length of the growing cycle. We tested various different indices [17], which all performed very poorly according to the three utility functions, most of them were indeed leading to gains that were less than 10% of the benchmark AYI gains in certain equivalent income (corresponding to a basis risk over 90%).

Third, there is a very high subzidation rate across different regions: the driest is subsidized, while the most humid is taxed, cf. Table 5.VI for MASD insample optimization with $\phi = 1$. Figure C.6 in the Appendix, illustrate the inequal geographic distribution of indemnities, when calibrating insurance on the whole cotton zone. It cannot be addressed by simply standardizing meteorological index times series for two main reasons. The first is that we try to find a relation between

17. From the simplest to the most complicated: annual cumulative rainfall, the cumulative rainfall over the rainy season (onset and offset set according to Sivakumar, 1988 criterion) and the simulated growing phases (GDD accumulation and cultivars characteristics), the same indices with daily rainfall bounded to 30 mm, the length of the rainy season and the length of the cotton growing season, sum and maximum bi-monthly NDVI values over the rainy season and the NDVI values over October (the end of the season), the cumulative rainfall after cotton plant emergence and the observed duration of the growing season after emergence in days...

a meteorological variable and cotton yield, which is based on a biophysical ground. Standardizing time series would thus lead to loose such relationship. Moreover as shown in Figure C.4 in the Appendix, some meteorological indices show fat tails, especially on the left-hand side of the distribution, subsidization would thus not disapear with standardization.

Table 5.VI: Net subvention rate (in percentage of the sum of preiums paid) of MASD index-based insurances across the 5 rainfall zones (RZ), for ϕ=1.

	RZ 1	**RZ 2**	**RZ 3**	**RZ 4**	**RZ 5**
CR_{obs} after sowing	4.39%	34.21%	24.05%	-60.97%	-62.57%
BCR_{obs} after sowing	-22.93%	54.15%	37.39%	-49.57%	-83.88%
$Length_{obs}$ after sowing	41.16%	135.27%	-86.02%	-38.43%	-40.94%
Sowing $date_{obs}$	108.98%	139.31%	-86.20%	-59.49%	-80.57%

5.4.2.2 Rainfall zoning

Table 5.VII displays, for each index, the in-sample and out-of-sample (in italic) CEI gains. We only considered two different levels of risk aversion, we chose both highests levels since only the most risk averse agents will insure (Gollier, 2004). The in-sample gains are the gain of an insurance contract calibrated and tested on the same data. This estimation thus may suffer from overfitting, which could lead to overestimate insurance gain (Leblois et al., 2012, cf. Chap. 4). On the other, for out of sample estimates, we calibrated, for each sector, the insurance contract parameters on the other sector of the same rainfall zone. Insurer profits (losses) that are superior (inferior) to the 10% charging rate are equally redistributed to each grower. This artificially keeps the insurer out-of-sample gain equal to the in-sample case and thus allows comparison with in-sample calibration estimates. We show more indices in-sample results as a percentage of each rainfall zone AYI performance in Table C.III in the Appendix.

Looking at optimizations among different rainfall zones lead to a different picture. First, for some rainfall zones, no index can be used to pool risks, that is the case of the third and the fourth rainfall zones. Both zones are quite specific in terms of agro-meteorological conditions. The Mandara mountains, present in

Table 5.VII: In-sample and out-of-sample* estimated CEI gain of index insurances relative to AYI absolute gain, among different rainfall zones, from 1991 to 2004.

	CARA				MASD	
	$\rho = 2$	$\rho = 3$	$\psi = 2/W$	$\psi = 3/W$	$\phi = .5$	$\phi = 1$
First rainfall zone						
AYI CEI **absolute** gain	1.30%	2.40%	*.57%*	*1.10%*	*3.22%*	*8.61%*
CR_{obs} after sowing	.00%	1.34%	.00%	.00%	14.73%	19.52%
	-.31%	*-.52%*	*-.09%*	*-.26%*	*-1.69%*	*-3.77%*
BCR_{obs} after sowing	7.36%	13.75%	N.A.	7.03%	19.99%	20.57%
	-18.76%	*-28.66%*	*.00%*	*-21.59%*	*-63.92%*	*-43.64%*
$Length_{obs}$ after sowing	24.47%	**34.76%**	19.66%	**30.32%**	**43.40%**	**45.15%**
	37.10%	*24.72%*	*-23.25%*	*1.61%*	***34.75%***	*12.37%*
Sowing $date_{obs}$	**37.58%**	**45.64%**	**33.89%**	**42.29%**	**39.82%**	**44.98%**
	97.74%	***91.68%***	***32.68%***	***43.58%***	***35.65%***	***63.91%***
Second rainfall zone						
AYI CEI **absolute** gain	.63%	1.43%	.17%	.44%	4.84%	12.39%
CR_{obs} after sowing	N.A.	8.64%	.00%	8.02%	6.05%	8.37%
	.19%	*.67%*	*.08%*	*.27%*	*-.81%*	*.78%*
BCR_{obs} after sowing	N.A.	9.89%	.00%	9.85%	11.53%	13.77%
	-33.13%	*9.28%*	*-115.47%*	*-14.66%*	*-16.03%*	*-25.08%*
$Length_{obs}$ after sowing	20.22%	24.85%	18.27%	**25.36%**	**39.99%**	**43.64%**
	39.96%	***49.90%***	*9.20%*	*9.08%*	*.25%*	*8.33%*
Sowing $date_{obs}$	**44.86%**	**54.61%**	**39.23%**	**55.52%**	**55.78%**	**60.82%**
	48.72%	***69.06%***	*14.52%*	*-56.34%*	*-12.35%*	*-2.49%*
Third rainfall zone						
AYI CEI **absolute** gain	.99%	2.06%	.22%	.55%	1.31%	4.22%
CR_{obs} after sowing	4.81%	4.85%	5.32%	5.33%	9.41%	9.42%
	.00%	*.00%*	*.00%*	*-.03%*	*.00%*	*.62%*
BCR_{obs} after sowing	4.81%	4.85%	5.32%	5.33%	10.62%	10.83%
	.00%	*.00%*	*N.A.*	*.00%*	*-72.74%*	*-42.67%*
$Length_{obs}$ after sowing	.00%	.89%	.00%	1.17%	2.63%	3.67%
	-178.99%	*-147.85%*	*-223.85%*	*-117.81%*	*-68.75%*	*-38.18%*
Sowing $date_{obs}$	.00%	.00%	.00%	.00%	1.26%	1.46%
	-416.22%	*-158.67%*	*-357.76%*	*-158.65%*	*-94.21%*	*-30.96%*
Fourth rainfall zone						
AYI CEI **absolute** gain	.95%	1.96%	.49%	.98%	2.85%	7.24%
CR_{obs} after sowing	.00%	1.30%	.00%	2.03%	4.20%	6.28%
	-.06%	*-.01%*	*-.03%*	*.00%*	*-.29%*	*-.35%*
BCR_{obs} after sowing	.00%	1.30%	.00%	2.03%	4.20%	6.28%
	-8.89%	*-3.62%*	*-10.74%*	*-5.46%*	*-10.08%*	*-4.30%*
$Length_{obs}$ after sowing	.00%	.00%	.00%	.00%	6.52%	8.70%
	.00%	*.00%*	*.00%*	*.00%*	*-8.02%*	*-1.93%*
Sowing $date_{obs}$	.00%	.00%	.00%	.00%	.00%	.00%
	.00%	.00%	.00%	.00%	*-11.60%*	*-8.39%*
Fifth rainfall zone sample						
AYI CEI **absolute** gain	1.49%	2.35%	.19%	.50%	1.09%	2.86%
CR_{obs} after sowing	24.15%	27.79%	20.92%	**25.12%**	**40.95%**	**41.53%**
	-.10%	*-.37%*	*-.03%*	*-.16%*	.64%	1.73%
BCR_{obs} after sowing	**47.41%**	**44.69%**	**46.01%**	**43.39%**	**51.75%**	**50.13%**
	-108.54%	*-23.07%*	*-83.17%*	*-41.19%*	***29.86%***	***47.22%***
$Length_{obs}$ after sowing	**46.60%**	**44.71%**	**45.03%**	**44.03%**	**60.44%**	**61.67%**
	-25.54%	***48.40%***	***28.24%***	***43.22%***	*4.31%*	***28.57%***
Sowing $date_{obs}$	**49.91%**	**46.82%**	**48.45%**	**45.75%**	**61.22%**	**60.21%**
	-10.80%	***78.99%***	***92.74%***	***68.33%***	***86.27%***	***102.49%***

* Leave-one-out estimations are displayed in italic

the West of the third rainfall zone, are known to stop clouds, explaining such specificity and a relatively high annual cumulative rainfall, with very specific features. The fourth rainfall zone is corresponding to the Benoue watershed. The Benoue is the larger river of the region, contributing to more than the half the flow of the Niger river. Moreover, the fifth rainfall zone, i.e. the zone with the highest cumulative rainfall (cf. Figure 5.5), would mainly benefit from an index insurance based on the length of the growing cycle.

As found in the agronomic literature (Sultan, 2010 and Blanc, 2008), the length of the growing season is the index that shows higher performance insample. It is the only index that almost systematically leads to positive out-of-sample CEI gain estimations. However as shown in the Table C.III, simulation of the sowing date using daily rainfall does not seem to be enough accurate to pool risk significantly. Once more, this result can be interpretated as an evidence of the existence of institutional constraints determinant for explaining late sowing.

Insuring against a late sowing is the most effective contract to reduce the basis risk. However, trying to simulate that observed date does not help [18]. Such result underline either the difficulty to simulate the start of the growing season or the existence of institutional delays. Delays in seed and input delivering, as mentioned by Kaminsky et al. (2011), indeed could explain some late sowing and thus the inconsistence of indices that are only based on daily rainfall observations and not on the observed sowing date.

Using the actual sowing date in an insurance contract is usually difficult because it cannot be observed costlessly by the insurer. However, in the case of cotton in French speaking West Africa, cotton production mainly relies on interlinking input-credit schemes taking place before sowing and obliging the cotton company to follow production in each production group. As mentioned by De Bock et al. (2010), cotton parastatals (i.e. Mali in their case and Cameroon in ours) already gather information about production, yield, input use and costs

18. There is a difference between observed and simulated cropping cycles that could be partly explained by a measure approximation of 10 days in the observed sowing date.

and the sowing date in each region. It would thus be available at no cost to the department of production at the Sodecoton Under those circumstances observing sowing date, making it transparent and free of any distortion and including it in an insurance contract would not be so costly.

There are also potential moral hazard issues when insuring against a lately declared sowing date. However, in our case, the sowing date is aggregated at the sector level (about 55 GP each representing about 4 000 producers, i.e. about 200 per GP). This means that a producer, and even a coordination of producer within a GP, is not able to influence the average sowing date at the sector level by declaring a false date.

It is interesting to observe that the theoretical result of Clark (2011) seem to be realised. As found in Leblois et al. (2011, Chap. 4), a high risk aversion lead to higher the impact of basis risk on the expected utility. It means that an agent who show very high risk aversion could be reluctant to buy insurance if it shows significant basis risk.

5.4.3 Implicit intra-annual price insurance

As already mentioned by Boussard et al. (2007) and Fontaine and Sindzingre (1991), cotton parastatals in WCA buy cotton at pan-seasonally and pan-teritorially fixed price, that is varying marginally depending on cotton quality at harvest [19].

Our argument is the following: as Sodecoton announces harvest price at sowing, the firm insures growers against international intra-seasonal price variations. Furthermore, looking at the variation of sectoral yields and intra-annual international cotton price variations, the latter seem to vary two times more than the first one when considering the harvest before the 1994 devaluation and the year 2010 which see a peak of cotton price (coefficient of variation of .28 for yield vs. .42 for intra-annual international cotton price) and at least of the same order

19. Those prices are announced before sowing and a bonus is payed at harvest when the international prices allows it.

without both those very specific years (.20 for intra-annual international cotton price). However, both major shocks are positive shocks and thus do not radically modify the following analysis in terms of downside risk.

Sodecoton possibly offers such implicit price insurance at a cost, it is however very difficult to compute such cost. We will thus consider it is a free insurance mechanism, this does not affect the scope of the argument saying that the level of the price risk relatively to other risks.

Table 5.VIII: CEI gain of intra-annual price and yield stabilisation (insample parameter calibration) in each rainfall zones (RZ) and in the whole cotton zone (CZ)

	RZ1	RZ2	RZ3	RZ4	RZ5	**CZ**
CEI gain of intra-annual price stab. (MASD, ϕ=.5)	3.07%	0.19%	3.49%	4.53%	4.78%	2.49%
CEI gain of intra-annual price stab. (CARA, ψ=2/W)	5.41%	4.96%	7.23%	8.84%	6.66%	6.72%
CEI gain of intra-annual price stab. (CRRA, ρ=2)	10.28%	11.33%	12.85%	17.85%	11.84%	12.98%
CEI gain of yield stab. (MASD, ϕ=.5)	2.81%	1.48%	3.26%	1.61%	3.21%	0.80%
CEI gain of yield stab. (CARA, ψ=2/W)	1.49%	1.07%	1.00%	1.77%	.40%	1.06%
CEI gain of yield stab. (CRRA, ρ=2)	3.09%	2.88%	1.91%	3.75%	.74%	2.30%

Contrarily to inter-annual price variations that can be integrated in and compensated by cultivation and input decisions at sowing, intra-annual price variations cannot. We computed the relative variation between the average price during a 4 months period before sowing and compared it to the 4 month period after harvest [20]. It allows us to simulate the profit variations resulting from intra-annual price variations and to compute the gain in term of CEI of the implicit insurance offered by the cotton company. Table 5.VIII shows the gain due to the stabilization of intra-annual cotton price variations as compared to the gain of a stabilization of sectoral yield levels (fixed to the average sectoral yield) with the observed yield distribution in each rainfall zone. The last column of Table 5.VIII shows the CEI gain brought by the stabilization of intra-annual cotton international price level during the 1991-2007 period.

20. Figure C.5 in the Appendix shows the observed distribution of profit of one hectare of cotton, the distribution without any inter-annual cotton and input price variations (black) and the distribution with intra-annual price variations (red). The figure shows that the inclusion of intra-annual price variations has a much larger impact on income risk than inter-annual observed price variations.

As a conclusion, we can say that the complete stabilization of yield bring a gain in CEI that is lower than the implicit insurance already offered by the cotton company.

5.5 Conclusion

The main conclusion we can draw from such results is that one should be cautious when designing and testing ex ante insurance contracts, this for two reasons. First, we show that considering a large area, with potentially different agro-ecological zones, leads, in our case, to significant cross subsidisation. It underlines the need for a precise calibration fitting local climate characteristics, even for a unique crop and in a bounded area. Cutting the cotton growing zone into smaller units, of about 1 decimal degree according to annual rainfall levels, shows that the southern part of the zone will benefit much less from such an insurance scheme. We argue that calibrating a contract that will be worth implementing is not trivial and seem to need precise agrometeorological data with a significant density of observations (depending on the spatial and inter-annual variability of the climate), at least for the Sudano-sahelian zone. This result is able to explain the very low observed take-up rates found when index based insurance where offered to farmers (i.e. Cole et al., 2012). As already mentioned in Leblois et al (2011), insample calibration tend to overestimate insurance gains. In the light of the out of sample results, the basis risk seem to have a significant impact on certain equivalent income, even when calibrating the contract parameters in order to maximise the growers expected utility.

We also show that offering rainfall index-based insurance for cotton growing in Cameroon is only able to smooth yield if the observed sowing date is available. In accordance with the agronomic literature, we found the length of the growing cycle, that determines the growing potential of the cotton tree, to be the best performing index for cotton. Moreover, insuring against a late sowing seems efficient. It however poses some moral hazard issues that probably could be

overcome by the design of sowing date monitoring by the cotton companies. The revelation of sowing dates at low costs is indeed possible in many WCA countries, were the cotton company still plays a large role in cotton cultivation campaigns.

The basis risk, as defined by the relative performance of index-based insurance to an area-yield insurance, is generally high. However, one should consider the costs of yield (or alternatively damage) observations and moral hazard issues to make a trade off between both options. In the case of cotton in a sector managed by a parastatal, such as in Cameroon where the observation of yield is already implemented at the sector level, the gain of index-based insurance has to be compared with those latter costs.

Finally we show that the gain of implicit insurance against intra-village price variations, offered by the Cameroonian cotton company by announcing a minimum guaranteed price at the beginning of the cultivation period, is comparable, if not higher, to the maximum equivalent income gain of an index-based insurance. This conclusion could be put into perspective under the light of the study of the firsts chapter (1 and 2) about cotton sector reforms. International institutions indeed ask African countries to liberalise their agricultural sectors since the 90's, which also lead to abandon guaranteed price mechanisms, as it is the case in Mali in 2005, indexing the cotton purchasing price on international cotton prices.

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CONCLUSION

5.6 Vers un changement de paradigme ?

Les recommandations émanant des institutions touchant au développement rural en Afrique visent souvent à intensifier l'agriculture et augmenter la taille des exploitations pour augmenter la productivité. Or transférer les techniques qui ont fait leurs preuves dans d'autres endroits du monde et à une autre époque, mais qui sont aujourd'hui également connues pour causer des dégâts environnementaux qui limitent ces progrès dans le long terme, devrait peut-être inciter à la précaution et donc à repenser certaines méthodes. R. Dumont suggérait déjà en 1963 que les pays africains font fausse route en imitant le modèle agricole occidental. Ces conclusions sont renforcées aujourd'hui par le constat de l'irréversibilité de ces pratiques, encore relativement rares sur le continent africain. Il convient dès lors peut-être de profiter des erreurs du passé et de permettre de construire sur celles-ci pour développer le secteur agricole en Afrique. On peut voir la question de l'adoption de technologie à travers le prisme de l'opposition entre traditionalisme et modernisme, mais la coévolution des deux pratiques pourrait peut-être permettre d'innover en respect des contraintes respectives que s'imposent ces deux visions du monde. Il semble que le défi du XXIe siècle pour l'agriculture Africaine sera de dépasser le dualisme entre agriculture moderne et traditionnelle. C'est ce que nous allons tenté d'illustrer par quelques exemples concrets.

La révolution verte asiatique a été portée par les interventions des États, par le biais de subventions ou de mesures de soutien aux prix, qui ont notamment permis aux prix des fertilisants d'être 25% inférieurs au prix de marché. Mais en plus d'être incertaines du point de vue de l'équilibre des finances publiques, ces politiques ont mené à un mauvais usage des sols et à leur dégradation (Pingali et Rosegrant, 1994). Le consensus autour de la nécessité d'une révolution verte en Afrique est universel, mais les caractéristiques structurelles du continent africain semble appeler à un changement de paradigme et à davantage de précaution quant

à l'intérêt de l'application des recettes du passé.

L'Afrique est, contrairement à l'Asie, très hétérogène en terme de conditions agro-écologiques, de cultures et de pratiques. La FAO considère qu'il existe 14 systèmes d'exploitation agricole différents reposant sur d'autres plantes que le riz et le blé qui ont été les moteurs de la révolution verte asiatique. La plupart de ces systèmes dépendent de la pluie car ils ne disposent pas d'infrastructures d'irrigation (4% des terres seulement en disposent contre 34% en Asie et 14% en Amérique Latine, selon FAOSTAT, 2007 ; De Janvry and Sadoulet 2009 et Svendsen et al., 2009).

Depuis la fin des années 90 on sait que la fertilité des terres du continent suit une tendance à la baisse et que l'utilisation d'intrants organiques est une solution durable pour faire face au déficit d'offre d'intrants chimiques de qualité sur le contient (Yanggen et al., 1998). Contrairement à ce que l'on pensait dans les années 80, de nombreuses combinaisons plante-environnement ne sont pas propices à l'usage de fertilisants chimiques, trop coûteux. Au Sud, il semble qu'il faille éviter le recours aux énergies fossiles, carburants ou engrais de synthèse, du fait de leur coût croissant. L'exemple du renchérissement du phosphate, ressource minérale épuisable, ou des produits azotés dont la production est intensive en énergie est parlante. C'est aussi dans le contexte des chocs pétrolier que Jacques Poly lance en 1978 sa formule d'une agriculture plus économe et plus autonome, concept sur lequel nous reviendrons par la suite.

Il semble donc que la libéralisation des marchés de fertilisants ne soit pas une étape suffisante pour résoudre des problèmes techniques, ni les problèmes fondamentaux des hauts coûts de transaction et des risques qui limitent l'incitation et d'une pauvreté omniprésente en milieu rural limitant les capacités des acteurs. Finalement, le très faible niveau d'infrastructures, routières en particulier, rendent de nombreux pays enclavés et les marchés intérieurs peu intégrés au marché mondial, même si le niveau d'intégration aux marchés régionaux est très important (Araujo-Bonjean et al., 2008).

En revanche des améliorations à la marge de l'environnement peuvent permettre de rendre leur usage rentable, en particulier en micro-dosage comme dans le chapitre IV, et empêcher l'installation de cercles vicieux de faible demande et d'un développement très limité des réseaux de distribution. Ceci passera, selon de nombreux auteurs (entre autres Yanggen, 1998 et Faure et al., 2004) par la mise en œuvre de services et conseil agronomiques inclusifs et de la recherche participative permettant un échange entre utilisateurs et développeurs.

De même, l'intérêt du développement de nouvelles technologies, qui peut paraître nécessaire en premier lieu, se heurte parfois à une analyse de long terme remettant en cause leur utilité à l'instar des biotechnologies dont nous avons parlé en introduction. Ces dernières tendent à remplacer variétés sélectionnées au risque d'une potentielle réduction de la biodiversité, entraîné par leur dissémination. Le développement de variétés (OGM ou sélectionnées) est relativement lent, les recherches prenant beaucoup de temps avant d'être validés : Eicher et al. (2006) estiment que l'usage généralisé de plants transgéniques ne se fera que dans 10 ou 15 ans. De plus, certains responsables politiques africains sont sceptiques quant à l'intérêt des biotechnologies du fait des inquiétudes des consommateurs envers les conséquences de ces technologies sur la santé et l'environnement dans les pays européens. Finalement l'utilisation de brevets pour stimuler la recherche rend l'utilisation de semences améliorées et/ou certifiées coûteuses pour les producteurs et risque de les rendre dépendants de ces ressources.

Cette problématique a particulièrement évolué face aux nouvelles contraintes et à la triple crise qui touche l'économie mondiale (écologique, financière et humanitaire). C'est en cela que l'idée d'une agriculture écologiquement intensive, utilisant un fort degré de nouvelles technologies, le cycle du carbone, de l'azote, mais aussi la connaissance aigüe des phénomènes biologiques pour favoriser les synergies et limiter les effet secondaires se développe au Nord, constitue une alternative intéressante aux recommandations usuelles. Une telle analyse nécessite une multidisciplinarité (agronomie, anthropologie et économie institutionnelle et

comportementale...) tant les complexités des phénomènes à l'œuvre sont difficilement appréhendable au sein de chacune de ces disciplines. De même un retour vers des services de vulgarisation et de conseil agricole pourrait être envisagé, peut-être avec une approche plus participative et inclusive. C'est pourquoi les changements organisationnels parce qu'ils modifient les incitations sans être trop coûteuses et sans imposer structurellement des changements irréversibles aux générations futures semblent être des outils efficaces pour faciliter le développement d'une agriculture écologiquement intensive.

5.7 Bilan de deux réponses organisationnelles

Nous avons, dans un premier temps, tenté de montrer que les réformes qui ont lieu depuis le milieu des années 90 dans le secteur du coton en Afrique sub-Saharienne, ne sont pas de la même nature que celle qui les précédèrent. Comparant l'évolution d'indicateurs objectifs de structure de marché dans 25 pays sur la période 1961-2008, nous avons aussi pointé du doigt le fait que l'évolution vers une libéralisation des marchés qui caractérisa les pays anglophones dans années 80 s'est quelque peu estompée depuis. Ceci est en partie dû à la difficulté des secteurs coton des pays de l'ancienne zone CFDT à s'accommoder aux contraintes structurelles des institutions internationales. La mise en œuvre de réformes a en effet été très différente selon les zones. Les systèmes de provisions d'intrants et de services de vulgarisation n'ont que très rarement été remis en cause dans les pays francophones d'Afrique de l'Ouest et du Centre, même après régulation du secteur. Cette difficulté est particulièrement due à la spécificité de ces secteurs qui sont fondés sur une interdépendances des acteurs du marché dont la coordination ne peut avoir lieu sans une certaine intégration verticale du marché.

La volonté d'estimer l'effet des réformes nous amène à définir trois niveau de libéralisation : la régulation, la faible et la forte mise en concurrence des acheteurs de coton graine. Dans les pays anglophones, la régulation des *boards*[21] n'ont pas

21. Équivalent des filières devenues entreprises en monopsone, gérant le secteur, de la culture

empêché les crises de défaut sur le crédit et les problèmes de distribution des intrants.

Le crédit aux intrants au semis, est en effet la source principale de la relation particulière entre l'acheteur en monopsone dans le schéma des filières coton de l'ancienne CFDT, qui prévaut encore au Cameroun, au Mali, au Sénégal, et au Tchad. Or ce crédit, dont la seule garantie est la revente de la récolte au même créancier, est la clef de l'intensification des filières coton en Afrique de l'Ouest et du Centre. Ceci pour trois raison : premièrement du fait du manque de moyens pour investir en fin de période de soudure (absence de marché du crédit), ensuite de l'absorption du risque intra-annuel de variation du prix du coton à l'international [22] et finalement de l'offre d'intrants de qualité adapté aux modes cultures locaux.

Or ce schéma, en particulier la fourniture d'intrants à crédit, semble difficilement compatible avec la mise en compétition de plusieurs acheteurs/égreneurs sur le marché. De plus l'investissement en infrastructure et en recherches et l'approvisionnement en semences, l'offre de conseils agronomiques et de services de vulgarisation sont aussi des composantes de ces filières, qui de nouveau, peuvent-être mises à mal par la mise en place d'acheteurs concurrents sur les marchés.

La description du contexte de réformes et l'élaboration d'un indicateur de structure de marché nous a ensuite permis d'analyser l'impact des différents types de réformes sur deux indicateurs de la performance des secteurs cotonniers nationaux, que sont le rendement (productivité) et les surfaces cultivées (taille du secteur). Nous montrons que la mise en place de réformes vers une concurrence forte, toutes choses égales par ailleurs, réduit les surfaces cultivées. C'est, selon nous, ce qui permet une hausse de la productivité au sein de ces secteurs, par le

jusque l'égrenage et souvent même la commercialisation du coton graine dans la zone Francophone.

22. Le prix d'achat du coton graine est fixé à la récolte, et la plupart du temps maintenu jusqu'à la récolte. Il existe aussi des fonds de stabilisation au sein des sociétés cotonnières, aussi souvent exercées par l'organisations de producteurs comme c'est le cas au Cameroun, facilitant l'absorption d'une partie des variation inter-annuelles du prix international du coton.

biais d'un effet de sélection (des meilleurs ou les plus gros producteurs, cultivant leurs meilleures terres). Il semble toutefois que la baisse des surfaces dans les filières fortement concurrentielles ne compensent pas la hausse des rendements, amenant à une baisse de la production dans ces derniers cas. Une telle évolution peut donc être souhaitable pour le développement d'une agriculture commerciale, mais semblent difficilement compatible avec les objectifs de réduction de la pauvreté, souvent mis en avant dans le cas des filières coton qui fournissent un revenu monétaire à près de 15 millions de producteurs. C'est, de plus, une des première source de devises pour 15 pays du continent (75% au Bénin, 50% in Mali and 60% in Burkina Faso dont le coton représente près d'un tiers du PIB). Un signal consistant de hausse des rendement et des surfaces cultivées dans les filières régulées et privatisées semblent toutefois montrer que certains déboires dus au caractère monopolistique des secteurs qui n'ont pas été réformés du tout, pourraient être évités (fixation politique des prix, faible pouvoir de négociation de producteurs...). Il semble finalement qu'il faille faciliter la mise en œuvre de filières facilitant les relations imbriqués entre producteurs et acheteurs tout en remettant en question de mode de fonctionnement des monopoles nationaux profitant parfois à des élites accaparant la rente en période faste, sans permettre d'éviter les crises de dette des société dans les périodes moins fastes (comme c'est le cas au Tchad).

Dans un second temps, nous avons tenté d'améliorer les connaissances quant à la conception et la calibration des assurances fondées sur des indices météorologiques. Cela nous semble être une étape nécessaire avant l'introduction de tels produits qui, si ils sont inadéquats ou en décalage avec les besoins de agriculteurs, peuvent jouer un rôle négatif sur l'appréhension de cette innovation institutionnelle, probablement utile pour le futur de l'adaptation de l'agronomie africaine aux risques émergeants.

Nous avons étudié, en particulier, le potentiel d'assurances fondées sur des indices météorologiques dans deux cas particuliers que sont le cas du mil dans la région de Niamey et le cas du coton dans le Nord du Cameroun.

Dans le premier cas nous avons montré que les gains à l'assurance doivent prendre en compte la distribution des rendements au sein du village. Nous montrons aussi dans ce cas, que les gains réalisés grâce à des indices simples, ne souffrant pas d'un déficit de confiance auprès des producteurs du fait d'une élaboration complexe, sont largement comparable à ceux d'indices plus complexes. Nous avons enfin pointé l'importance de la prise en compte de l'over-fitting et la nécessité de la cross-validation, ce que nous réalisons par une méthode de leave-one-out. Mais nous avons aussi cherché à tester, dans ce contexte, si l'utilisation d'intrants peut dépendre des incitations qui sont améliorés par des changements organisationnels comme la réduction des risque grâce à l'usage d'assurance météorologiques.

Dans le cas du coton au Cameroun, nous avons mis en exergue l'importance de la prise en compte d'une aire géographique importante (ce qui n'était pas le cas au Niger) nécessite une analyse précise des relations agro-météorologiques, souvent différentes dans différentes zones. Nous discutons ensuite la nécessité d'utiliser les dates de semis observées, ce qui ne semblait pas primordial dans le cas du mil au Niger. Le fait que la filière coton au Cameroun soit une filière organisée, joue potentiellement un rôle dans ce résultats pointant soit la limite des critère météorologique dans le choix de la date de semis, soit l'existence de contrainte institutionnelles dans ce choix, comme des retards dans les livraisons de graines et d'intrants.

Nous avons finalement montré l'impact limité d'une telle assurance, du fait d'un fort risque de base. Ceci vient conforter les résultats de la première analyse au Niger. Finalement cet impact semble limité en terme de réduction de la variabilité du profit, surtout en comparaison à une autre source de risque : la variabilité intra-annuelle des prix internationaux. En effet la variabilité du profit des producteurs dépendrait largement autant de la variations intra-annuelle des prix internationaux que des risques météorologiques si la société cotonnière n'annonçait pas un prix en début de période de culture.

Il nous semble donc possible de relier les constats réalisés dans le premier et le dernier chapitre de la thèse. Nous constatons d'abord dans le premier chapitre que les organisations internationales poussent à la libéralisation de filières. Ceci tend, plus ou moins directement, à la disparition des systèmes de protection face aux variations de prix internationaux. En effet, la libéralisation des filières poussent à indexer les prix sur le prix international du cotton, comme ce fut le cas en 2005 au Mali qui vu disparaître le système de prix minimum garantie indexé sur les coûts de production. D'autre part, les même institutions poussent à la recherche, au développement et à la mise en œuvre dans les même pays, de systèmes de protection contre le risque climatique. Il semble contradictoire de la part des institutions internationales de promouvoir le démantèlement des monopoles nationaux sans prévoir de compensations permettant une stabilisation des prix offerts aux producteurs, alors qu'ils favorisent, d'autre part, le développement de mécanismes visant à réduire le risque météorologique. Ceci semble contradictoire dans la mesure où le premier risque est largement comparable au second, au moins dans le cas des producteurs de coton Camerounais. Toutefois on peut remarquer que des système d'options pourraient permettre de conjuguer les réformes, poussant à intégrer les contraintes de prix internationaux et la stabilisation des prix d'achat aux producteurs.

Finalement, il nous semble que par le renforcement des organisations paysannes existantes, les bailleurs internationaux pourraient renforcer le pouvoir de négociation des producteurs et de rendre plus transparente la gestion des filières cotonnières dans les pays qui n'ont pas libéralisés, tout en permettant d'atteindre les objectifs de réduction de la pauvreté.

5.8 Travaux futurs envisagés

Dans le cas du Cameroun, il nous semble intéressant d'approfondir la dimension des choix individuels par le biais de données micro-économiques plus détaillées, par exemple celle recueillies dans le cadre du terrain au Nord-Cameroun

en Décembre 2011. D'autre part, le dernier article pourrait bénéficier d'une analyse d'économétrie structurelle qui permettrait d'expliquer les déterminants des choix de surfaces cultivées, grâce à des données très détaillées, au niveau secteur, sur la période 1998-2010. Ces dernières jouent en effet un rôle important, tant dans le second que dans le dernier chapitre. Il nous semble que le second chapitre pourrait aussi être enrichi d'une analyse incluant les prix offert aux producteurs et l'existence et le poids des organisations paysannes, en particulier dans la négociation pour l'achat du coton.

Il serait aussi intéressant, afin de donner une perspective opérationnelles aux conclusions du dernier chapitre, de proposer l'imbrication d'une indemnisation sur le système de primes existant. Cette indemnisation pourrait-être forfaitaire ou linéaire en fonction de l'indice choisi et la zone de pluie. Le système de prime actuel est en effet extrêmement complexe et peu lisible et il semble très peu incitatif au niveau individuel. Incorporer une incitation, non négligeable, à atteindre un niveau de rendement indexé sur le potentiel de rendement indiqué par l'indice météorologique, pourrait en effet permettre de rendre cet objectif atteignable et enfin de limiter les déclarations abusives de surfaces cultivées en coton, ces dernières donnant droit au crédit aux intrants. Ceci peut-être réalisé au niveau du secteur ou même du groupe de producteur.

Nous chercherons donc par la suite à exploiter les données géoréférencées et d'appréhender la transmission des chocs météorologiques. L'exploitation de données micro-économiques pourrait révéler les variables déterminantes dans la transmissions de la vulnérabilité des ménages et peut-être des éléments constitutifs de la résilience (par exemple grâce à l'usage de données de panel). Ce travail a été engagé en croisant les variables anthropométriques des enquêtes DHS avec une base de données météorologiques mondiale (CRU) et d'un indice de végétation issu d'observation satellite : le NDVI (MODIS). Les données de poids, de taille et d'indices de masse corporelle peuvent permettre d'estimer l'ampleur des chocs météorologiques et de production depuis les années 80, sur les femmes interogées

n'ayant pas migré depuis leur naissance, grâce à la variation de la dimension temporelle offerte par la révélation de l'âge des individus.

Finalement l'adaptation aux changement futurs, comme les changements climatiques prévus par les modèles de climat, dépend de choix issu de l'analyse des comportement, l'appréhension du risque est indissociable de celle de l'ambiguité qui réside dans les évènements incertains, caractéristique intrinsèque (au moins en partie) à tout risque météorologique ou de climat de long terme.

Nous aimerions aussi continuer les recherhes sur la complexité de la notion d'aversion pour le risque au niveau individuel. Ceci par exemple par le biais d'expérimentations sur les choix techniques et plus généralement les décisions productives et d'investissements pour l'adaptation en univers incertain. En effet l'appréhension de l'ambiguité est intrinsèque aux risques météorologiques et cette spécificité semble être un sujet de recherche stimulant, en particulier dans le contexte africain. L'adaptation au changements est une caractéristique de nombreuses sociétés traditionnelles africaines, il pourrait être intéressant de mieux comprendre comment l'adapation et l'appréhension de ces risques et de cette ambiguité, façonne les relations entre les membres de réseaux de solidarité. Nous voudrions exploiter les cause de la formation des échanges solidaires et le potentiel rôle des chocs (par exemple météorologiques) passés. Il semble que cette capacité d'adaptation soit une force majeure des sociétés rurales, bientôt probablement contraintes à faire évoluer les modes de production comme nous l'avons décrit dans la partie précédente.

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Annexe A

Appendix for the second chapter

A.1 dataset and variable description

A.1.1 Dataset

Our regressions exclude pre-independence observations in countries where independence was gained post-1961 as we lacked sufficient information to adequately characterize market structure in the pre-independence period. Our panel has a maximum of 766 observations (up to 48 years for 16 countries).

A.1.2 Dependant variable

Data for production (000 Tons), area (000 Ha) and yields (Kg/Ha) are taken alternatively from the Food and Agriculture Organization of the United Nations (FAO) or alternatively from the International Cotton Advisory Committee (ICAC). ICAC data are used as a robustness check, we found very similar results with that other dataset, however due to space issues we did not displayed the results in this article.

A.2 Weather indices

In each regressions we control for weather indices including the lenght of the cropping season, the cumulative rainfall and the maximum and average temperature over this season.

Following Schlenker and Lobell (2010), rainfall and temperature are defined as average cumulative rainfall during the cotton growing season, over all .5 by .5 degree grid cells falling in a country's boundaries, weighted by the share of crop land dedicated to cotton cultivation in each grid cell. These shares are taken from Monfreda et al. (2008). They are based on national and subnational statistics

matched with estimated potential for cotton cultivation for the year 2000 at the 5 arc-minute level. The major limitation associated to the use of this dataset is the fact that it rests on a static estimation of land use as it is only available for 2000 (there is however, to our knowledge, no any other data that can overcome such drawback). However the potential for cultivating cotton (estimated with satellite data and agricultural inventories) is little submitted to time variations. This should therefore affect our estimation only marginally. The onset and offset of the growing season are defined, as in Blanc et al. (2008), by fixed percentages of annual rainfall (the onset of the rainfall season is triggered by a rainfall superior to 5% of annual cumulative rainfall and the offset.

We specify a quadratic impact of each of these variables (rainfall, length of the rainy season, maximum and average temperature) in each yield regressions since it was found to have a significant impact in Blanc et al. (2008). Concerning area regressions, weather indices were included but only those of month before the onset when farmers can sow. Area sown with cotton is indeed fixed at the sowing and can not be impacted by later weather variables.

Weather indices, contrary to dependant variables, are not log-transformed, following Schlenker and Lobell (2010) and Blanc (2012). We thus use Kennedy (1981) for computing elasticities and then final impact on production.

A.3 Climatic cotton growing zones

We control for the existence of different impact of weather variables in each of different cultivation zones by adding interaction terms for each of them. Cotton is mostly grown under (relatively dry) sub-humid tropical savanna, however the availability of water diverge within this climate. This strategy seems justified since we find that a number of them are significant. We distinguish between four climatic cotton cultivation zones :

- The Sudano-Sahelian (semi-arid) climate zone includes Burkina-Faso, Chad, Mali, Nigeria and Senegal. It is characterized by an estimated average of

990 mm annual cumulative rainfall on the period considered.

- The Guinean (sub-humid) climate zone includes Benin, Cameroon, the Ivory Coast and Togo. It is more humid, with 1250 mm of annual cumulative rainfall on average.
- The semi-arid eastern zone zone includes Kenya, Zimbabwe and Zambia. It is the driest part of Eastern Africa, with annual cumulative rainfall of 810 mm on average.
- The sub-humid eastern zone includes Mozambique, Tanzania, Uganda and Malawi. It is characterized by 1100 mm of annual cumulative rainfal.

A.4 Conflict

Three binary dummy variables are considered, each indicating whether at least one conflict of three types occurred during year t in country i. 'Conflict Type 2' indicates an interstate armed conflict, 'Conflict Type 3' an internal armed conflict opposing the government to one or more internal opposition group(s) and 'Conflict Type 4' an internationalized internal armed conflict occurring between a government and one or more internal opposition group(s) with intervention from other states (UCDP/PRIO, 2009 : codebook). The first type reported in the database, Conflict Type 1, is excluded as it refers to conflicts occurring between a state and a non-state group outside its own territory.

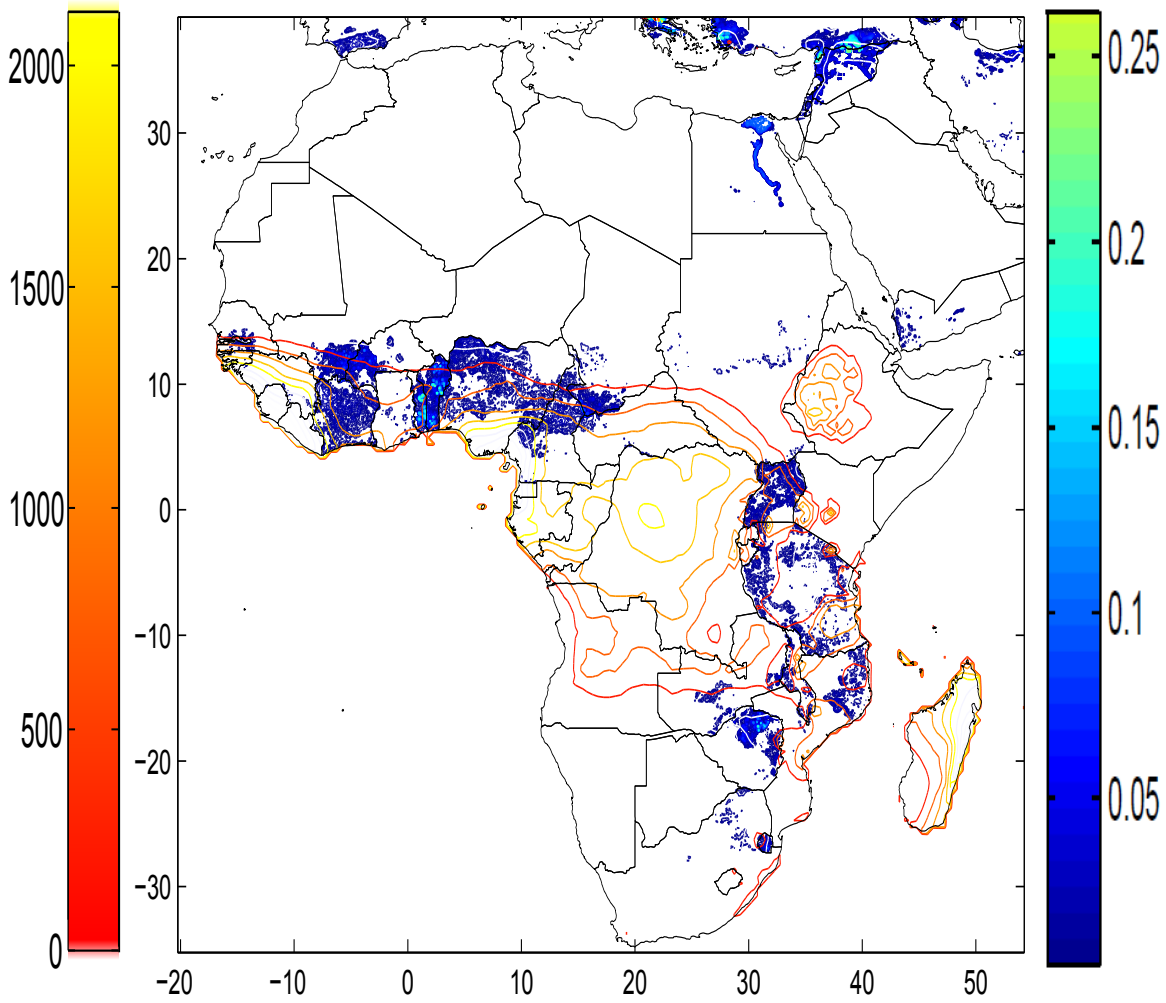

FIGURE A.1 – Isohyets (annual cumulative rainfall, lefthand legend in mm) and intensity of cotton cultivation in 2000 (righthand legend in %), Source : CRU TS3.0 (Climate Research Unit, University of East Anglia, 2011) & Monfreda et al. (2008).

Annexe B

Appendix for the fourth chapter

B.1 In-sample calibrations

TABLE B.I – Parameters of index insurance policy : *calibrated on the whole sample*

	$\rho = .5$	$\rho = 1$	$\rho = 2$	$\rho = 3$	$\rho = 4$
M (maximum indemnification) in kg of millet					
CR_{obs}-based insurance	0	129	109	109	99
BCR_{obs}-based insurance	0	129	129	119	109
CR_{siva}-based insurance	0	139	149	119	119
BCR_{siva}-based insurance	0	119	139	129	119
$WACR_{siva}$-based insurance	0	119	129	129	119
$WABCR_{siva}$-based insurance	0	109	129	119	109
λ (slope related parameter)					
CR_{obs}-based insurance	0	1	1	1	1
BCR_{obs}-based insurance	0	.95	.95	.95	.95
CR_{siva}-based insurance	0	1	1	1	1
BCR_{siva}-based insurance	0	1	1	1	1
$WACR_{siva}$-based insurance	0	1	1	1	1
$WABCR_{siva}$-based insurance	0	1	1	1	1
Strike					
CR_{obs}-based insurance	.	370	389	389	389
BCR_{obs}-based insurance	.	350	350	350	350
CR_{siva}-based insurance	.	303	303	359	359
BCR_{siva}-based insurance	.	321	321	321	321
$WACR_{siva}$-based insurance	.	197	197	197	197
$WABCR_{siva}$-based insurance	.	187	187	187	187
Annual premium in kg of millet					
CR_{obs}-based insurance	.00	16.45	23.65	23.65	21.60
BCR_{obs}-based insurance	.00	24.25	24.25	22.46	20.67
CR_{siva}-based insurance	.00	16.77	17.92	24.23	24.23
BCR_{siva}-based insurance	.00	26.08	30.24	28.16	26.08
$WACR_{siva}$-based insurance	.00	15.22	17.86	16.54	15.22
$WABCR_{siva}$-based insurance	.00	26.08	28.16	28.16	26.08
Rate of indemnification					
CR_{obs}-based insurance	0%	10.56%	10.56%	10.56%	17.70%
BCR_{obs}-based insurance	0%	19.04%	19.04%	19.04%	19.04%
CR_{siva}-based insurance	0%	11.12%	11.12%	18.76%	18.76%
BCR_{siva}-based insurance	0%	16.40%	16.40%	16.40%	16.40%
$WACR_{siva}$-based insurance	0%	19.04%	19.04%	19.04%	19.04%
$WABCR_{siva}$-based insurance	0%	12.08%	12.08%	12.08%	12.08%

Figure 3 shows the indemnification of the CR_{siva}-based insurance across the area and over the period considered. In spite of a relatively low basis risk : most of the low yield situations are indeed insured, the certain equivalent income gain is rather low (1.27%).

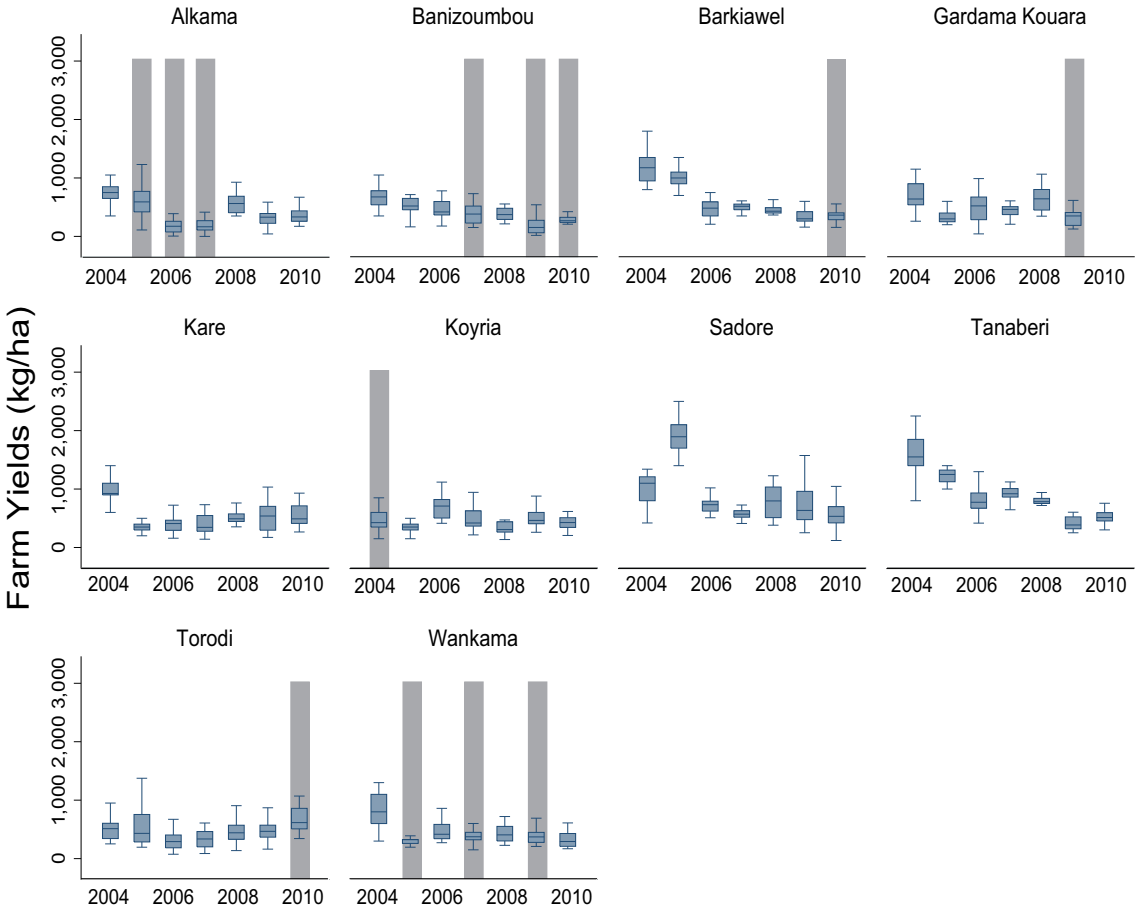

FIGURE B.1 – Indemnities (grey bars : amount to 129kg/ha) of a CR_{siva} based insurance for ρ=2 and box plot of yields by village over the 2004 to 2010 period.

Table B.II – Insurance contract parameters *calibrated on village average yields values*

	$\rho = .5$	$\rho = 1$	$\rho = 2$	$\rho = 3$	$\rho = 4$
M (maximum indemnification) in kg					
CR_{obs}-based insurance	.	142	142	153	153
BCR_{obs}-based insurance	.	131	142	142	131
CR_{siva}-based insurance	.	142	142	153	153
BCR_{siva}-based insurance	.	131	153	164	164
$WACR_{siva}$-based insurance	.	110	131	142	142
$WABCR_{siva}$-based insurance	.	110	121	142	142
λ (slope related parameter)					
CR_{obs}-based insurance	.	1	1	1	1
BCR_{obs}-based insurance	.	.95	.95	.95	.95
CR_{siva}-based insurance	.	1	1	1	1
BCR_{siva}-based insurance	.	1	1	1	1
$WACR_{siva}$-based insurance	.	1	1	1	1
$WABCR_{siva}$-based insurance	.	1	1	1	1
Strike					
CR_{obs}-based insurance	.	370	389	389	389
BCR_{obs}-based insurance	.	334	350	350	350
CR_{siva}-based insurance	.	303	360	360	360
BCR_{siva}-based insurance	.	321	321	321	321
$WACR_{siva}$-based insurance	.	174	198	198	198
$WABCR_{siva}$-based insurance	.	188	216	188	188
Annual premium in kg of millet					
CR_{obs}-based insurance	.00	16.48	32.96	35.40	35.40
BCR_{obs}-based insurance	.00	17.44	25.90	25.90	23.97
CR_{siva}-based insurance	.00	16.48	28.25	30.34	30.34
BCR_{siva}-based insurance	.00	28.33	32.87	35.14	35.14
$WACR_{siva}$-based insurance	.00	14.64	28.07	18.83	18.83
$WABCR_{siva}$-based insurance	.00	18.30	30.51	32.96	32.96
Rate of indemnification					
CR_{obs}-based insurance	0%	10.56%	17.70%	17.39%	17.39%
BCR_{obs}-based insurance	0%	19.04%	19.04%	18.84%	18.84%
CR_{siva}-based insurance	.11%	11.07%	18.76%	20.29%	20.29%
BCR_{siva}-based insurance	.22%	10.67%	16.40%	15.94%	15.94%
$WACR_{siva}$-based insurance	0%	14.83%	20.73%	20.29%	20.29%
$WABCR_{siva}$-based insurance	0%	12.08%	20.45%	11.59%	11.59%

B.2 Out-of-sample calibrations

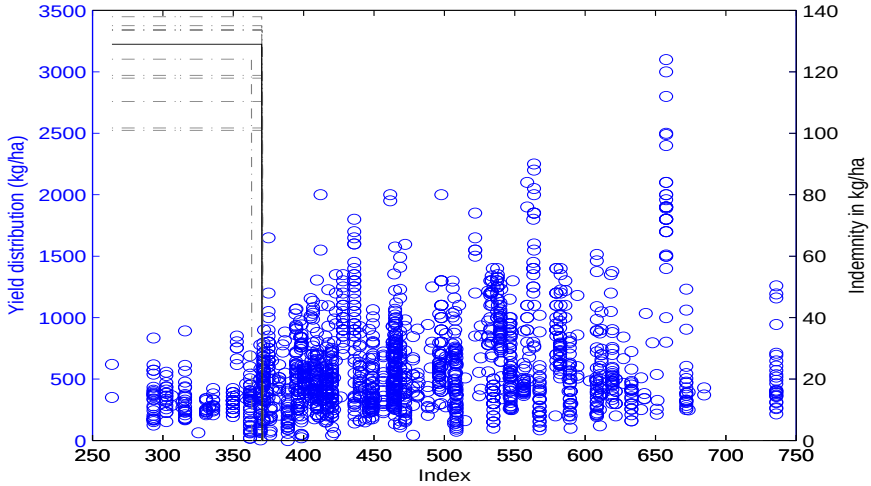

FIGURE B.2 – In-sample (solid line) and out-of-sample (dotted lines) indemnity schedules (kg/ha) for CR_{obs} insurance, for $\rho = 2$ and scatter plot of yield distribution across index.

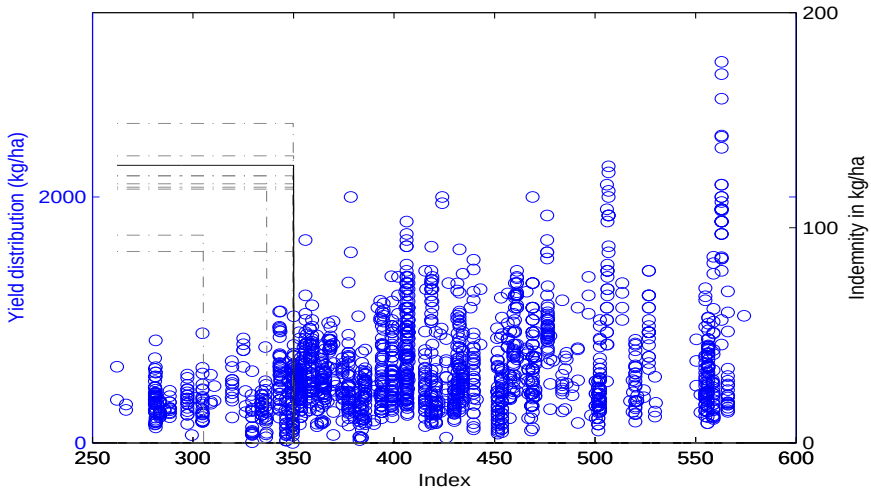

FIGURE B.3 – In-sample (solid line) and out-of-sample (dotted lines) indemnity schedules (kg/ha) for BCR_{obs} insurance, for $\rho = 2$ and scatter plot of yield distribution across index.

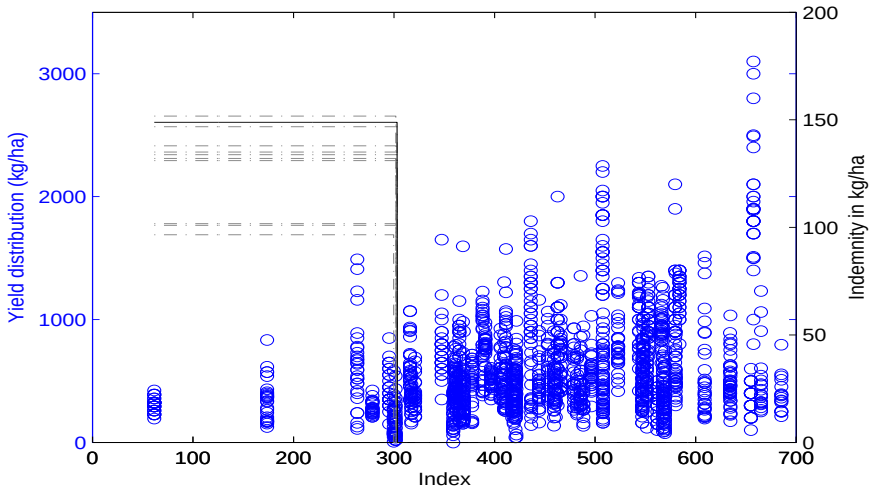

FIGURE B.4 – In-sample (solid line) and out-of-sample (dotted lines) indemnity schedules (kg/ha) for CR_{siva} insurance, for $\rho = 2$ and scatter plot of yield distribution across index.

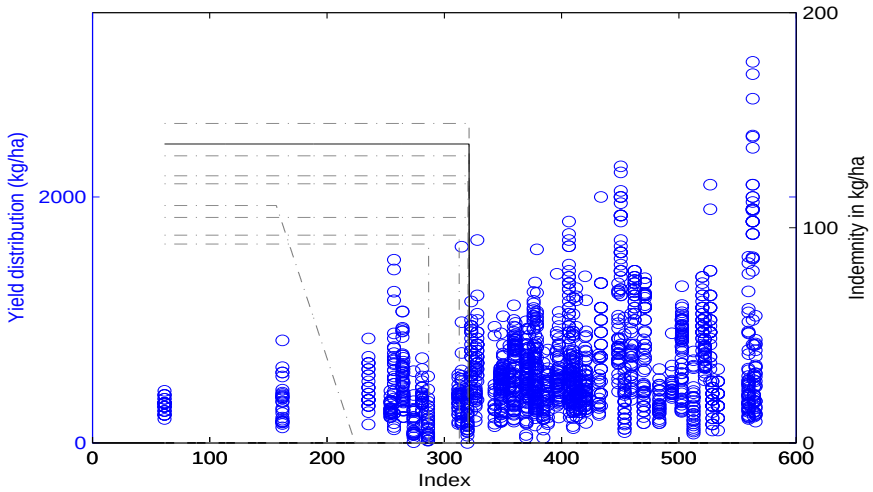

FIGURE B.5 – In-sample (solid line) and out-of-sample (dotted lines) indemnity schedules (kg/ha) for BCR_{siva} insurance, for $\rho = 2$ and scatter plot of yield distribution across index.

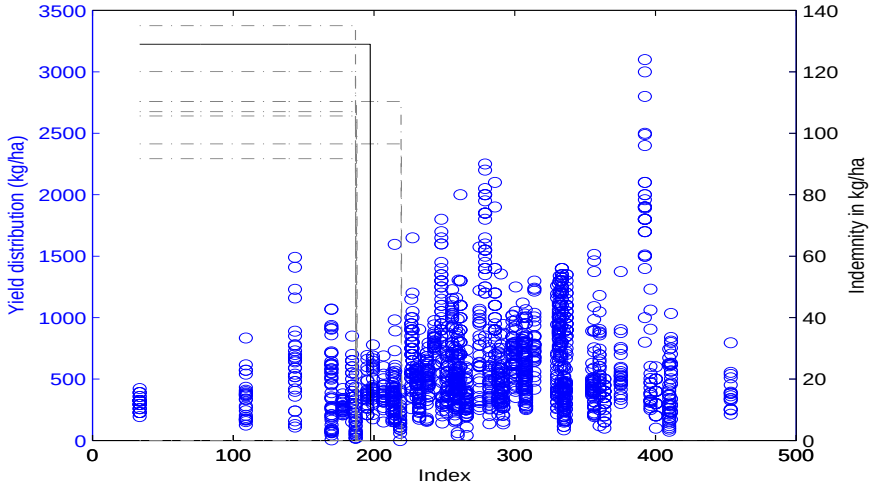

FIGURE B.6 – In-sample (solid line) and out-of-sample (dotted lines) indemnity schedules (kg/ha) for $WACR_{siva}$ insurance, for $\rho = 2$ and scatter plot of yield distribution across index.

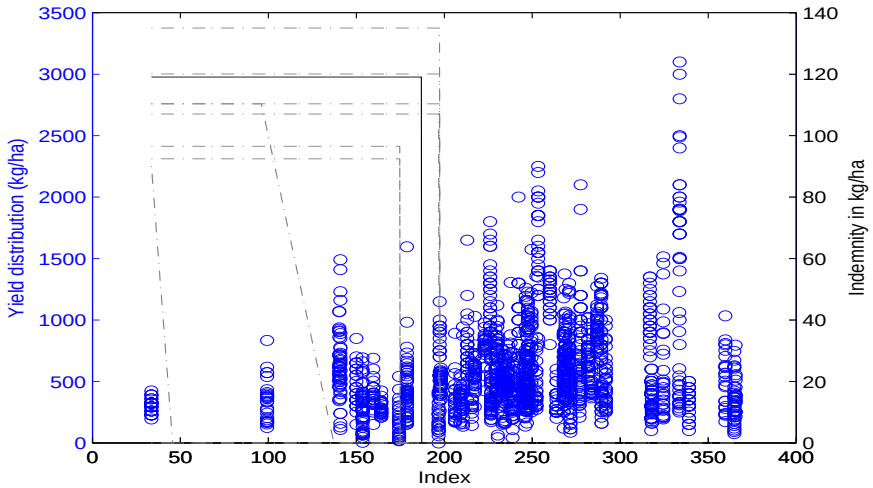

FIGURE B.7 – In-sample (solid line) and out-of-sample (dotted lines) indemnity schedules (kg/ha) for $WABCR_{siva}$ insurance, for $\rho = 2$ and scatter plot of yield distribution across index.

B.3 Robustness checks

B.3.1 Prices

We now take the millet cultivation income (plot income summary statistics are displayed in Table 1) for one hectare and compute the CEI gain associated to the distribution of income for the 2004-2010 period. The only difference between Table 3 and Table 12 is that in the latter, we multiplied the yield by the post-harvest millet price, which varies across years. This does not alter any of the results (ranking of index performance, superiority of indices with bounded daily rainfall and superiority of simulated crop cycles) as shown by the comparison of Table 12 with Table 3. The only difference between Table 3 and Table 12 is that we multiplied the yield by the annual post-harvest millet price for the Table 12, the sample and parameters are all the same in each case.

Table B.III – Average plot income CEI gain of index insurance.

	$\rho = .5$	$\rho = 1$	$\rho = 2$	$\rho = 3$	$\rho = 4$
CR_{obs} ins.	.00%	.19%	.90%	1.91%	3.12%
BCR_{obs} ins.	.00%	.24%	1.21%	2.36%	3.71%
CR_{siva} ins.	.00%	.25%	1.10%	2.32%	4.24%
BCR_{siva} ins.	.00%	.25%	1.46%	3.07%	5.15%
$WACR_{siva}$ ins.	.00%	.10%	.78%	1.75%	3.03%
$WABCR_{siva}$ ins.	.00%	.24%	1.43%	3.04%	5.12%

B.3.2 Initial Wealth

Table B.IV – Average income gain of index insurance

	$\rho = .5$	$\rho = 1$	$\rho = 2$	$\rho = 3$	$\rho = 4$
W_0 **: one third of average yield.**					
CEI gain of CR_{obs}-based insurance	.00%	.24%	.94%	1.93%	3.08%
CEI gain of BCR_{obs}-based insurance	.00%	.28%	1.27%	2.40%	3.68%
CEI gain of CR_{siva}-based insurance	.00%	.31%	1.27%	2.62%	4.65%
CEI gain of BCR_{siva}-based insurance	.00%	.29%	1.52%	3.13%	5.21%
CEI gain of $WACR_{siva}$-based insurance	.00%	.16%	.95%	2.06%	3.52%
CEI gain of $WABCR_{siva}$-based insurance	.00%	.23%	1.38%	2.92%	4.95%
W_0 **: one sixth of average yield.**					
CEI gain of CR_{obs}-based insurance	.00%	.36%	1.48%	3.23%	5.63%
CEI gain of BCR_{obs}-based insurance	.00%	.47%	1.88%	3.83%	6.48%
CEI gain of CR_{siva}-based insurance	.02%	.50%	2.01%	5.06%	10.01%
CEI gain of BCR_{siva}-based insurance	.00%	.54%	2.45%	5.57%	10.39%
CEI gain of $WACR_{siva}$-based insurance	.00%	.32%	1.59%	3.68%	6.50%
CEI gain of $WABCR_{siva}$-based insurance	.00%	.46%	2.27%	5.32%	10.13%
$W_0 = \big((average\, yield)/1.5\big)$.					
CEI gain of CR_{obs}-based insurance	.00%	.10%	.58%	1.08%	1.69%
CEI gain of BCR_{obs}-based insurance	.00%	.08%	.75%	1.44%	2.15%
CEI gain of CR_{siva}-based insurance	.00%	.12%	.71%	1.41%	2.19%
CEI gain of BCR_{siva}-based insurance	.00%	.05%	.83%	1.71%	2.68%
CEI gain of $WACR_{siva}$-based insurance	.00%	.01%	.47%	1.05%	1.73%
CEI gain of $WABCR_{siva}$-based insurance	.00%	.01%	.72%	1.54%	2.47%

Table 13 shows how modifying the initial level hypothesis alters the results of Table 3, displayed in its first part. If risk premium increases when choosing very low levels of W_0 and large values for ρ, we can say that these results are quite robust regarding this hypothesis since with slight modifications (from 1/5 to 1.5 times average yield) the results are of the same order.

B.3.3 Influence of the period used for calibration

As explained above, our results so far are based on only seven years of data (2004-2010), since yield data are not available for a longer period.

However, weather data are available for a much longer period : 1990-2010. Because of this absence of yield data, we cannot optimize an insurance contract over this longer period, but we can apply over this longer period the contracts optimized over 2004-2010, in order to check whether our optimization period is representative or too specific. With this aim, Figure 11 displays the evolution of the CR_{siva} index during the 1990-2010 period in each of the ten villages. Fortunately, the 2004-2010 period does not show significantly lower or higher values of the index than the longer, 1990-2010 period.

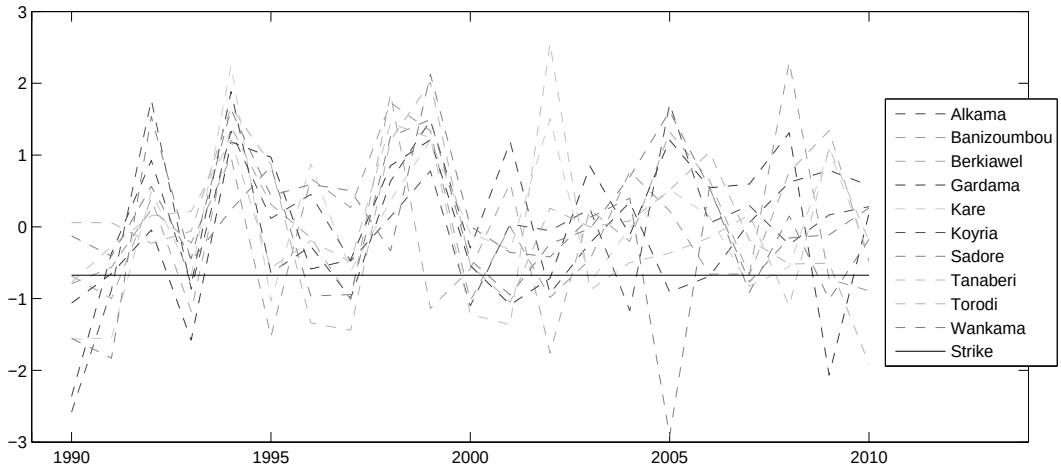

FIGURE B.8 – Evolution of the CR_{siva} index during the period 1990-2010 : the greyscale represents the latitude ; the northern villages are represented in darker grey).

One could also argue that the occurrence of droughts is correlated to locust invasions or other non weather-related events [1]. Such correlation would be a strong issue because it would artificially increase the insurance gain. Fortunately, these damages are reported in the survey we use. We display the correlation matrix between the indices and the non rainfall-related damages in Table 14. Damages are classified in three categories, from the least severe (degree 1) to the most severe (degree 3). Whatever the index, the correlation is lower than 10%, so we are confident that our results are not due to a spurious correlation between drought and locust invasions.

Table B.V – Correlation beween non rainfall-related damages (occurrence in percent of plots in a village) and indices.

	Non rainfall-related damages (NRD of degre 3)	NRD (degre 2 and 3)	NRD (degre 1, 2 and 3)
CR_{obs}	-0.050	-0.064	-0.083
BCR_{obs}	-0.044	-0.1055	-0.100
CR_{siva}	0.001	0.0173	0.025
BCR_{siva}	0.01	-0.000	0.029
$WACR_{siva}$	0.037	0.069	0.081
$WABCR_{siva}$	0.045	0.0427	0.076

B.4 Incentive to use costly inputs

1. We thank an anonymous referee for suggesting this robustness check.

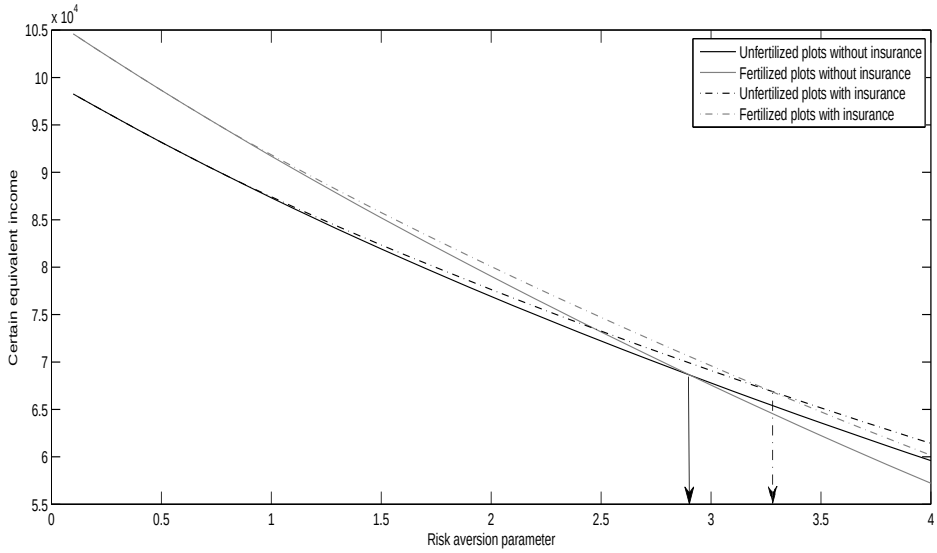

FIGURE B.9 – CEI (in FCFA) of encouraged and regular plots without (plain lines) and with BCR_{obs} based insurance (dotted lines), depending on the risk aversion parameter, ρ and an initial wealth (W_0) of 1/3 of average income.

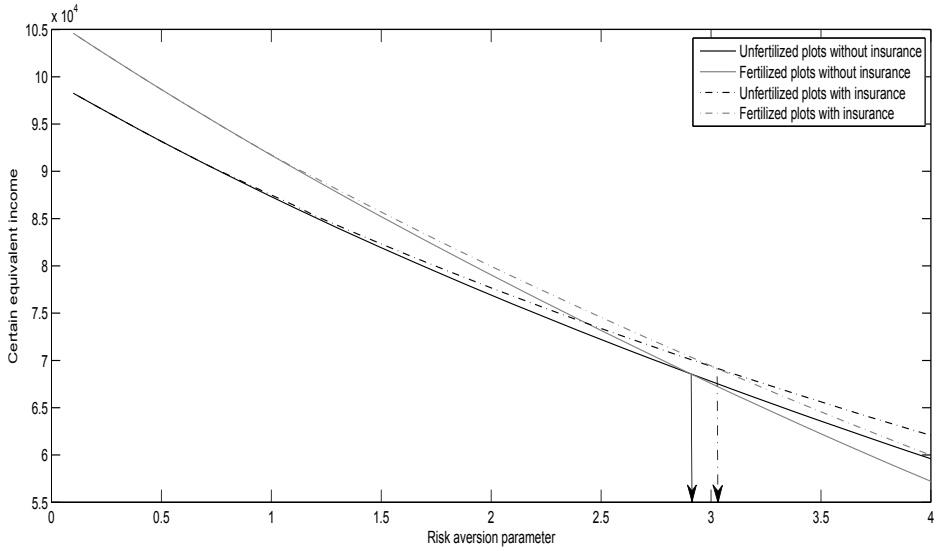

FIGURE B.10 – CEI (in FCFA) of encouraged and regular plots without (plain lines) and with CR_{siva} based insurance (dotted lines), depending on the risk aversion parameter, ρ and an initial wealth (W_0) of 1/3 of average income.

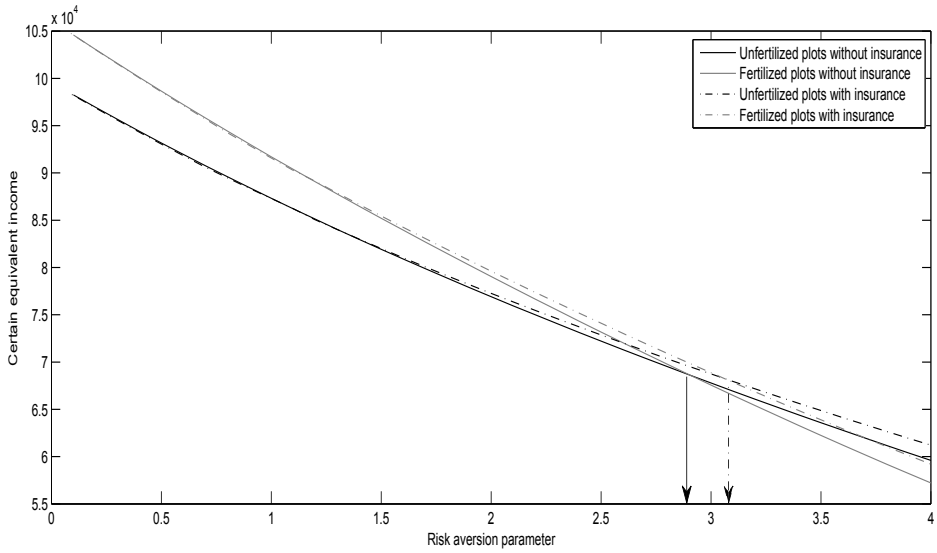

FIGURE B.11 – CEI (in FCFA) of encouraged and regular plots without (plain lines) and with BCR_{siva} based insurance (dotted lines), depending on the risk aversion parameter, ρ and an initial wealth (W_0) of 1/3 of average income.

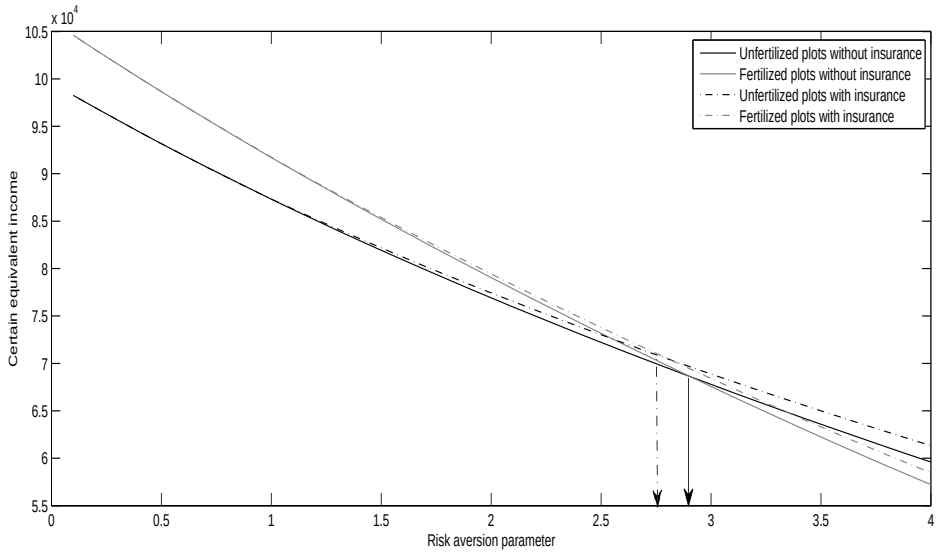

FIGURE B.12 – CEI (in FCFA) of encouraged and regular plots without (plain lines) and with $WACR_{siva}$ based insurance (dotted lines), depending on the risk aversion parameter, ρ and an initial wealth (W_0) of 1/3 of average income.

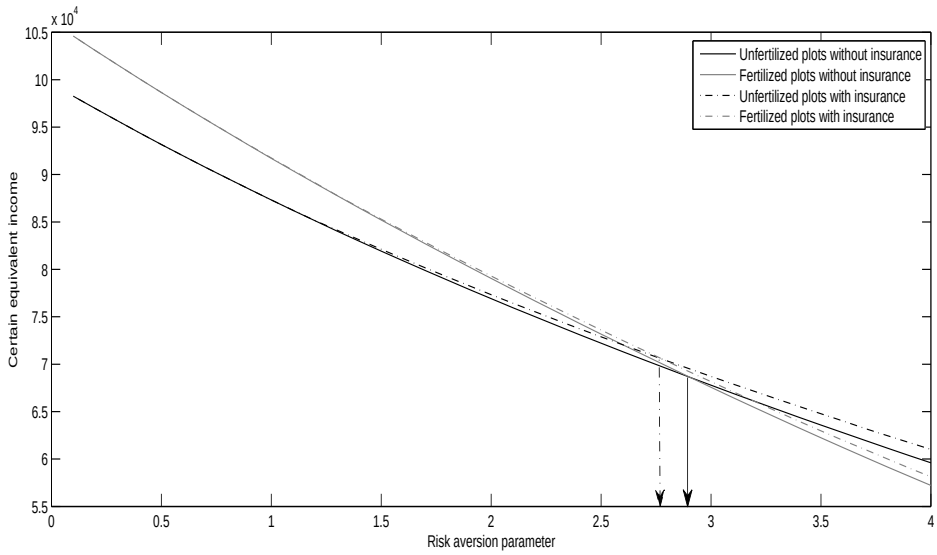

FIGURE B.13 – CEI (in FCFA) of encouraged and regular plots without (plain lines) and with $WABCR_{siva}$ based insurance (dotted lines), depending on the risk aversion parameter, ρ and an initial wealth (W_0) of 1/3 of average income.

Annexe C

Appendix for the fifth chapter

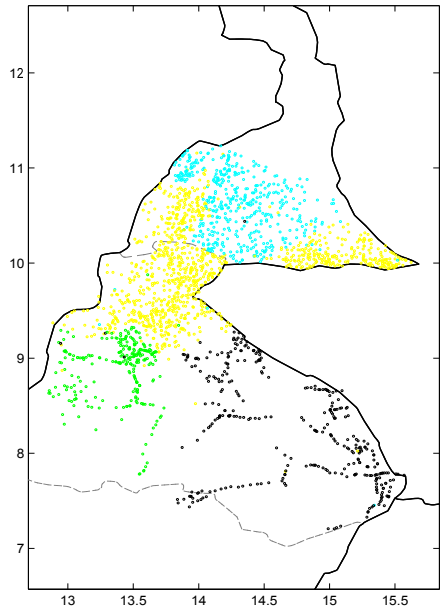

FIGURE C.1 – Spatial repartition of cultivars in 2010, dots are representing producers groups buying seeds, IRMA 1239 in black, IRMA A 1239 in green, IRMA BLT-PF in yellow and IRMA D742 in cyan.

Table C.I – Cotton cultivars average spatial and temporal allocation

Cultivars *(by province)*	1st **flower date** (Days after emergence)	1st **boll date** (Days after emergence)	**Period of use**
Allen commun	61	114	untill 1976
444-2			untill 1976
Allen 333	59	111	1959-197 ?
BJA 592	61	114	1965-197 ?
IRCO 5028	61	111	untill 1987
IRMA 1243	53	102	1987 - 1998
IRMA 1239	52	101	2000-2007
IRMA A 1239	52	101	2000-2007
L 457	52	104	2008-onwards
Extrême-Nord			
IRMA L 142-9	59	109	until 1984
IRMA 96+97	55	115	1985 - 1991
IRMA BLT	51	99	1999-2002
IRMA BLT-PF	56	116	2000 - 2006
IRMA D 742	51	95	2003-2006
IRMA L 484	51	105	2007 - onwards

Sources : Dessauw (2008) and Levrat (2010).

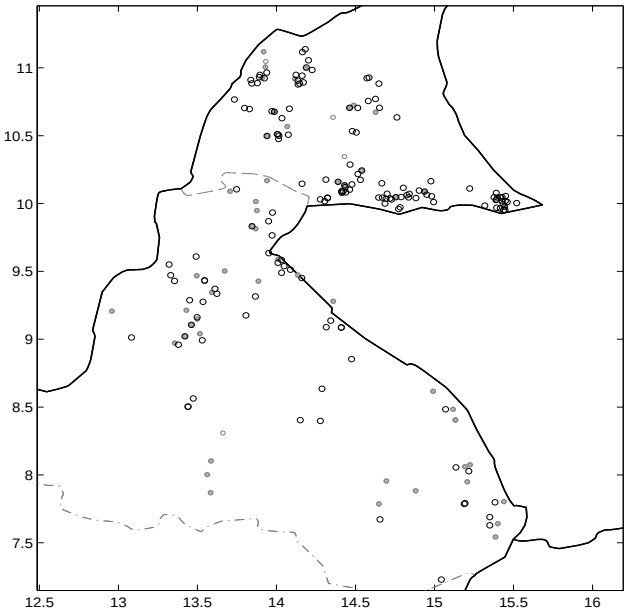

Figure C.2 – Sodecoton's surveys localization : light gray dots for 2003, gray circles for 2006 and black circles for 2010.

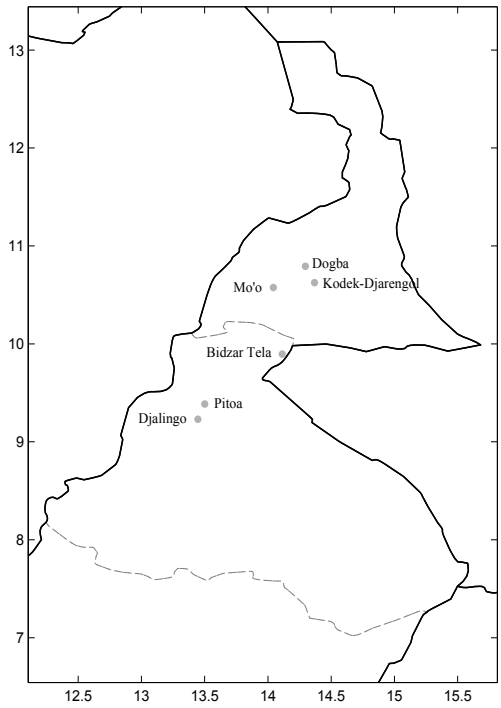

FIGURE C.3 – Villages in which lotteries were implemented.

TABLE C.II – Risk aversion summary statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
ρ	1.635	1.181	0	3	64
Among which :					
ρ (Dogba)	1.35	0.539	0.724	1.768	10
ρ (Mo'o)	1.796	1.302	0	3	10
ρ (Djarengol-Kodek)	1.897	1.199	0	3	11
ρ (Bidzar)	2	1.5	0	3	9
ρ (Pitoa)	0.901	0.75	0	3	12
ρ (Djalingo)	1.958	1.371	0	3	12

Source : Authors calculations.
Note : risk aversion level that are found to be superior to 2 are arbitrarily set to 3 and those found inferior or equal to zero are set to zero.

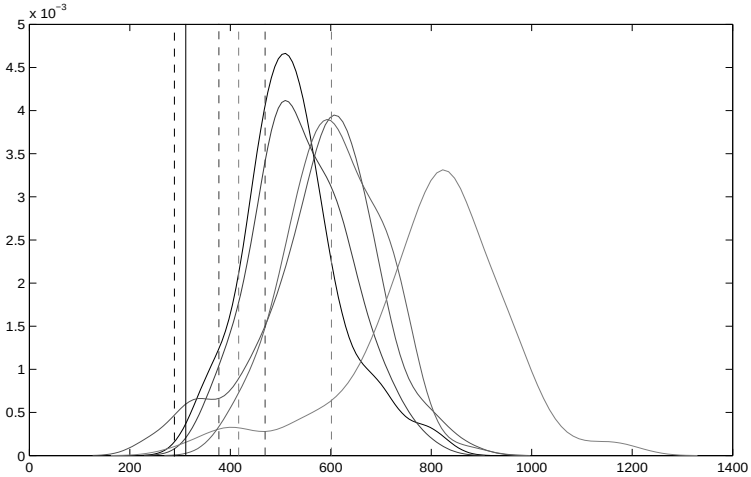

FIGURE C.4 – Distribution of length of growing season by rainfall zone, the vertical axes represent the strike levels, in black the level when calibrating on the whole sample and in grey and the levels when considering different rainfall zones.

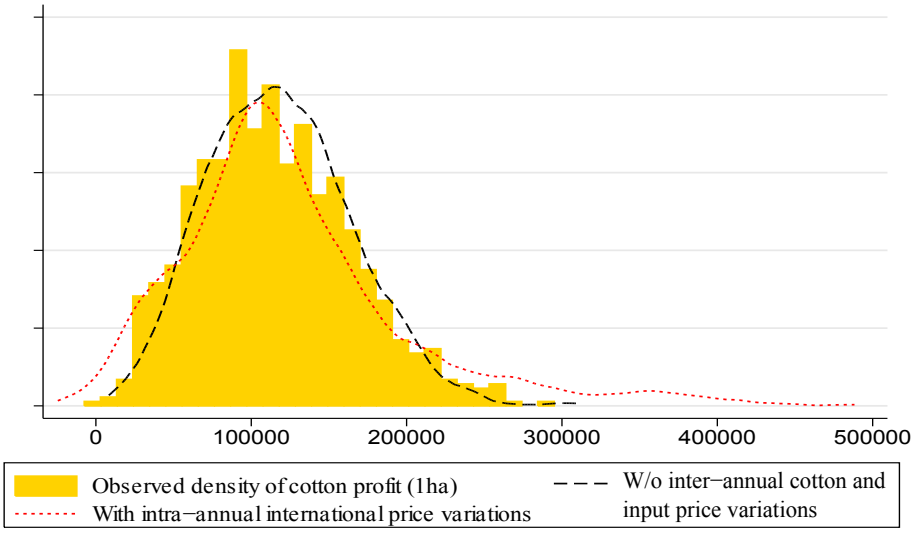

FIGURE C.5 – Distribution of cotton profit for one hectare, after reimbursement of inputs (in yellow the observed distribution, in black the kernel density of the simulated profit when considering fixed inter-annual cotton and input prices and in red the simulated distribution when adding international intra-annual prices variations).

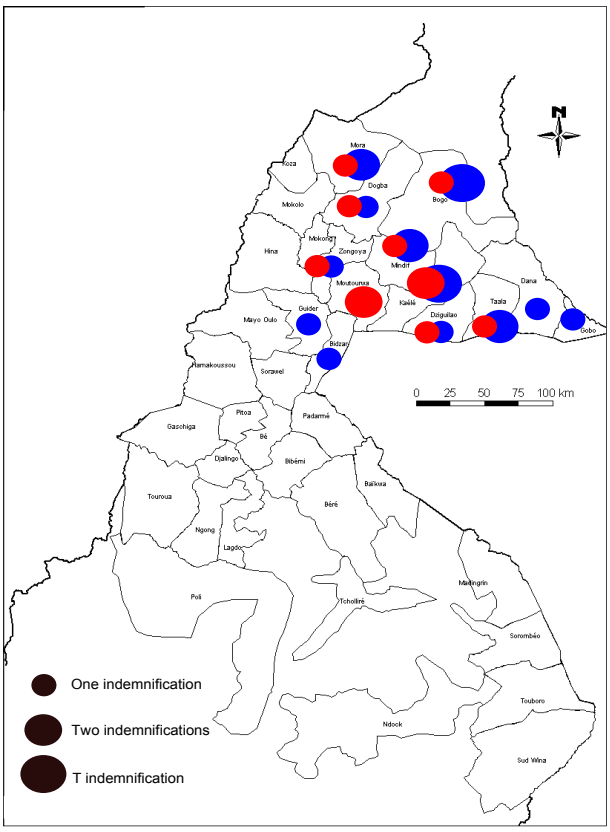

FIGURE C.6 – Indemnifications of two WII contracts : % of area sown at the 30 of June (red) and BCR_{obs} (blue) ; both optimized with a CRRA and $\rho = 2$ between 1991 and 2004).

Table C.III – Share of the maximum risk premium reduction among different indices and different rainfall zones (1991-2004).

	CRRA			CARA			MASD		
	$\rho = 1$	$\rho = 2$	$\rho = 3$	$\psi = 1/W$	$\psi = 2/W$	$\psi = 3/W$	$\phi = .25$	$\phi = .5$	$\phi = 1$
First rainfall zone									
Annual cumulative rainfall (CR)	.00%	.00%	1.88%	.00%	.00%	.00%	13.26%	12.99%	12.73%
CR_{sim}	5.94%	5.74%	5.31%	N.A.	6.23%	5.80%	24.85%	21.09%	19.57%
BCR_{sim}	5.94%	5.74%	5.31%	N.A.	6.23%	5.80%	24.83%	21.06%	19.61%
CR_{simgdd}	5.94%	5.81%	5.74%	N.A.	6.56%	6.58%	27.17%	24.02%	22.66%
BCR_{simgdd}	5.94%	5.89%	5.89%	N.A.	6.69%	6.74%	27.71%	24.61%	23.26%
CR_{obs} after sowing	.00%	.00%	1.34%	.00%	.00%	.00%	5.86%	14.73%	19.52%
BCR_{obs} after sowing	.00%	7.36%	13.75%	.00%	N.A.	7.03%	18.40%	19.99%	20.57%
$Length_{sim}$	.00%	.00%	.00%	.00%	.00%	.00%	7.79%	8.42%	8.51%
$Length_{simgdd}$	.00%	.00%	1.05%	.00%	.00%	N.A.	10.76%	11.16%	15.42%
$Length_{obs}$ after sowing	6.52%	24.47%	34.76%	N.A.	19.66%	30.32%	39.83%	43.40%	45.15%
Standardized NDVI (Oct. 1-15)	.00%	.00%	.00%	.00%	.00%	.00%	-2.68%	1.64%	10.36%
Sowing $date_{obs}$	.00%	37.58%	45.64%	.00%	33.89%	42.29%	25.92%	39.82%	44.98%
AYI	.46%	1.90%	3.66%	.17%	.77%	1.45%	1.97%	5.35%	13.78%
Second rainfall zone									
Annual cumulative rainfall (CR)	.00%	.00%	.00%	N.A.	.00%	.00%	15.72%	22.49%	26.69%
mm. per day in ph. 2	N.A.	7.93%	8.22%	N.A.	8.53%	8.84%	40.94%	40.17%	39.40%
CR_{sim}	.00%	.00%	.00%	N.A.	.00%	.00%	5.20%	11.75%	16.74%
BCR_{sim}	.00%	4.20%	5.62%	N.A.	N.A.	5.70%	21.57%	21.41%	22.42%
CR_{simgdd}	.00%	.00%	.00%	N.A.	.00%	.00%	.00%	5.10%	7.44%
BCR_{simgdd}	.00%	.00%	.00%	N.A.	.00%	.00%	2.33%	7.29%	8.93%
$Length_{sim}$	.00%	1.76%	2.04%	N.A.	N.A.	2.25%	17.88%	22.68%	29.15%
$Length_{simgdd}$	.00%	.00%	2.98%	N.A.	.00%	.00%	26.97%	41.29%	45.78%
$Length_{obs}$ after sowing	.00%	20.22%	24.85%	N.A.	18.27%	25.36%	27.21%	39.99%	43.64%
CR_{obs} after sowing	.00%	N.A.	8.64%	N.A.	.00%	8.02%	3.83%	6.05%	8.37%
BCR_{obs} after sowing	.00%	N.A.	9.89%	N.A.	.00%	9.85%	6.15%	11.53%	13.77%
Standardized NDVI (Oct. 1-15)	.00%	.00%	.00%	N.A.	.00%	.00%	1.26%	3.20%	4.79%
Sowing $date_{obs}$	.00%	44.86%	54.61%	N.A.	39.23%	55.52%	34.74%	55.78%	60.82%
AYI	.05%	.62%	1.38%	.01	.17%	.42%	1.11%	3.61%	10.03%
Third rainfall zone									
Annual cumulative rainfall (CR)	.00%	.00%	.00%	.00%	.00%	.00%	.00%	.00%	.00%
CR_{obs} after sowing	.00%	.00%	1.30%	.00%	.00%	2.03%	.00%	4.20%	6.28%
BCR_{obs} after sowing	.00%	.00%	1.30%	.00%	.00%	2.03%	.00%	4.20%	6.28%
$Length_{simgdd}$	.00%	.00%	.00%	.00%	.00%	.00%	.00%	.00%	.00%
$Length_{obs}$ after sowing	.00%	.00%	.00%	.00%	.00%	.00%	.00%	2.13%	5.08%
$Length_{obs}$ after emergeance	.00%	.00%	.00%	.00%	.00%	.00%	1.33%	6.52%	8.70%
Standardized NDVI (Oct. 1-15)	.00%	.00%	.00%	.00%	.00%	.00%	.00%	.00%	.00%
Sowing $date_{obs}$	.00%	.00%	.00%	.00%	.00%	.00%	.00%	.00%	.00%
AYI	.16%	.94%	1.88%	.08%	.47%	.93%	1.03%	3.04%	7.94%
Fourth rainfall zone									
Annual cumulative rainfall (CR)	N.A.	8.22%	7.71%	N.A.	9.03%	8.22%	36.18%	32.41%	30.99%
mm. per day in ph. 2	16.47%	8.93%	7.43%	N.A.	9.42%	8.02%	36.31%	31.53%	29.77%
CR_{sim}	.00%	6.57%	6.30%	.00%	7.65%	7.22%	35.51%	32.13%	31.01%
BCR_{sim}	.00%	2.18%	3.20%	.00%	N.A.	4.04%	23.37%	23.68%	24.13%
CR_{simgdd}	.00%	6.57%	6.30%	.00%	7.65%	7.22%	35.51%	32.93%	32.00%
BCR_{simgdd}	N.A.	6.14%	5.65%	.00%	6.80%	6.27%	26.68%	25.59%	25.11%
CR_{obs} after sowing	N.A.	24.15%	27.79%	N.A.	20.92%	25.12%	47.28%	40.95%	41.53%
CR_{obs} after emergeance	57.45%	46.60%	44.71%	55.11%	45.03%	44.03%	59.17%	60.44%	61.67%
BCR_{obs} after sowing	51.56%	47.41%	44.69%	48.97%	46.01%	43.39%	58.52%	51.75%	50.13%
$Length_{sim}$	31.67%	14.33%	11.85%	31.84%	14.47%	11.86%	26.84%	24.54%	23.66%
$Length_{simgdd}$	.00%	.00%	2.20%	.00%	.00%	N.A.	22.73%	22.92%	23.84%
$Length_{obs}$ after sowing	57.45%	46.60%	44.71%	55.11%	45.03%	44.03%	59.17%	60.44%	61.67%
Standardized NDVI (Oct. 1-15)	47.84%	23.82%	20.13%	46.96%	23.80%	19.92%	.84%	6.45%	22.99%
Sowing $date_{obs}$	69.48%	49.91%	46.82%	66.54%	48.45%	45.75%	66.33%	61.22%	60.21%
AYI	.29%	1.40%	2.73%	.12%	.63%	1.20%	1.31%	3.99%	10.73%
Fifth rainfall zone sample									
Annual cumulative rainfall (CR)	N.A.	4.17%	3.92%	N.A.	4.48%	4.20%	18.33%	15.54%	14.29%
CR_{sim}	N.A.	4.17%	3.92%	N.A.	4.48%	4.20%	17.84%	14.67%	13.32%
BCR_{sim}	.00%	4.17%	3.92%	N.A.	4.48%	4.20%	17.85%	14.69%	13.34%
CR_{simgdd}	N.A.	4.17%	3.92%	N.A.	4.48%	4.20%	17.81%	14.65%	13.30%
BCR_{simgdd}	N.A.	4.17%	3.92%	N.A.	4.48%	4.20%	17.81%	14.65%	13.30%
mm. per day in ph. 2	.00%	.00%	.00%	.00%	.00%	.00%	8.28%	6.62%	6.18%
Accumulation of GDD during ph. 5	28.54%	34.50%	33.51%	26.92%	33.76%	32.87%	18.33%	18.04%	19.06%
CR_{obs} after sowing	N.A.	4.81%	4.85%	N.A.	5.32%	5.33%	9.31%	9.41%	9.42%
BCR_{obs} after sowing	N.A.	4.81%	4.85%	N.A.	5.32%	5.33%	9.80%	10.62%	10.83%
$Length_{sim}$	.00%	2.51%	5.12%	.00%	N.A.	4.61%	10.17%	8.87%	8.25%
$Length_{simgdd}$	.00%	.00%	.00%	.00%	.00%	.00%	12.90%	10.56%	9.57%
$Length_{obs}$ after sowing	.00%	.00%	.89%	.00%	.00%	1.17%	N.A.	2.63%	3.67%
Standardized NDVI (Oct. 1-15)	.00%	.00%	.00%	.00%	.00%	.00%	2.59%	3.82%	7.50%
Sum of GS bi-bi-monthly NDVI	N.A.	9.66%	9.25%	N.A.	9.84%	9.43%	18.82%	16.06%	15.26%
Sowing $date_{obs}$	.00%	.00%	.00%	.00%	.00%	.00%	N.A.	1.26%	1.46%
AYI	.10%	.91%	1.87%	.05%	.44%	.88%	.81%	2.57%	6.72%