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The Perception of and Adaptation to Climate Change in Africa

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Abstract

The objective of this paper is to determine the ability of farmers in Africa to detect climate change, and to ascertain how they have adapted to whatever climate change they believe has occurred. The paper also asks farmers whether they perceive any barriers to adaptation and attempts to determine the characteristics of those farmers who, despite claiming to have witnessed climate change, have not yet responded to it. The study is based on a large-scale survey of agriculturalists in 11 African countries.

The survey reveals that significant numbers of farmers believe that temperatures have already increased and that precipitation has declined. Those with the greatest experience of farming are more likely to notice climate change. Further, neighboring farmers tell a consistent story. There are important differences in the propensity of farmers living in different locations to adapt and there may be institutional impediments to adaptation in some countries. Although large numbers of farmers perceive no barriers to adaptation, those that do perceive them tend to cite their poverty and inability to borrow. Few if any farmers mentioned lack of appropriate seed, security of tenure, or market accessibility as problems.

Those farmers who perceive climate change but fail to respond may require particular incentives or assistance to do what is ultimately in their own best interests. Although experienced farmers are more likely to perceive climate change, it is educated farmers who are more likely to respond by making at least one adaptation.

This paper—a product of the Sustainable Rural and Urban Development Team, Development Research Group—is part of a larger effort in the group to mainstream climate change research. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at d.maddison@ucl.ac.uk.

THE PERCEPTION OF AND ADAPTATION TO CLIMATE CHANGE IN AFRICA[1]

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SUMMARY

It is doubtful whether farmers know immediately what constitutes the best response to climate change when such agricultural practices as it requires are outside their range of experience. Nor can they be expected to recognize immediately that the climate has changed. Together these facts point to a period of transitional losses of unknown duration as a result of adapting to climate change.

The objective of this paper is to determine the ability of farmers in Africa to detect climate change, and to ascertain how they have adapted to whatever climate change they believe has occurred. The paper also asks farmers whether they perceive any barriers to adaptation and attempts to determine the characteristics of those farmers who, despite claiming to have witnessed climate change, have not yet responded to it. The study is based on a large-scale survey of agriculturalists in 11 different African countries.

The survey reveals that significant numbers of farmers believe temperatures have already increased and that precipitation has declined. Those with the greatest experience of farming are more likely to notice climate change. This is consistent with farmers engaging in Bayesian updating of their prior beliefs. Statistical tests also reveal significant spatial clustering in the proportion of farmers claiming to have observed particular forms of climate change. Alternatively put, neighboring farmers tell a consistent story. Unfortunately evidence about whether farmers' perceptions of climate change tally with records from weather monitoring stations is somewhat equivocal. In many cases available climate records are shorter than the memories of the farmers themselves.

Among adaptations made in response to climate change, planting different varieties of the same crop and changing dates of planting are important everywhere. But stratifying the data by the precise perception of climate change (for example increased precipitation, decreased precipitation, changes in the timing of the rains, etc.) provides greater insights. When temperatures change farmers plant different varieties, move from farming to non-farming activities, practice increased water conservation and use shading and sheltering techniques. For changes in precipitation and particularly in the timing of the rains, varying the planting date appears to be an important response. There is also evidence that adaptation measures are linked to baseline climate and that adaptation occurs mainly on those sites that are already marginal in the sense of being hot and dry.

There are important differences in the propensity of farmers living in different locations to adapt and there may be institutional impediments to adaptation in certain countries. Although large numbers of farmers perceive no barriers to adaptation those that do perceive them tend to cite their poverty and inability to borrow. Few if any farmers mentioned lack of appropriate seed, security of tenure and market accessibility as problems.

Those farmers who perceive climate change but fail to respond may require particular incentives or assistance to do what is ultimately in their own best interests. Adaptation to climate change actually involves a two-stage process: first perceiving that climate change has occurred and then deciding whether or not to adopt a particular measure. This gives rise to a sample selectivity problem since only those individuals who perceive climate change will adapt, whereas we wish to make statements about the population of agriculturalists in general.

Using Heckman's sample selectivity probit model, econometric investigation reveals that although experienced farmers are more likely to perceive climate change, it is educated farmers who are more likely to respond by making at least one adaptation. Farmers who have enjoyed free extension advice and who are situated close to the market where they sell their produce are also more likely to adapt to climate change. Land tenure has little if any impact on the propensity of farmers to adapt.

In terms of policy implications it appears that improved farmer education would do most to hasten adaptation. The provision of free extension advice may also play a role in promoting adaptation. In so far as distance to the selling market is a significant determinant of whether a farmer adapts to climate change, it may be that improved transport links would improve adaptation although the precise mechanism underlying this is unclear. Better roads may allow farmers to move from subsistence farming to cash crops, or facilitate the exchange of ideas through more regular trips to the market. There are many country specific differences in the propensity of farmers to adapt and further analysis would be required to understand the underlying factors. Adaptation, however, is something undertaken only by those who perceive climate change. The perception of climate change appears to hinge on farmer experience and the availability of free extension advice specifically related to climate change. But while the policy options for promoting an increased awareness of climate change are more limited the perception of climate change is already high.

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1. Introduction

Existing explorations of the effects of climate change on agriculture have used a variety of modeling approaches to predict the long-run impact. Mendelsohn and Dinar (1999) identify three broad strategies to uncover the impact of climate change on productivity: agronomic modeling, agro-economic modeling and the Ricardian technique. Agro-economic models allocate crops to particular ecological zones according to climatic suitability. As the climate changes, land is then reallocated and changes in producer and consumer surplus are calculated. Agronomic models are based on crop simulation under controlled conditions. These models can incorporate arbitrary adjustments, which are often observed to dramatically reduce the perceived costs. The Ricardian model compares the net returns on land in locations which have already adapted. The great strength of the Ricardian approach is that it deals effectively with the problem of accounting for an almost infinite number of adaptations. Its weakness lies in the need to control for many variables in addition to climate, and the failure to account for the carbon dioxide fertilization effect.

In response to Mendelsohn and Dinar's article, Reilly (1999) does not dispute that adaptation can reduce the impacts of climate change and increase benefits. But Reilly underlines the fact that cross-sectional models such as the Ricardian technique represent a long-run equilibrium. Do agents know immediately what adaptations will work best? Agents need to learn the correct response, and public policy may be required. Farmers may take time to realize that unusual weather represents a permanent shift in the climate and in this regard it is important whether farmers engage in forward or backward looking behavior. The Ricardian technique does not attempt to deal with the process of adaptation and how it occurs, nor those factors that may retard or hasten the process of adaptation. But equally, since no model is capable of simultaneously addressing all such questions, one might ultimately reach the conclusion that transitional costs are trivial and should be allowed to take a backseat to the task of comparing equilibrium outturns.

This paper is intended to complement an ongoing Ricardian analysis of climate and agriculture in Africa by investigating precisely these issues. The study setting is of particular interest since it is precisely in Africa, because of institutional constraints and other factors, that adaptation to climate change may be slow in forthcoming and populations most vulnerable to disrupted agricultural production. Although this paper does not attempt to review the current evidence on climate change impacts on agriculture, Winters et al. (1998)

analyze the impact of global climate change on developing countries by using CGE (Computable General Equilibrium) multiple market models for three economies representing the poor cereal importing nations of Africa, Asia, and Latin America. Results show that all these countries will potentially suffer income and production losses because of climate change. It is notable however, that Africa, with its low substitution possibilities between imported and domestic foods, fares worst in terms of income losses and the drop in consumption of low-income households.

Adaptation to climate change requires that farmers using traditional techniques of agricultural production first notice that the climate has altered. Farmers then need to identify potentially useful adaptations and implement them. This paper attempts to answer the following questions in particular: Do farmers perceive climate change to have occurred already and if so have they begun to adapt? What kinds of adaptations have they made to climate change? What, if any, is the role of government in overcoming barriers to adaptation? It is very important to identify these barriers to adaptation, particularly if they are amenable to public policy.

In order to answer these and other questions the paper uses data on agriculturalists' perceptions of climate change, lists of adaptations and perceived barriers to adaptation, linked to farmer characteristics and other spatially referenced data. These data were made available through an ongoing project entitled *Climate, water and agriculture: Impacts on and adaptations of agro-ecological systems in Africa*, for which the Global Environmental Facility and World Bank provided core funding. The study was led and coordinated by the Center for Environmental Economics and Policy in Africa (CEEPA) at the University of Pretoria and implemented by multidisciplinary research teams from 11 African states, of which ten are analyzed here. The countries are Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Niger, Senegal, South Africa and Zambia. Technical assistance was provided by CEEPA, Yale University, the University of Colorado, the International Water Management Institute and the Food and Agriculture Organization.

Open-ended questions were used to ask farmers whether they had noticed long-term changes in temperature and precipitation, and about the adaptations they had made as a response to whatever changes they had noticed. For those farmers who felt they had experienced climate change there were further questions about the nature of any barriers which prevented them from fully adapting to climate change. To anticipate the major finding of the empirical analysis, it seems it is the experienced farmers who are more likely to perceive climate change but the more educated ones who respond to it.

The remainder of the report is structured as follows. Section 2 describes the theory of agricultural adaptation to climate change. Section 3 briefly reviews the empirical evidence on adaptation in agriculture, focusing in particular on adaptation in the developing country context and the types of econometric model that have been used to study this adaptation. Section 4 examines evidence of perceptions of climate change, appropriate adaptations and barriers to their implementation in several African countries. The final section concludes.

2. The theory of agricultural adaptation to climate change

Most analyses examining the impact of climate change on agriculture compare equilibrium outturns corresponding to a baseline and climate change scenario, and have nothing at all to say about the nature and scale of transitory losses experienced in the process of adaptation. In the whole of the climate change and agriculture literature it appears that only two papers deal with the issue of transitional costs: Kolstad et al. (1999) and Kaiser et al. (1993). This is surprising given the sheer number of papers exploring the impact of climate change on agriculture.

The following section draws heavily on Kolstad et al. (1999), who concern themselves with the transitory cost of adapting to climate change. According to their paper, a farmer may perceive several hot summers but rationally attribute them to random variation in a stationary climate. The authors distinguish between the cost of adaptation once all desired adjustments have been made and expectations no longer lag behind reality, and the transitional cost arising from misperceptions.

The difference between the cost of adaptation and the transitional cost is best explained as follows. The cost of adaptation is the difference between the maximum value of net revenues per acre evaluated in the current and in the perfectly perceived future climate. The transitional cost is the difference between the maximum value of net revenues per acre following perfect adaptation and the net revenues actually experienced by farmers given that their expectations of (and therefore response to) how the climate will change lag behind what it actually does. If farmers could at each instant correctly predict the climate then there would be no transitional cost. The main issue addressed by Kolstad et al., therefore, is the manner in which agriculturalists update their expectations of the climate in response to unusual weather patterns.

One possibility is that farmers engage in simple Bayesian updating of their prior beliefs according to the standard formula. Kolstad et al. argue that this process of updating is likely to be slow and that one should not expect decades of information to be thrown out overnight. However, Kolstad et al. cite some evidence that suggests that farmers do not update their priors in this way. In particular, it appears that some farmers place more weight on recent information than is efficient. Smit et al. (1997) for example point out that there are many varieties of corn with differing suitability to climate and that Canadian farmers appear to adjust their hybrid selection on the basis of the previous year's climatic conditions. Farmers are recommended to match hybrid climatic requirements to 30-year climate averages at their locations but frequently choose strains above or below the averages. About 30% of farmers said that this was because of the previous year's weather. No evidence was found that farmers plan on the basis of climatic norms but rather that a higher weight is given to more recent years.

Kolstad et al. implement their theoretical model empirically, albeit in a somewhat limited manner that does not capture all of the potential adjustments that might be made in the face of climate change (in particular they focus exclusively on corn). Two separate equations explain planting decisions, and realized output of corn from US counties is expressed as a function of, among other things, climate and realized weather. This model is then used to simulate the adjustment that might be made to an unanticipated 5°F increase in July temperatures. Using Bayesian updating, farmers appear to learn about the change in climate remarkably slowly, and as long as the quantity of corn they produce actually increases under the current climate change scenario this obscures the fact that they are failing to seize the opportunity to plant wheat instead. Their consequent loss represents the transitional costs of climate change and it is not to be confused with case of the 'dumb farmer' who does not update his or her expectations at all in the light of experience. Farmers suffer from transitional losses even when using sophisticated Bayesian updating of their beliefs when they experience change.

There are naturally a number of caveats to the model, most of which are pointed out by the authors themselves. First, there is the possibility that in the face of uncertainty about future climate change the farmer may adopt practices that are more robust in the face of unexpected weather. Second, there is the issue of fixed factors such as buildings and specialized machinery dedicated to the cultivation of particular crops and whose design renders it inefficient in climates other than those they were intended for. Kolstad et al. remark that for agriculture such factors would appear to be of only limited importance.

A third issue not discussed by Kolstad et al. but of arguably even greater importance, especially in the developing country context, is the implicit assumption that farmers possess sufficient knowledge to move along the envelope of maximum net revenue per acre, taking full advantage of whatever the weather brings and not worrying about the long-term effects of climate. This assumption of free and immediate knowledge with respect to the best crops to grow and how to grow them is in my opinion much more problematic. One might argue that farmers only gradually learn about the best techniques for precisely the same reason that they only gradually learn that the climate has changed. In fact learning about the most appropriate crops and best production technique could take a variety of forms, such as learning by doing, learning by copying or learning from instruction. The costs of transition hinge on the efficacy of these mechanisms, but all of them imply delays. Learning by doing requires time consuming and potentially costly experimentation, learning by copying requires that someone take the initial first step, and learning from instruction requires an instructor.

The experience of agriculture in Africa in adopting technologies associated with the green revolution does not engender confidence. The rate at which these have been adopted has been very slow in some areas and it is not clear why adoption of new technologies for reasons of climate change should fare any better. The empirical literature relating to Africa's experience of adopting new technologies is the subject of the next section.

The only piece of work to deal explicitly with the issue of transitional costs is Kaiser et al. (1993), which examines the potential economic and agronomic impacts of gradual climate warming at the farm level in Minnesota. It analyzes several climate warming scenarios of varying severity. In one scenario the planting decisions taken are those which would have been optimal the previous decade. This obviously reduces considerably the costs of climate change compared with a situation in which there is no response whatsoever but is still inferior to a situation in which farmers immediately and perfectly perceive the change in climate, as hypothesized by the Ricardian approach. But as a prediction, a ten-year delay in appropriate response may be more realistic.

3. Empirical evidence on the adoption of new technologies in agriculture

The preceding section focused on how farmers learn about climate change and also identified the issue of how farmers learn about and eventually come to adopt the required technology. In fact there is an almost overwhelming literature dealing with the adoption of different technological innovations in agriculture as a response to the green revolution. Several literature reviews exist, including Feder et al. (1985), Birkhaeuser et al. (1991), Lin (1992), Rauniyar and Goode (1992) and Feder and Umali (1993). Unfortunately even the most recent of these is now more than ten years old. Nevertheless this literature may hold clues about how farmers will adapt to the changed production opportunities presented to them by climate change.

The literature generally has four themes concerning adoption of new technologies: that it is linked to resource scarcity or price changes; that it is affected by capital or savings constraints; that the rate of adoption is affected by learning costs; and that technology adoption and risk aversion are linked. The aforementioned reviews of the diffusion of new technologies show that farm size, tenure status, education, access to extension services, market access and credit availability are major determinants of the speed of adoption. (The review by Feder et al. is particularly good in this respect.) The literature also finds that the ultimate ceiling of adoption is determined by agro-climatic conditions, topographical features and the availability of water. Such findings are of course hardly surprising and very much in line with the underlying spirit of the Ricardian approach.

Regarding policy implications, given that the empirical evidence has shown that a variety of market imperfections can impede the adoption of apparently profitable technologies, the divergence between the private and the social rates of return on these technologies creates at least a potential role for governments. To overcome whatever imperfections exist, they can broadly provide two things: information through extension services, and subsidies and price supports. They can also affect the rate of adoption through more diffuse policies such providing infrastructure and literacy programs. Whether or not these interventions have been effective in promoting timely and profitable adaptation is a matter of some conjecture. The appropriate setting for them requires high levels of information and if badly designed they may diminish rather than increase welfare and also lose their rationale over time.

Besley and Case (1993) review the econometric approaches to modeling technological innovations in agriculture. Studies very frequently use cross-sectional survey data. Discrete technologies are analyzed using the probit or logit model, whereas continuous technologies are usually modeled by the tobit model or two limit tobit. Unfortunately, despite their ubiquitous appeal such studies reveal very little about the pace of adoption (the issue most at stake here); they reveal merely those factors that impede or facilitate eventual adoption. Another common approach has been to use aggregate time series data to model the proportion of farmers adopting a given technology. The data have typically been used to fit a sigmoid shaped curve, underlining the fact that adoption of new technologies does not occur overnight. Owing to the lack of panel data these studies cannot examine the microeconomic details of dynamic processes such as learning. In one of the few papers that uses panel data Cameron (1999) studies the adoption of a new high-yielding variety of seed. There is also a time lag between the existence of a technology and the time at which farmers become aware of it. In Australia a study cited by Pannell (1999) asked farmers to record the date at which they became aware of a particular innovation as opposed to adopting it. Considerable time lags were observed.

What follows now is an attempt to update the early literature reviews. Since there is a vast quantity of material this update does not attempt to be comprehensive, but rather focuses on developing country case studies and in particular on Africa. It also has a narrower purpose, namely to obtain ideas for an empirical study of the process of adapting to climate change and to identify emerging research themes. The attempt to tie this literature together with the issue of adaptation to climate change comes at the end.

Necessary preconditions for adaptation

Pannell (1999) points out that if farmers are to adopt land conservation techniques they must first be aware that the technology exists and *perceive* that it is profitable. Other papers have sought to separate the acquisition of the technology from the intensity of its use. Climate change adaptation studies should do the same.

Nichola (1996) argues that the double-hurdle model is more appropriate to identify the socio-economic variables that influence adoption when agricultural technologies are scarce. In such cases the variables identified by probit or tobit models may confound the ability to acquire the scarce technology with the motivation to adopt. The double-hurdle model avoids this problem by separating the adoption process into two stages: the decision to adopt, and the decision on how much of the technology to use. This is illustrated with the adoption of a sorghum hybrid in Sudan. The empirical results show that the decision to adopt and the decision on the intensity of adoption are indeed explained by different sets of variables. Shiferaw and Holden (1998) report results from a study of resource degradation and conservation behavior of peasant households in a degraded part of the Ethiopian highlands. Once more, peasant households' choice of conservation technologies is modeled as a two-stage process: recognition of the erosion problem, and adoption and level of use of control practices.

Differing propensities for the adoption of technology and agriculture

Much of the recent literature has dealt with the differing potential for adoption of technology given gender differences and the complementarity of new technologies with existing ones.

Doss (2001) notes that the adoption of technology by women in Africa is especially low and Doss and Morris (2001) suggest that gender affects adoption rates indirectly through access to complementary inputs. Examining household data from rural Ethiopia Knight et al. (2003) find that schooling encourages farmers to adopt innovations.

Johnson and Masters (2004) argue that, besides the socio-economic characteristics of the farmer, complementarity among interrelated innovations may help explain the location and timing of productivity growth and may be particularly important in transforming semi-subsistence agrarian economies. They study the case of cassava in West Africa, where both mechanized processors and new varieties are more widespread in Nigeria than in neighboring countries. Historically, mechanization came first but the later development of new varieties made mechanization much more profitable, and the two then spread together.

Rauniyar and Goode (1992) investigate the interrelationships among technological practices adopted by maize-growing farmers in Swaziland. Technology adoption requires simultaneous decisions by farmers regarding the use of practices within a package. This study suggests that understanding interrelationships among practices is important for successful technology planning in developing countries.

Leathers and Smale (1991) note that agricultural innovations are often promoted as a package – a new seed variety, a recommended fertilizer application, and other recommended cultivation practices. Nevertheless, many farmers adopt pieces of the package rather than the whole, in a sequential fashion. This paper presents a behavioral model which explains sequential adoption as a consequence of the way farmers learn. In order to learn more about the entire technological package, the farmer may adopt a part of it. The model is shown to be consistent with observed patterns of sequential adoption.

Anderson et al. (1999) note that strategic investments in agriculture are often lumpy and irreversible, with significant impacts on fixed costs. The implication is that large mechanized farms will probably be the first to adapt to climate change.

Extension advice

The early literature shows that extension advice and attendance at workshops generally speeds adoption. Gautam (2000) provides an empirical assessment of the impact of Kenya's World Bank-financed National Extension Projects I and II, which ran during 1983–1991 and 1991–1998. The paper also reports on a contingent valuation study of farmers' willingness to pay for extension services. Kaliba et al. (2000) insist that future research and extension policies should feature farmer participation in the research process and on-farm field trials for variety evaluation and demonstrations. According to Pannell (1999), advice is never a substitute for a personal trial and the heterogeneity of farm situation invariably makes it difficult to provide extension advice.

Spatial studies

Perhaps the most interesting research to emerge in recent years is that which acknowledges the existence of a spatial component to technology adoption. This research builds on new statistical techniques and requires spatially referenced datasets. Below I will argue that these studies have special relevance for studies investigating adaptation to climate change since climate change itself is a spatial process.

Several studies have dealt with the way the adoption of technologies diffuses through a country. Case (1992) presents an estimation model that allows farmers to be influenced by neighbors when making discrete choice decisions. This model is used to test interdependence in farmers' attitudes towards adopting new technologies in Indonesia. Strong neighborhood effects are found and the results suggest that failure to control for neighbors' influence may bias the estimation of parameters of interest. Best et al. (1998) find that the adoption of rice/fish cropping systems is highly clustered, with a spatial reach of two to three kilometers. Although not applying explicitly spatial techniques, Ransom et al. (2003) consider the adoption of improved maize in Nepal where communities are isolated, with few roads. The movement of technology is also correspondingly slow.

Staal et al. (2002) consider the location and uptake of technology in Kenya. Geographical information system techniques are used to examine neighborhood effects and information spillovers but the authors note that spatial autocorrelation can be caused by information spillovers as well as by non-measured characteristics of locations. Zhang et al. (2002) find noticeable clustering in the adoption of HYV (high yielding variety) seeds in India. They suggest that skillfully located demonstration fields could be used to hasten the adoption of technology.

Holloway et al. (2002) provide what is currently the most advanced attempt to get to grips with the adoption of discrete technologies in the presence of spatial autocorrelation, using the adoption of HYV rice in Bangladesh as an example. Once more it is suggested that the location and scale of neighborhood effects can help in planning ways to provide extension advice. They also note that the size of the information externality for copying is of paramount importance. When spatial effects are accounted for it is discovered that neighborhood effects are the *only* significant variable in the model. Including such effects makes other variables insignificant. It is interesting to speculate on the extent to which early studies' neglect of spatial effects may have led researchers to draw misleading conclusions.

Copying

Although spatial proximity can facilitate copying, such behavior is obviously far more complex. Shampine (1998) discusses the role of information in the adoption of new technologies. Of particular interest is the role of information externalities when non-adopters observe adopters in order to gather information. The fact that the information externality is uncompensated suggests that too little adoption may occur.

Analyzing the adoption of new technologies by tea and coffee growers in Kenya, Bevan et al. (1989) find that the current and previous number of adopters in the same cluster affects the adoption decision of non-adopters. Subsequent work confirms that copying requires more than mere physical proximity. Pomp and Burger (1995) consider the adoption of new technologies for cocoa production by Indonesian smallholders. They discover that some early adopters are more likely to be copied than others, depending on their socio-economic characteristics, and term this a peer group effect. Adoptions by more educated individuals are more likely to influence others.

Bandiera and Rasul (2002) note that despite their potentially strong impact on poverty, agricultural innovations are often adopted slowly. Using a unique household dataset on adoption of new techniques by sunflower farmers in Mozambique, they analyze whether and how individual adoption decisions depend on the choices of others in the same social networks. In line with information sharing, the network effect is stronger for farmers who report discussing agriculture with others.

Conley and Udry (2001) argue that farmers learn about new innovations in many ways. They may learn from extension advice, from their own experimentation and from their neighbors' experimentation. On the basis of what they observe their neighbors doing and the success that they have, farmers update their own prior beliefs and it is therefore important that farmers can observe others' success. But although it may seem self-evident that farmers can observe the activities and successes of others, these assumptions are contradicted by studies of pineapple growers in Ghana. A sample of farmers was asked about their knowledge of neighbors' inputs and outputs. Only 11% of farmers in the same village had benefited from advice and only 7% could provide some information about others' activities. According to the authors, information flows through social networks and does not necessarily spread simply because of geographical proximity.

Climate change related adaptations

The majority of the technologies considered in the empirical literature owe their existence to scientific progress and the green revolution. For the purposes of climate change, however, it may be important to distinguish between those technologies that have already been adopted elsewhere because of more favourable agro-ecological conditions. This is what Somda et al. (2002) mean when they refer to the introduction of 'internal' as opposed to 'external' technologies. Most of the studies conducted by economists in the past dealt with the adoption of external technologies. But the adaptation envisaged by Ricardian studies involves the adoption of internal ones.

Foltz (2003) deals with the adoption of drip-feed water conservation in Tunisia. It uses revealed preference and direct elicitation methods. The model introduces the factor of distance from the point at which the technology was first introduced and finds geographical proximity to be strongly predictive of adoption. This is consistent with information spillovers as well as with natural resource factors. Capital constraints, insecurity of tenure and information are all important. Baidu-Forson (1999) considers the adoption of various conservation measures in Niger including *tassa* water holes and crescent-shaped nutrient mounds.

Note however that while irrigation has frequently been mooted as a possible means for vulnerable agricultural populations to adapt to climate change, some authors have questioned the wisdom of such a step. Eakin (2003) presents a case study which shows that for some smallholders in Mexico irrigated vegetable production does not, in itself, necessarily address farmers' sensitivity to climate hazards. Furthermore, the interaction of market uncertainty and price volatility with climate risk may in some cases actually exacerbate the vulnerability of these households.

Social capital and customs

Learning has already been shown to require more than mere physical proximity. Analyzing additional factors conducive to the transmission of information may require disciplinary approaches other than economics, including sociology, geography and anthropology.

Boahene et al. (1999) use a multidisciplinary model to explain the adoption of agricultural innovations in developing economies with reference to hybrid cocoa in Ghana. A system of cooperative labor exists in Ghana called *nnoboa* which apparently contributes to adoption, as does hired labor. The authors suggest that extension advice should target members of such farm cooperatives and farms employing hired labor. In other words, knowledge is embodied in itinerant laborers.

Rogers (1993) argues that ethnic homogeneity, participatory norms and leadership heterogeneity all imply a greater range of contacts with the outside world. Isham (2002) examines the importance of social capital for fertilizer adoption in Tanzania and finds strong evidence in support of the views put forward by Rogers.

In many locations the religious and the agricultural calendar have become intertwined. The perpetuation of such customs risks impeding adaptation to climate change. As an example, Morales and Perfecto (2000) note that the agricultural seasons in Guatemala are defined in terms of religious festivals. For example, maize is never planted after the feast of San Antonio. Farming practices are a strong part of Mayan culture.

Seed and fertilizer availability

One of the many adaptations to climate change involves the use of different varieties of seed, for example the use of early maturing varieties or drought resistant ones. The non-availability of seed may be a significant impediment to adaptation and unfortunately there are indications in the literature that such impediments do indeed exist. Similar statements could be made regarding fertilizer availability.

A particularly interesting paper by Hintze et al. (2003) deals with the adoption of HYVs in Honduras. The authors find that, depending on the region in question, between 27% and 64% of farmers use seed saved from a previous harvest, while at least 25% of the remainder obtain their seed from neighbors. The free seed distributed after hurricane Mitch (1998) was the strongest predictor of the adoption of HYVs. This fact points to non-adoption being linked to an information deficit or non-availability of seed. Ransom et al. (2003) find that the reason most frequently given for not adopting HYVs in Nepal was the lack of seed (and not lack of desire on the part of the farmer). Examining the adoption of HYV maize in Mexico Bellon and Risopoulos (2001) once more encounter almost complete reliance on farmers' own seed.

In an unusual paper Kosarek et al. (2001) examine the diffusion of HYV maize in the Caribbean and Latin America. The model is a cross-country empirical analysis and emphasizes the incentives of the seed industry itself and the structure of the seed market. Variables used to explain differences in diffusion rates are the protection offered to the seed industry, the establishment of intellectual property rights, and the involvement of private firms. Strong evidence is found in favor of the hypothesis that the characteristics of the seed industry affect the uptake of the HYVs.

In India Chauhan et al. (2002) attempted to estimate the way the demand for and supply of seed is managed so as to avoid a glut or shortage of seeds in future. They compiled a list of factors supporting and hindering the use of quality seed and found that non-availability of the desired variety seed and higher price of quality seed were the most significant hindering factors in the cultivation of paddy, cotton, rapeseed and mustard.

Using a nationally representative dataset, and information on why farmers did not purchase fertilizer, Croppenstedt et al. (2003) estimate a double-hurdle fertilizer adoption model for Ethiopia. Market access and credit are shown to be major supply-side constraints, suggesting that households generally do not have enough cash to buy fertilizer. The results underline the importance of increasing the availability of credit and reducing the procurement, marketing and distribution costs of fertilizer. Kaliba et al. (2000) also find that non-availability is a major factor influencing the adoption of improved maize seeds and the use of inorganic fertilizer for maize production by farmers in the intermediate and lowland zones of Tanzania.

Institutional features

Certain institutional features may inhibit adaptation to climate change, especially in so far as such adaptation requires making long-lived investments. Land tenure has frequently been mooted as a barrier to technology adaptation and recent research continues to support this hypothesis. It is often found that older farmers are less likely to adopt soil conservation practices because of their shorter planning horizons and a less than perfect capitalization of such benefits because of underdeveloped land markets (see Feder and Umali 1993 for a review).

Schuck et al. (2002) find that land tenure issues may limit the effectiveness of extension education in Cameroon. They examine the extent to which extension education can promote adoption of cropping systems other than slash and burn, and whether or not land tenure issues reduce the effectiveness of extension education. Their results indicate that higher visitation rates by extension personnel reduce the likelihood of farmers choosing slash and burn agriculture, but farmers with lower levels of land ownership are less likely to adopt alternatives than those with higher levels of land ownership. Bezbaruah and Roy (2002) find that being a tenant farmer discourages the application of higher doses of fertilizers in Assam. Anim (1999) however finds that the probability of adopting silt traps and contour ploughing as methods of soil conservation is not affected by security of land tenure.

Regarding market imperfections more generally, Pradhan and Quilkey (1993) consider the problems arising from the non-separability of production and consumption decisions – a situation which typically characterizes farming households in developing countries. Such non-separability occurs when there is imperfect substitutability of family and hired labor, and differences in the purchase and sale prices of inputs and outputs as well as in the presence of interlinked transactions. Naturally such imperfections can affect the household's adoption of new technology. In the context of their model applied to data from Orissa the authors confirm that household decisions to allocate land to HYVs are affected. Saxena (1992) found that because the total labor required for growing eucalyptus is much less than for seasonal crops it was preferred by labor-constrained households in Uttar Pradesh.

What the empirical literature suggests about adaptation to climate change

A vast number of studies have drawn attention to a range of factors affecting the speed with which new technologies are adopted. Although the technologies required to deal with climate change are not necessarily untried in other regions they nevertheless have to be transplanted into areas where they are currently unknown. Arguably the same factors are likely to hinder or promote the take-up of these technologies. Some of these factors, such as age and gender of the population of farmers, are completely beyond the control of policy makers. Other factors, such as infrastructure, security of tenure, HIV infection rates, literacy and education, are much more general. The benefits of addressing problems such as literacy are not primarily their contribution to the task of adapting to climate change but nevertheless they are connected. This connection will give further impetus to attempts to promote such activities. The remaining policies, such as the price of agricultural inputs and outputs and extension advice, are more directly related to agriculture. The arguments for such interventions are related to the public good aspects of knowledge. Obviously the nature of the extension advice relating to climate change differs from location to location and this limits the extent to which costs can be saved by combining activities. The evidence also warns us that subsidies and other interventions can cause welfare losses as well as correcting for divergences between private and social benefits. Particular attention should be paid to the structure, conduct and performance of the seed industry, since a surprising number of papers mention the non-availability of seed as a reason for farmers not adopting HYVs. In so far as new drought-resistant and early maturing strains have a role to play in adapting to climate change this is obviously a cause for concern. It seems probable that, given the fixed costs of acquiring knowledge, larger farms will be the first to adapt to climate change, just as they were the first to participate in the green revolution.

However, adaptations to climate change are different in one important way from the more general adaptations that farmers make to improve productivity. This difference relates to the spatial characteristics of climate change. Most technologies which are introduced have probably not attracted or needed any particular spatial consideration. But if the existing studies are correct and geographical proximity is a major factor in copying, learning and adoption then the spatial nature of climate change matters. If climate change amounts to a slow advance then adaptations will occur along the boundary of shifting agro-climatic zones. If, however, climate change is discontinuous in the sense that the climate does not grow to resemble adjacent areas, then adaptation will be more problematical. In such circumstances farmers will not have the advantage of being able to observe what their already-adapted neighbors are doing. Similar arguments may apply to instances in which physical barriers exist. The fact that there may be farmers elsewhere in Africa already operating in particular types of climate may be of no use if they are physically separated from those who need to learn from them. Some of the empirical analyses also suggest that the range of spatial copying is very short indeed, implying that the pace of climate change will be an important determinant of the extent of transitional costs.

Apart from spatial issues, the literature also reveals that geographical proximity is not necessarily sufficient for learning to take place. Population density, ethnic mix and social hierarchy are also important. People are less inclined to learn from other ethnic groups. Although it is has not been addressed in the literature, one might state that tribal differences and differences in language will impede adaptation. Climatically diverse – perhaps because of varying topography – and ethnically homogeneous countries may be better able to adapt than small ethnically fragmented countries challenged by climates that do not resemble those of adjacent areas. The issue is to identify those population characteristics that facilitate the transmission of information. Even if these characteristics cannot be changed they can alert policy makers to the areas where climate change may strike hardest.

The use of GIS (Geographical Information System) based techniques, combined with knowledge about the characteristics of locations and the pattern of climate change, in the planning of demonstration effects and targeting of extension advice remains largely unexplored but deserves consideration. Agent based spatial modeling used as a simulation tool for technology diffusion and policy analysis may yield important insights (see for example Berger, 2001). Whilst such models are highly computer-intensive despite being still in their infancy, with time they could identify those areas which are likely to be slow to adapt to climate change and could also assist with the geographical targeting of policy measures.

4. The perception of and adaptation to climate change in Africa

The empirical part of this paper uses data obtained from an ongoing project entitled *Climate, water and agriculture: Impacts on and adaptations of agro-ecological systems in Africa* and funded by the Global Environmental Facility and the World Bank. This project involves surveying a large number of farmers in Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Niger, Senegal, South Africa and Zambia (results from Zimbabwe were collected according to a different rubric and could not be analyzed). In total, over 9500 farmers were interviewed and the main purpose of the survey was to collect data for a Ricardian analysis of net revenues and climate in order to predict the potential impact of climate change. But at the end of the survey were a number of questions about the perception of climate change, the adaptations made by farmers, and their perception of barriers to adaptation. More specifically farmers were requested to describe verbally any long-term changes in temperature and precipitation, as well as any measures that they had taken in order to adapt to whatever changes they had seen. Finally they were asked what the greatest obstacles to adaptation were.

The answers to these questions were subsequently coded as binary variables, following discussion with the country teams responsible for implementing the survey. Responses to the question about whether the farmer had witnessed changes in temperature were classified as falling into one or more of six different categories: 'warmer', 'cooler', 'more extreme', 'other', 'no change' and 'don't know'. The question about whether the farmer had witnessed changes in precipitation was classified as falling into one of seven different categories. No less than 25 different categories were identified for adaptations to climate change and 12 different barriers to climate change.

Results from the survey are analyzed here using a variety of techniques appropriate to binary value data and spatially referenced data. This paper also uses techniques appropriate to instances in which responses of interest were observed only for a subset of the variables of interest (sample selectivity). These methods are described in more detail below.

The fact that the main objective of the survey was to collect data for a Ricardian analysis means that many factors potentially influencing the speed with which farmers adapt to climate change cannot be examined. There are also some concerns about the integrity of the data. It is not always clear, for instance, whether farmers who were recorded as having made no change to their agricultural practices failed to adapt or simply refused to answer the question. Naturally this has important implications in terms of interpretation. There were also some confusing results: some people adapt to climate change even though they have noticed no change in the climate. Those inputting the data may have applied differing criteria to coding open-ended questions. Many country teams experienced difficulty in providing precise spatial coordinates. It also proved impossible to control for the potential influence of interviewer effects since the identity of the interviewer was not systematically recorded. This may be of concern when trying to interpret a geographical clustering of responses (interviewers tended to work in particular geographical areas). Despite these reservations, a set of surprisingly consistent findings emerges from the data, making the effort that has gone into analyzing it worthwhile.

Whilst it is necessary to code the data into binary responses for the purposes of statistical analysis it is clear that in so doing potentially important information might be lost. This suggests that a qualitative report might provide a useful adjunct to the quantitative analysis attempted in this paper.

The perception of climate change

Theoretical research has highlighted the importance of expectations formation with regard to climate and whether expectations lag behind reality in determining the transitional costs associated with climate change. The literature on adaptations also makes it clear that perception is a necessary prerequisite for adaptation. The preliminary evidence from a number of African countries described above reveals that large numbers of agriculturalists already perceive that the climate has become hotter and the rains less predictable and shorter in duration. Given the nature of the data that has already been collected, the issue of expectations and how the perception of climate change might be tackled is addressed by means of three alternative analyses.

The first analysis examines whether perceptions of climate change are dependent on years spent as an agriculturalist. One would expect that more experienced farmers would be better at distinguishing climate change from merely inter-annual variation. Indeed, a finding that such farmers were no more likely than others to claim to have observed climate change would be evidence that they do not employ Bayesian updating in generating their expectations with regards to the future climate.

The second analysis considers whether perceptions of climate change are spatially autocorrelated or, put another way, whether individual respondents' assessments can be validated by neighboring farmers' responses. Spatial autocorrelation would not be expected in a dataset in which respondents were randomly reporting that they perceive climate change because, for example, they want to gain status in the eyes of the interviewer or helpfully provide the information the interviewer is seeking.

The third, and perhaps most important, analysis considers whether agriculturalists' perceptions of climate change correspond to the evidence of changes provided by nearby climate monitoring stations. If they do not, then agriculturalists reveal themselves in dire need of help. One possible way of testing for this could be by comparing the probability that the climate has changed, as revealed by analysis of the statistical record, with the proportion of individuals who believe that such a change has in fact occurred. Interesting too is how many agriculturalists mentioned, unprompted, a lack of meteorological advice as a barrier to adaptation. The analysis in this paper, however, begins with a simple analysis of perceptions of climate change by country.

Elsewhere in the survey agriculturalists were asked if they had received any information on expected precipitation and temperature from extension officers. It would of course have been interesting to discover the proportion who have received such advice and whether it has made any difference to their assessment of whether climate change has occurred. Unfortunately the data are as yet unavailable.

Perceptions of climate change by country

Farmer perceptions of climate change by country are presented in Table 1. The data indicate that across the ten countries studied significant numbers of farmers believed average temperatures had increased. By contrast almost none believed they had decreased or that the temperature range had altered, apart from some in Ethiopia. Only in Cameroon did more of those questioned believe there had been no change in temperatures than that there had been an increase.

The results for precipitation show a similar uniformity of opinion across the ten countries. In six out of the ten countries the majority of farmers believed rainfall levels had decreased. A sizeable minority also believed they had witnessed a change in the timing of the rains. Very few farmers believed they had lived through a change in the frequency of droughts, other than in Senegal and Kenya, where almost all believed they had.

On the surface, such results seem to suggest that African farmers are very good at detecting climate change, which is a basic precondition for adaptation. But it must be suspected that some farmers might obligingly suggest they had witnessed particular forms of climate change when in reality they had not. We should therefore attempt to validate these findings before concluding that African farmers are as perceptive to changes in climate as they claim. We can do this by looking more closely at the characteristics of those who claim to have witnessed changes, gauging the similarity of responses among those farmers living near one another, and by considering whether the responses coincide with the meteorological evidence.

What kind of farmer perceives climate change?

The farmers best placed to pronounce on whether climate change has occurred are presumably those who have had the most experience of farming. It is therefore interesting to classify the perceptions of climate change according to the respondents' years of farming experience. In Table 2 I distinguish the responses of farmers having less than 20 years, between 20 and 39 years, and 40 or more years of experience.

It appears that the more experience farmers have, the more likely they are to claim that temperatures have increased and the less likely to claim there has been no change. The results for precipitation are very similar: once again the experienced farmer is less likely to cling to the view that there has been no change. As experience increases farmers are more likely to claim that there is less rainfall, more likely to notice changes in the timing of the rains and more likely to notice a change in the frequency of droughts.

Unfortunately, Table 2 does not indicate whether the differences between the views of experienced and inexperienced farmers are statistically significant. Nor does it indicate whether the results are sensitive to other factors, such as differences in farmers' ages, their educational attainment or, indeed, their country. Table 3 shows results from a probit regression. This model is customarily used to analyze binary data, in this case whether or not the farmer registers a particular perception of climate change. This is regressed on a range of variables including farmer experience, age, years of education, gender, marital status, whether he or she is the head of the household or not, whether he or she engages in off-farm work, and the country of residence. I also include data on distance to market, an indicator for subsistence farming, and whether or not the farmer received any extension advice, including information on climate. These results are adjusted for clustering at the level of the village on the assumption that the responses from farmers in the same village are likely to be related anyway. Rather than present results for the entire list of climate change perception, Table 3 limits the analysis to explaining the twin perception that there has been no change in temperature and no change in precipitation. In either case the coefficient on the farmer experience is negatively signed and statistically significant at the 1% level. Experienced farmers are significantly less likely to perceive no change in the climate. Also significant is distance to market, although whether the market in question is the place where the farmer buys inputs or sells outputs seems to make a critical difference. Subsistence farmers are far more likely to notice climate than other kinds of farmers.

Spatial clustering of climate change perceptions

I raised the possibility that the fact that many farmers believe the climate has become hotter and drier might be a case of prominence bias in questionnaires dealing with climate change. But one would not expect the portion of farmers who believe they have observed particular kinds of climate change to exhibit spatial autocorrelation if the results reflected only prominence bias. It is therefore possible to validate farmers' responses by checking to see whether those who perceive a particular type of change are clustered together. Put another way, are neighboring farmers are more likely to share the same climate change perception?

I employed Moran's I test for spatial autocorrelation with an inverse distance weights matrix on the portion of farmers who perceive particular types of climate change within a particular administrative area (for further details of this test see Anselin, 2001). Because some of the data did not include spatial coordinates this test was possible only for Niger and Ghana but the results are very encouraging (see Table 4). In Niger there appear to be regions where neighboring farmers agree that precipitation has increased and others where they agree it has decreased. There are also regions where neighboring farmers agree that temperatures have remained constant. The results from Ghana are even more striking. There are regions where neighboring farmers independently questioned about their perceptions of climate change appear to agree that temperatures have increased or stayed the same, that precipitation has either increased or stayed the same, and even agreed that the timing of the rains has changed. This is perhaps the strongest evidence I have that farmers are capable of perceiving changes in climate – the fact that neighboring farmers tell a consistent story.

Do farmer perceptions tally with records provided by weather monitoring stations?

For comparison with the perceptions of those farmers who believe the climate has become hotter and drier, Table 5 shows the actual annual change in temperatures and precipitations as recorded by weather monitoring stations. Unlike the test for spatial autocorrelation this cannot be done in a formal way, not least because certain changes in climate are subtle and difficult for respondents to describe. Compared to other countries Africa has few weather monitoring stations and many of these have been established only recently.

The climate data in Table 5 are taken from ARTES and averaged over land area. Two sets of data are shown, the first referring to the period 1978–2000 and the second to 1948–2001. Only data on precipitation is available for the longer time period. Tests were undertaken for linear trends in annual means in maximum and minimum temperature, and annual rainfall totals. The data shown in Table 5 indicate that Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana and Zambia have indeed experienced significantly higher temperatures and that Burkina Faso, Ghana, Niger, Senegal and Zambia have experienced a significantly drier climate. Large numbers of farmers in those countries are therefore justified in stating that climate has become hotter and drier. Unfortunately, in a number of countries (Kenya, Niger, Senegal and South Africa) large numbers of farmers stated that the climate was becoming hotter despite there being no evidence for such a change in the meteorological data. Likewise there is no evidence that precipitation has changed over Egypt, Kenya and South Africa although large numbers of farmers claimed that the climate has become drier.

Two important caveats apply to the above comparison: the fact that the climate data are averaged over the entire land area of a country, and the relatively short time period for the temperature data. Because the climate has been averaged over the entire land area of a country, significant variation in climate within the country may be obscured. In some areas where climate has not changed there may be no agriculture anyway since the climate is too arid. However, even if the desert areas in the south of Egypt are excluded, the change in annual rainfall is still statistically insignificant (+0.04 mm per year). And in the Gauteng province of South Africa, where every farmer interviewed registered the belief that precipitation had declined there is no statistically significant trend (+0.64 mm per year). Besides this, the average farmer has had exactly 20 years of experience whereas the temperature data here covers 23 years. It may not therefore be surprising that they disagree with what the evidence says since their comparison is with the climate of an earlier time period.

Adaptation to climate change

The green revolution literature has been characterized by cross-sectional analyses of discrete or continuous adoption measures. Researchers have used such techniques indirectly to infer what factors affect the rate of adoption. A more direct alternative and one which might often reveal different information is simply to ask farmers what barriers they perceive that prevent them from adapting. The speed of adoption is also clearly of interest in establishing the relevance of Ricardian analyses, and in other contexts the speed of adoption has been examined using time series data fitted to sigmoid shaped functional forms. Such analyses are however impossible with cross-sectional data such as that collected by the questionnaire. Moreover, the questionnaire used in the project did not ask agriculturalists which out of a number of technologies they had adopted; rather it asked what technological adaptations they had made as a consequence of climate change. An important implication of this is that some individuals will not mention particular technologies as adaptations to climate change simply because they already employ them. Accordingly the dataset is best suited to looking at differences in adaptation rates according to socio-economic characteristics, and perceptions of climate change and baseline climate will be required as an additional control to account for prior adoption. It is also possible to distinguish between individuals who perceived climate change but did not adapt in any way. Such individuals may be experiencing barriers to adaptation, so their characteristics are of particular interest.

The intention of the study is to provide policy makers with an assessment of the scope for government intervention to hasten and in some cases unlock the process of adaptation. In the course of the survey farmers were asked about the major constraints to adapting to climate change and in many ways this was the most important question put to them. The nature and number of these barriers to adoption should be analyzed by country. These data should be analyzed jointly with the perception of climate change, since it is clear that only those farmers who perceive climate change will consider the need to adapt to it. And only those attempting to adapt to climate change will encounter barriers to adaptation.

Adaptations by country

In so far as adaptations are dependent on customs, institutions and policies one might expect to see differences in the extent of adaptation between countries. It turns out that these differences are indeed profound. There are many examples of adaptations that were important in some countries and completely irrelevant in others. Unfortunately, it is also possible that these may reflect differences in the way the survey was implemented or the data was inputted, with no way of telling which.

Analyzing adaptations made by country across all respondents (Data in Tables 6-10) reveals that in all countries apart from Cameroon and South Africa the planting of different varieties of the same crop is considered to be one of the most important adaptations. Different planting dates are also considered an important adaptation in Egypt, Kenya and Senegal. Adopting a shorter growing season is universally practiced in Senegal but is elsewhere almost irrelevant. In Egypt the majority of respondents have moved towards non-farming activities. In Egypt, Kenya and South Africa significant numbers of farmers have adapted by increased use of irrigation. In Burkina Faso, Kenya and Niger there is increasing use of water conservation techniques. Soil conservation techniques are increasingly practiced in Burkina Faso, Kenya, Senegal and Niger. There is also increasing use of shading and sheltering techniques in Burkina Faso, Niger and Senegal, where they have been adopted by approximately one third of respondents. Increased use of weather insurance is almost exclusive to Egypt. Prayer and ritual offerings are made in Senegal and Niger. There are however, several countries in which almost a third or more of respondents report no change in agricultural practices. These include Burkina Faso, Cameroon, Ghana, South Africa and Zambia. By contrast every Egyptian and every Ethiopian respondent claimed to have made at least one adaptation.

Adaptations by perception of climate change

The difficulty with analyzing adaptations by country is that any differences observed are not wholly due to the characteristics of the country and the capacity of its agriculturalists to adapt, but rather to the fact that farmers in those countries perceive a different set of climatic changes or perhaps no changes at all. It is arguably more meaningful to examine the adaptations made according to the perception of climate change.

In Table 7 adaptations are analyzed by temperature perception. It appears that for any kind of temperature change the planting of different varieties of the same crop is an important adaptation. Shortening the growing season is important whether the temperature increases or decreases. Moving to a different site is important when the temperature becomes more extreme and a change from farming to non-farming activities is contemplated when temperatures become hotter or when the climate becomes more extreme. Increased temperatures and non-specified temperature changes can increase the use of water conservation techniques. Any change other than decreased temperature encourages farmers to instigate soil conservation practices. Shading and sheltering techniques are also extremely important for dealing with changes in temperature and are practiced by about a quarter of respondents. There are many other adaptations not specified in Table 7 that are prompted by temperature changes, and equally large numbers of farmers who make no adaptations at all.

There are some interesting findings with regard to adaptations by perception of change in rainfall. Once again, it appears that whatever changes are perceived there is a tendency to adapt by planting different varieties. But there are also instances where different planting dates are important, and when it is important to shorten the growing season. These changes occur when there is a reduction in rainfall and a change in the timing of the rains or a change in the frequency of drought. These adaptations of course make perfect sense when there is uncertainty about the window of opportunity for growing crops. Changes in rainfall also give rise to changes in the use of water conservation techniques. These techniques also increase with higher rainfall, suggesting perhaps that farmers are storing rainwater. Once again, shading and sheltering techniques are very common and seen by many as an appropriate adaptation to any change in rainfall. There are many adaptations that are not specified and may be specific to particular locations. Again, there are many farmers who do not adapt to changes in rainfall. There are, however, very few farmers who do not respond to a perceived change in the frequency of drought.

To summarize, it appears that changes in temperature and precipitation cause changes in crop varieties, changes in the use of shading and sheltering, and changes in soil conservation. In addition, changes in precipitation are also met by changes in planting dates, a shorter growing season, and increased use of water conservation techniques.

Adaptations linked to baseline climate

Just as incremental changes in particular climate variables may be advantageous or disadvantageous depending on the current baseline climate, so the baseline climate itself can be expected to affect the probability of particular adaptations being made, holding perceptions of climate change constant. The next analysis therefore distinguishes among the respondents according to current climate. Respondents are first divided into those farming in hot and cool climates, then into those farming in dry and wet climates, and finally into those farming in areas characterized by high and low runoff.

Yet again, irrespective of the baseline climate, changes in the varieties grown appeared to be an important adaptation. Shortening the growing season was also very important but only in climates that were currently either hot or dry or had low runoff. Changes to non-farming activities took place in areas that were cool and dry with low runoff and therefore seemingly appropriate for agriculture. Such changes were not observed where the climate was already hot and wet. Increased use of water and soil conservation techniques was noted in regions that were already hot and dry with low runoff. Shading and sheltering techniques were also noted in those areas that were hot and dry with low runoff. There were significant numbers of farmers who did not adapt in each type of climate, but adaptations were far more frequent in hot climates and wet climates. These differences are even more marked if the data is divided into those regions where it is both hot and dry, and those where it is cool and wet.

Perceived barriers to adaptation by country

The analysis of adaptation by country revealed some important differences in the extent and prevalence of different adaptation measures. One possibility already explored is that these differences may be due to differences in the perception of climate change across countries or differences in baseline climate upon which these changes are overlaid. Another possibility is that the differences may be the result of institutional differences between countries. To examine this possibility, respondents were asked whether they perceived any difficulties in adapting to climate change. A variety of possible barriers were identified and coded, including lack of information about weather and climate, lack of knowledge about adaptations, rationing of key inputs including water, lack of appropriate seed, insecure property rights and lack of market access.

Few farmers perceived lack of information about the weather or long-term climate change to be a barrier to adaptation, except in Cameroon, Kenya and Zambia. Likewise, few believed they lacked knowledge about the appropriate adaptations. In Ethiopia a quarter of respondents felt that they lacked information about climate change. A large number felt, however, that lack of credit or savings represented a barrier to adaptation. This was felt most acutely in Niger, where more than half of all farmers claimed that they were impeded. Such findings are quite consistent with the evidence on the technology adoption rates. By contrast, virtually no respondents in Egypt or Senegal said they were blocked through lack of savings or credit. Lack of access to water was anticipated to be a major problem in adaptation, but in fact was not perceived to be a barrier except in Ethiopia, Kenya and Senegal. And lack of access to appropriate seed, lack of security of property rights and lack of market access were hardly mentioned except in Ethiopia. Such results are somewhat at odds with the literature on technology adoption in which studies have regularly blamed slow rates of technology adoption on these factors. Large numbers of farmers perceived no barriers to adaptation whatsoever. The barriers to adaptation seem higher in Cameroon, Egypt and Ethiopia than elsewhere. Very few farmers in Burkina Faso felt themselves to be impeded.

Farmers who perceive climate change but fail to respond

Although a majority of farmers who were interviewed claimed to have noticed at least one facet of the climate they felt had changed, some of those who perceived changes failed to respond to them. While this does not mean that such farmers were acting unreasonably given their circumstances, it is nevertheless important to know whether they share some common characteristics in order to understand better the reasons underlying their lack of response.

Adaptation to climate change involves a two-stage process: first perceiving change and then deciding whether or not to adopt a particular measure. This gives rise to a sample selectivity problem since only those who perceive climate change will adopt, whereas we might wish to make statements about the adaptation made by the population of agriculturalists in general. This implies using Heckman's sample selectivity probit model.

Heckman's sample selection model is based on the following two latent variable models:

$$Y_1 = \mathrm{b}'X + U_1 \qquad (1)$$

$$Y_2 = \mathrm{g}'Z + U_2 \qquad (2)$$

where X is a k-vector of regressors, Z is an m-vector of regressors, possibly including 1's for the intercepts, and the error terms U_1 and U_2 are jointly normally distributed, independently of X and Z, with zero expectations. Although we are primarily interested in the first model, the latent variable Y_1 is only observed if $Y_2 > 0$. Thus, the actual dependent variable is:

$$Y = Y_1 \text{ if } Y_2 > 0, Y \text{ is a missing value if } Y_2 <= 0 \quad (3)$$

The latent variable Y_2 itself is not observable, only its sign. We only know that $Y_2 > 0$ if Y is observable, and $Y_2 <= 0$ if not. Consequently, we may without loss of generality normalize U_2 such that its variance is equal to 1. If we ignore the sample selection problem and regress Y on X using the observed Y's only, then the OLS estimator of b will be biased, because:

$$E[Y_1|Y_2 > 0, X,Z] = b'X + rsf(g'Z)/F(g'Z) \quad (4)$$

where F is the cumulative distribution function of the standard normal distribution, f is the corresponding density, s^2 is the variance of U_1, and r is the correlation between U_1 and U_2. Hence:

$$E[Y_1|Y_2 > 0, X] = b'X + rsE[f(g'Z)/F(g'Z)|X] \quad (5)$$

The latter term causes sample selection bias if r is non-zero. In order to avoid the sample selection problem, and to get asymptotically efficient estimators, we have to estimate the model parameters by maximum likelihood.

As noted, many farmer characteristics that researchers in the past identified as being important for determining whether farmers adopted new technologies associated with the green revolution might also be important in determining whether farmers adapt to changes to climate. I therefore include a range of variables in the equation which describes the probability that someone who notices any aspect of climate change will adapt to it. I include farmer experience and farmer education both measured in years. I expect the latter to diminish the probability that no adaptation measure is taken. I also include the age of the respondent, gender, whether married, and whether head of the household or not. There is a suggestion from the literature that gender discrimination may make it difficult for some women to gain access to complementary inputs but otherwise there is no prior expectation regarding the sign of the coefficient on these variables. I include a dummy variable indicating the variable whether the respondent engages in off-farm work.

Also included in the data is distance to the market where the farmer buys inputs and sells outputs. Subsistence farmers are separately identified. Previous research has identified proximity to market as an important determinant of adaptation, presumably because the market serves as a means of exchanging information with other farmers. Free extension advice about livestock and crop production is recorded. Although available, the number of extension visits is excluded since these may well be endogenous and partly determined by the number of adaptations. Free extension advice on the other hand is presumably rationed by the provider.

Considerable variation in the size of the area farmed is observed in the data. If there is a fixed cost associated with the acquisition of information then it should be anticipated that large-scale farms would be more likely to adapt that would small-scale farms. My expectation is that larger farms are more likely to adapt.

One of the most frequently explored claims is that there is a link between tenure status and the propensity of farmers to adopt new measures. The data here provide a diverse set of tenurial relationships, including farmers who own their land, relationships based on sharecropping, communal lands, rented farmland, borrowed farmland and other non-specified relationships. I would anticipate that any form of tenure besides private ownership would inhibit adaptation involving sunk investments. The consequences of adaptations not involving sunk investments are, however, less clear. The only sunk investment described by farmers with any regularity as a consequence of climate change involves the planting of trees to obtain shade.

The baseline climate defines the number of outstanding adaptation measures that might be undertaken in response to a change in the climate. The baseline climate also dictates whether such adaptation measures are necessary. Annually averaged temperature, precipitation and runoff are included in the model.

Finally, I include dummy variables that identify the different countries in order to capture any institutional differences between nations having bearing on the ability of their farmers to adapt to climate change. The coefficients on these dummy variables indicate the propensity of farmers to respond to climate change in Zambia.

For the specification of the equation describing whether the farmer notices climate change, I include the same set of socio-economic characteristics of the respondent, namely farming experience, education, age, marital status, whether head of the household and whether engaging in non-farm activities. I also include a set of dummy variables describing the different countries in anticipation of climate change being more pronounced in some countries than in others. Of these variables, I expect farming experience to significantly increase the probability that climate change is noticed by the respondent. In order to identify the model I also include a variable indicating whether the respondent was receiving free advice about weather and climate.

The probit sample selection model is presented in Table 11.

The results from the sample selection model indicate that the adaptation process is driven by a number of factors. Firstly, it is apparent that more experienced farmers are more likely to record an adaptation measure. Being in receipt of free extension advice relating about either livestock or crop production also strongly increases the probability of the farmer adapting. Greater distance to the market where outputs are sold diminishes the probability of adaptation. The market may thus serve as a means of exchanging and sharing information, although distance to the market where inputs are purchased has no impact. The respondent's level of education (measured in years) also greatly increases the probability of adaptation. All of these factors have obvious implications for the question of what can be done to help farmers adapt to climate change. Being head of the household also increases the probability that the farmer can adapt, perhaps because he or she is in control of household resources. There is, however, no evidence that gender influences the probability of adaptation.

It appears that larger farms are more likely to adapt to climate change. This is consistent with the idea that adaptation has a fixed cost element, implying that information gathering is less worthwhile for small farmers. Many contributors to the literature have argued that tenurial arrangements influence adaptation. In the results obtained here, tenurial arrangements are not important apart from where land is borrowed. Individuals farming borrowed land appear less willing or able to adapt, possibly because they might be relieved of their land. There is strong evidence that current climate influences the probability of adaptation. Land that is already marginal in the sense of having high temperatures or low rainfall apparently compels farmers to adapt to whatever changes in climate they witness. There are very marked differences in the ability of farmers from different countries to respond. Farmers in Burkina Faso are much less likely to respond than farmers in Egypt, who almost invariably respond. The precise reasons for such differences are unclear. They may be related to the quality of institutions, the existence of infrastructure, differences in prices or simply a manifestation of the way the survey was conducted and the data inputted.

From the selection equation determining which farmers notice climate change, it appears that experienced farmers and farmers who have enjoyed extension advice about climate are in the vanguard of adaptation. Once again there are marked differences in the abilities of farmers from different countries to perceive climate change, but this may be because climate change is itself a regional phenomenon. Interestingly, the results indicate that the selection equation and the adaptation equation are statistically independent of one another.

Before concluding, a final caveat is in order: just because a farmer makes an adaptation to climate change does not mean that the adaptive measure taken is appropriate or that the farmer has made the same set of adaptations that one more accustomed to the climate might have made.

5. Conclusions

It is unlikely that farmers know immediately the best response to climate change when such agricultural practices as it requires are outside the range of their experience. Nor can they be expected to recognize immediately when the long-run climate has changed, because natural inter-annual variation in the climate obscures this. There will therefore inevitably be a period of transitional losses as a result of adapting to climate change. Preliminary research in the context of North American agriculture indicates that the extent to which climate expectations lag behind reality is a potentially significant determinant of the costs associated with the transition to the long-run equilibrium response. Unfortunately very little is known about the way agriculturalists update their expectations with respect to climate. And even if they do perceive that the climate has changed they may still, because of any number of market imperfections, be unable to respond in the way that they themselves or society at large would wish. There is a significant amount of evidence detailing the slow uptake of technological adaptations in agriculture during the green revolution, especially in Africa.

This paper analyzes the perceptions of African farmers, the more experienced of whom believe that the climate that has already changed over the course of their working lives. This is what one would expect to find if farmers were Bayesian updating while working the land. It appears, moreover, that the precise nature of the changes reported by farmers is similar to those reported by their neighbors, and that these assessments of climate change are not inconsistent with the meteorological evidence. The majority of those who felt that the climate had changed had made at least one adaptation. These adaptations seemed geared to the changes that the farmer perceived to have occurred as well as to the baseline climate. Of course the fact that experienced farmers appear to notice climate change does not mean that they are 'optimally' updating their expectations in the sense of making the most efficient prediction based on the historical information available to them. And the fact that they are making adaptations to their agricultural practices in the light of the changes they perceive does not necessarily mean that those adaptations are appropriate and resemble those already made by farmers working in such climates. Consequently, all that can be said is that the available evidence does not enable one to dismiss use of the Ricardian technique for the purposes of predicting the impact of future climate change on agriculture.

An increasingly important question is whether agricultural adaptation in the face of climate change can be expected to occur autonomously or whether government intervention has a role in promoting the process. The results of this study make it clear that at least some adaptation takes place autonomously. Nevertheless, in the context of the green revolution numerous impediments were identified by researchers as slowing the process of agricultural development and some of these were considered to be amenable to policy interventions. In so far as the spread of technology associated with the green revolution can be compared to the altered opportunities for agricultural production associated with changing climate it is likely that researchers will begin to believe there is a role for government.

The nature and rationale for such interventions will be a subject for further discussion. Perhaps something can be learned from the literature evaluating the successes and failures of such instruments in promoting the use of new technologies. But one of the things that will certainly emerge from an examination of the literature on policy instruments is that their proper use requires considerable information if they are to serve their purpose. Such measures can all too readily be manipulated to justify serving interests other than those of correcting market imperfections. On the other hand, some interventions merely imply a greater impetus to projects that are worth undertaking in their own right.

From the present study a number of findings emerge that resonate with the earlier literature. These relate to the importance of extension services and proximity to the market in determining whether individual farmers respond to the perception of a changed climate. Together these highlight the importance of accounting for alternative channels of learning. One of the main way in which farmers learn what adaptations are appropriate is from observing their neighbors. Future work in this area should attempt to model copying from neighbors. But perhaps the single most important finding from this study is that whereas it is farming experience that determines whether or not farmers perceive climate change, it is education that largely determines whether or not they adapt to it.

Policy implications

In terms of policy implications it appears that improved farmer education would do most to hasten adaptation. The provision of free extension advice may also play a role in promoting adaptation. In so far as distance to the selling market is a significant determinant of whether a farmer adapts to climate change, it may be that improved transport links would improve adaptation, although the precise mechanism underlying this is unclear. Better roads may allow farmers to switch from subsistence farming to cash crops, or facilitate the exchange of ideas through more regular trips to the market. There are many country specific differences in the propensity of individuals to adapt and further analysis would be required to understand underlying factors. Adaptation, however, is something undertaken only by those who perceive climate change. The perception of climate change appears to hinge on farmer experience and the availability of free extension advice specifically related to climate change. But while the policy options for promoting an increased awareness of climate change are more limited, earlier analysis indicates that the perception of climate change is already high.

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Table 1: Perceptions of climate change by country (% of respondents)

Perception	BF	Cam	Egy	Eth	Gha	Ken	Nig	Sen	SA	Zam
Increased temperatures	29	22	74	14	62	62	50	69	59	32
Decreased temperatures	1	4	1	63	1	9	10	2	1	4
Altered temperature range	0	28	11	0	2	.28	20	0	13	5
Other temperature change	11	9	0	0	7	1	6	0	0	14
No change in temperature	0	29	12	3	14	42	13	0	22	32
Increased precipitation	5	11	5	10	3	9	13	1	1	9
Decreased precipitation	42	25	53	9	57	70	60	84	54	26
Change in timing of rains	30	18	7	58	38	30	2	85	17	25
Change in frequency of droughts	9	n.a.	0	8	3	100	9	84	7	10
Other changes in precipitation	4	11	0	0	6	0	5	0	1	14
No change in precipitation	19	27	32	4	4	27	5	0	23	13

Table 2: Perceptions of climate change by farmer experience (% of respondents)

	Years of experience		
Perception	**0-19**	**20-39**	**40+**
Increased temperatures	42	53	60
Decreased temperatures	5	5	6
Altered temperature range	11	9	7
Other temperature change	7	5	4
No change in temperature	22	12	7
Increased precipitation	7	6	5
Decreased precipitation	44	54	62
Change in timing of rains	27	32	35
Change in frequency of droughts	14	20	28
Other changes in precipitation	6	4	3
No change in precipitation	17	14	11

Table 3: The probability of perceiving no change in temperature and precipitation as a function of farmer characteristics

	Perceives no change in temperature	Perceives no change in precipitation
Farmer experience	-0.001***	-0.001**
Extension advice regarding climate	-0.026	-0.021*
Distance to selling market	0.001***	0.001***
Distance to purchasing market	-0.001**	-0.001**
Subsistence farmer	-0.102***	-0.062**
Age	0.000	0.000
Married	-0.020	-0.008
Education	0.001	0.001
Male	0.006	-0.010
Head of household	-0.008	-0.024**
Engages in non-farm work	0.019	-0.000
Burkina Faso	-0.208***	0.076*
Cameroon	-0.029	0.092**
Egypt	-0.102***	0.181***
Ethiopia	-0.126***	-0.061**
Ghana	-0.090	-0.067***
Kenya	0.045	0.091**
Niger	-0.107**	-0.069***
Senegal		-0.137***
South Africa	-0.075***	0.043
Wald test (zero slopes)	241.79***	253.93***
Pseudo R-squared	0.154	0.154
Number of observations	6627	7571

Notes: The coefficient indicates the impact of a marginal change on the probability, while dF/dx is for discrete change of dummy variable from 0 to 1.
*** significant at 1% level ** significant at 5% level * significant at 10% level
Standard errors are adjusted for clustering at the level of the village.

Table 4: Moran's I test for spatial clustering in the perception of climate change

Perception	Niger	Ghana
Increased temperatures	-0.042	0.544**
Decreased temperatures	-0.070	-0.049
Altered temperature range	-0.018	0.069*
Other temperature change	0.005	0.030
No change in temperature	0.063**	0.372**
Increased precipitation	0.092**	0.574**
Decreased precipitation	0.124**	-0.064
Change in timing of rains	0.006	0.270**
Change in frequency of droughts	0.052*	-0.017
Other changes in precipitation	0.010	0.014
No change in precipitation	-0.024	0.673**

Notes: ** significant at 1% level * significant at 5% level Spatial weight matrix = Inverse distance
Tests relate to the proportion of individuals possessing a certain perception within each region. The mean value of the statistic is -0.034 for Niger and -0.017 for Ghana.

Table 5: National trends in temperature and precipitation

	Data refer to 1978–2000			Data refer to 1948–2001
Country	**Change in min temp (°C)**	**Change in max temp (°C)**	**Change in precip (mm)**	**Change in precipitation (mm)**
Burkina Faso	+0.16*	0.00	-4.12	-3.92**
Cameroon	+0.31*	+0.02	+7.48	-4.30
Egypt	+0.25**	+0.04	-1.63	+0.06
Ethiopia	+0.63**	-0.03	+9.12	-0.39
Ghana	+0.29**	+0.02	-11.27**	-3.66**
Kenya	+0.12	+0.02	+4.20	+3.01
Niger	0.00	-0.01	-0.16	-1.19**
Senegal	+0.11	+0.01	-1.79	-5.97**
South Africa	+0.02	0.00	+0.19	+0.19
Zambia	0.15**	+0.10*	-16.49**	-2.21*

Notes: Data are taken from ARTES. Coefficients refer to change per annum.
** significant at 1% level * significant at 5% level

Table 6: Adaptations to climate change by country (% of respondents)

Adaptation	BF	Cam	Egy	Eth	Gha	Ken	Nig	Sen	SA	Zam
Different varieties	36	1	4	45	16	25	36	25	3	13
Different crops	0	0	0	15	15	30	1	2	3	6
Crop diversification	5	6	1	15	2	8	1	0	3	9
Different planting dates	2	12	17	1	7	21	2	27	6	3
Shortening growing season	0	3	0	9	1	0	0	91	0	0
Lengthening growing season	0	2	0	3	5	0	0	0	0	0
Moving to a different site	8	0	0	0	2	1	16	0	0	2
Changing quantity of land under cultivation	0	0	0	0	5	1	0	1	3	5
Change from crops to livestock	0	0	0	1	1	3	0	0	1	1
Change from livestock to crops	0	0	0	1	0	0	0	0	0	0
Adjustments to livestock management	0	0	0	0	0	9	1	0	16	0
Change from farming to non-farming activity	0	0	75	0	0	1	0	0	2	1
Change from non-farming to farming activity	0	0	8	6	0	0	0	0	0	0
Increased use of irrigation / groundwater / watering	0	14	20	1	7	21	5	7	21	2
Decreased use of irrigation / groundwater / watering	0	0	6	6	0	0	0	0	0	0
Changed use of capital and labour	3	0	0	0	0	0	0	0	0	0
Changed use of chemicals and fertilisers	0	6	2	0	1	4	19	3	3	0
Increased use of water conservation techniques	38	11	10	4	9	28	18	9	2	0
Decreased use of water conservation techniques	0	2	0	3	0	0	2	0	0	0
Soil conservation techniques	38	19	0	6	0	20	12	20	7	1
Shading and sheltering / tree planting	26	5	0	18	5	11	40	33	2	1
Use of insurance or weather derivatives	0	0	53	29	0	0	0	0	0	0
Prayer or ritual offering	1	4	0	4	2	0	15	12	0	0
Other	3	8	0	6	19	5	5	17	4	58
No adaptation	27	15	0	2	37	10	6	05	42	27

Table 7: Adaptations made by those who perceive a change in temperature (% of respondents)

Adaptation	Increased	Decreased	More extreme	Other
Different varieties	9	4	6	2
Different crops	4	6	2	0
Crop diversification	1	2	5	1
Different planting dates	10	4	8	2
Shortening growing season	18	7	0	0
Lengthening growing season	0	2	0	0
Moving to a different site	2	0	4	1
Changing quantity of land under cultivation	1	0	0	0
Change from crops to livestock	0	0	0	0
Change from livestock to crops	0	0	0	0
Adjustments to livestock management	1	0	2	0
Change from farming to non-farming activity	14	0	8	0
Change from non-farming to farming activity	0	4	4	0
Increased use of irrigation / groundwater / watering	7	2	6	2
Decreased use of irrigation / groundwater / watering	0	1	0	0
Changed use of capital and labour	0	0	0	0
Changed use of chemicals and fertilisers	3	7	2	3
Increased use of water conservation techniques	11	2	4	13
Decreased use of water conservation techniques	0	4	0	0
Soil conservation techniques	8	4	13	12
Shading and sheltering / tree planting	17	25	24	22
Use of insurance or weather derivatives	2	12	2	0
Prayer or ritual offering	3	3	2	0
Other	10	7	6	14
No adaptation	24	20	21	40

Table 8: Adaptations made by those who perceive a change in precipitation (% of respondents)

Adaptation	Increase	Decrease	Change in timing	Drought frequency	Other
Different varieties	14	24	24	26	11
Different crops	4	6	5	3	2
Crop diversification	3	3	4	2	1
Different planting dates	5	11	16	22	44
Shortening growing season	4	22	37	68	0
Lengthening growing season	1	0	1	0	0
Moving to a different site	8	4	1	1	0
Changing quantity of land under cultivation	1	1	2	1	1
Change from crops to livestock	0	0	0	0	0
Change from livestock to crops	0	0	0	0	0
Adjustments to livestock management	0	1	0	0	0
Change from farming to non-farming activity	0	6	2	0	0
Change from non-farming to farming activity	4	0	0	0	0
Increased use of irrigation / groundwater / watering	7	8	6	7	5
Decreased use of irrigation / groundwater / watering	1	0	0	0	0
Changed use of capital and labour	0	0	12	0	0
Changed use of chemicals and fertilisers	4	3	2	3	5
Increased use of water conservation techniques	11	12	10	10	9
Decreased use of water conservation techniques	2	0	0	0	0
Soil conservation techniques	8	12	15	17	10
Shading and sheltering / tree planting	5	12	16	27	12
Use of insurance or weather derivatives	3	5	2	0	0
Prayer or ritual offering	0	6	5	10	3
Other	15	11	17	17	26
No adaptation	21	14	15	7	27

Table 9: Adaptations made by those farming in different climates (% of respondents)

Adaptation	Hot	Cool	Dry	Wet	Low runoff	High runoff
Different varieties	27	11	24	16	22	19
Different crops	5	6	2	10	3	8
Crop diversification	3	5	2	6	4	3
Different planting dates	10	11	12	8	10	10
Shortening growing season	22	1	23	1	21	6
Lengthening growing season	1	0	0	2	0	1
Moving to a different site	6	0	5	2	5	2
Changing quantity of land under cultivation	1	2	0	3	0	3
Change from crops to livestock	0	0	0	1	0	1
Change from livestock to crops	0	0	0	0	0	0
Adjustments to livestock management	0	3	1	1	0	2
Change from farming to non-farming activity	0	23	15	1	17	1
Change from non-farming to farming activity	0	2	1	0	2	0
Increased use of irrigation / groundwater / watering	5	14	9	8	10	6
Decreased use of irrigation / groundwater / watering	0	2	1	0	1	0
Changed use of capital and labour	0	0	0	0	1	0
Changed use of chemicals and fertilisers	5	3	5	2	6	2
Increased use of water conservation techniques	18	8	18	9	16	12
Decreased use of water conservation techniques	0	0	0	0	1	0
Soil conservation techniques	18	6	17	8	16	10
Shading and sheltering / tree planting	24	3	24	6	24	9
Use of insurance or weather derivatives	1	16	11	1	11	2
Prayer or ritual offering	7	1	6	2	6	2
Other	12	18	7	23	11	17
No adaptation	19	15	11	25	8	26

Table 10: Perceived barriers to adaptation by country (% of respondents)

Barriers	BF	Cam	Egy	Eth	Gha	Ken	Nig	Sen	SA	Zam
Lack of information about weather	0	12	7	0	2	14	7	0	3	18
Lack of information about climate change	0	5	0	28	2	3	8	0	2	16
Lack of knowledge about adaptations	12	5	0	28	2	31	4	0	5	1
Lack of credit or savings	20	34	0	31	16	73	56	1	25	28
Rationing of inputs other than water	0	0	0	27	2	5	0	0	0	12
No access to water	0	4	0	15	2	14	4	19	2	0
Lack of appropriate seed	0	0	0	18	3	8	0	0	0	2
Adaptation not cost effective	0	8	0	18	4	6	0	0	7	0
Insecure property rights	0	5	0	9	0	5	0	0	0	0
Lack of market access or transport problems	0	2	0	0	0	5	3	0	0	1
Other	20	n.a.	0	5	20	100	17	44	2	33
No barriers to adaptation	63	6	6	12	50	15	18	44	56	25

Table 11: Heckman's sample selection model of whether a farmer fails to respond to climate change

	Probability of no adaptation measure being taken Heckman selection model
Farmer experience	-0.003**
Free extension advice regarding crops	-0.171***
Free extension advice regarding livestock	-0.155***
Distance to selling market	0.005***
Distance to purchasing market	-0.002
Subsistence farmer	0.195*
Age	-0.002
Education	-0.016***
Male	-0.076
Head of household	-0.177***
Married	-0.213***
Engages in non-farm work	0.019
Farm size	-0.000**
Proportion of land owned	0.224
Proportion of land rented out	-0.327
Proportion of land under sharecropping	0.048
Proportion of land under community ownership	-0.079
Proportion of land rented	0.194
Proportion of land borrowed	0.323**
Mean temperature	-0.119***
Mean monthly precipitation	0.005***
Mean monthly runoff	0.000
Burkina Faso	1.208***
Cameroon	-0.566***
Egypt	-1.761***
Ethiopia	-1.073***
Ghana	0.919***
Kenya	-0.431*
Niger	0.687***
Senegal	0.307*
South Africa	0.193
Constant	1.766***

Table 11 (continued):

	Probability of no adaptation measure being taken Heckman selection model
Selection equation	
Farmer experience	0.005***
Extension advice relating to climate	0.218***
Age	-0.003*
Education	-0.003
Head of household	0.123***
Married	0.029
Male	0.060
Engages in non-farm work	-0.012
Burkina Faso	1.803***
Cameroon	-0.490***
Egypt	-0.065
Ethiopia	0.760***
Ghana	0.621***
Kenya	-1.386***
Niger	0.558***
Senegal	0.324***
South Africa	-0.414***
Constant	1.077***
Wald test (zero slopes)	810.83***
Wald test (independent equations)	0.16
Censored observations	1042
Uncensored observations	6589

Note: *** significant at 1% level ** significant at 5% level * significant at 10% level