Global Environmental Change 23 (2013) 774–781

Contents lists available at SciVerse ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

Paleoclimate histories improve access and sustainability in index insurance programs

Andrew R. Bell[a,*], Daniel E. Osgood[b], Benjamin I. Cook[c,e], Kevin J. Anchukaitis[c,f], Geoffrey R. McCarney[d], Arthur M. Greene[b], Brendan M. Buckley[c], Edward R. Cook[c]

[a] International Food Policy Research Institute, Washington, DC 20006, USA
[b] International Research Institute for Climate and Society, The Earth Institute at Columbia University, Palisades, NY 10964, USA
[c] Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY 10964, USA
[d] School of International and Public Affairs, Columbia University, New York, NY 10027, USA
[e] NASA Goddard Institute for Space Studies, 2880 Broadway, New York, NY 10025, USA
[f] Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA

ARTICLE INFO

Article history:
Received 11 April 2012
Received in revised form 29 January 2013
Accepted 11 March 2013

Keywords:
Paleoclimate
Tree rings
Index insurance
Non-stationarity
Agriculture

ABSTRACT

Proxy-based climate reconstructions can extend instrumental records by hundreds of years, providing a wealth of climate information at high temporal resolution. To date, however, their usefulness for informing climate risk and variability in policy and social applications has been understudied. Here, we apply tree-ring based reconstructions of drought for the last 700 years in a climate index insurance framework to show that additional information from long climate reconstructions significantly improves our understanding of the underlying climate distributions and variability. We further show that this added information can be used to better characterize risk to insurance providers, in many cases providing meaningful reductions in long-term contract costs to farmers in stand-alone policies. The impact of uncertainty on insurance premiums can also be reduced when insurers diversify portfolios, and the availability of long-term climate information from tree rings across a broad geographic range provides an opportunity to characterize spatial correlation in climate risk across geographic regions. Our results are robust to the range of climate variability experienced over the last 400 years and in model simulations of the twenty-first century, even within the context of changing baselines due to low frequency variability and secular climate trends. These results demonstrate the utility of longer-term climate histories in index insurance applications. Furthermore, they make the case from a climate-variability perspective for the continued importance of such approaches to improving the instrumental climate record, even into a non-stationary climate future.

1. Introduction

Droughts and other climate-related events have severe impacts on smallholder farmers in developing economies (e.g., Adamson and Bird, 2010; Kallis, 2008). Agricultural insurance plays an important role in allowing farmers to manage risk in high-income countries, but is largely unavailable in lower-income countries, where it is limited by implementation costs and the potential for perverse incentives to farmers (such as reducing inputs or destroying crops to increase the size of losses) (IRI, 2009). Thus, it is often the case that the farmers who are most vulnerable to climate risk lack access to insurance tools that could help to protect them.

Index insurance has the potential to solve many of the problems blocking access to insurance in lower-income countries (Barrett et al., 2007). By triggering payouts on an index (such as total seasonal rainfall, temperature, or soil moisture), it addresses perverse incentives and greatly reduces the costs of insuring smallholder farmers. Accordingly, index insurance has generated a great deal of interest in the development community, with dozens of ongoing pilot projects underway to determine if it is an affordable, viable tool for adaptation and poverty reduction (Hazell et al., 2010; Hellmuth et al., 2009), with the greatest development having occurred in India where millions of farmers hold contracts (Clarke et al., 2012), and in China where recent index insurance pilots have shown promise, following the introduction of a major insurance subsidy in 2007 and explosive growth in agricultural insurance provision (Hazell et al., 2010). However, a trade-off to the benefits of index insurance is that indices may have limited

---

[*] Corresponding author. Tel.: +1 202 862 4644.
E-mail address: a.bell@cgiar.org (A.R. Bell).

0959-3780/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.gloenvcha.2013.03.003

accuracy in calibrating payouts to actual losses, an issue commonly known as basis risk. Furthermore, there are still challenges concerning both the supply and demand of index insurance for smallholder farmers that must be overcome.

For example, concerns have been raised in the literature that demand for index insurance among farmers may be too low (Banerjee and Duflo, 2011; Cole et al., 2009; Giné and Yang, 2009; Hazell et al., 2010), due to the degree of uninsured basis risk not covered by index contracts, as well as issues of trust, communication, consumer education, and price (Patt et al., 2010; Trærup, 2012). However, initial efforts to encourage demand are yielding results. Projects in the Horn of Africa have grown from hundreds to tens of thousands of farms over only two to three years (Oxfam, 2011; Syngenta Foundation, 2011) while in India, subsidized index insurance had expanded to include nearly twenty million farmers by 2008 (Mahul et al., 2012). Studies on Ethiopia (Meze-Hausken et al., 2009) and Tanzania (Trærup, 2012) further suggest that shifting the scale at which insurance is applied and allowing spatial pooling of risk among networks of farmers has potential to overcome barriers of trust and perceived risks, and further enhance demand. On the supply side, there is concern that the science underlying the construction of these indices is not sufficiently strong to scale up insurance programs. The lack of suitable climate data, particularly in developing countries, therefore remains a key constraint to the development of robust insurance products (Brown et al., 2011; Norton et al., 2011).

Lacking sufficient climate data, insurance providers are unable to accurately price their products, forcing them to price contracts conservatively to ensure that they can be honored. This leads to premiums that are prohibitively expensive (Meze-Hausken et al., 2009), or to insurance companies not being willing to offer any product at all (IFC, 2010). Moreover, if existing climate records are insufficient to adequately characterize climatic variability, then the premium in a given period may reflect over- or under-estimates of the probability of a payout, so that they are again priced inaccurately.

The risk of using shorter climate records to determine index insurance premiums is therefore that the price will not correspond well to the underlying climate risk, limiting access to insurance products for poor farmers (if the premium is set too high), or jeopardizing the sustainability of the insurance project (if the premium is set too low). These problems have been central hurdles faced by major index insurance efforts (Hazell et al., 2010).

Paleoclimate records have the potential to improve the accuracy of index insurance pricing and therefore improve access to, and the sustainability of, climate insurance for poor farmers. Annual growth rings of trees, for example, provide millennium-scale, annually-resolved records of climate that can be used to estimate past climate variability and derive uncertainties for those estimates. Trees are ubiquitous over much of the planet, so that networks of tree ring chronologies can be used to develop objective estimates of climate variability in both space and time – providing improved characterization of local hydroclimatic variability, the return interval of extrema, and the possible range of climate anomalies. Temperature or moisture stresses manifest as reductions in radial growth, so that the relative width of tree rings can provide a history of environmental conditions (in particular and of interest in this study, drought) of potential value in natural resource decision-making.

The notion that tree rings could inform decision-making is decades old, with work since the 1930s in the US Southwest linking tree rings to streamflow (Hardman and Reil, 1936; Stockton and Jacoby, 1976) and reservoir reliability (Potts, 1962), with more recent application in ecosystem (e.g., Swetnam et al., 1999; Willis et al., 2010) and water management (e.g., Woodhouse and Lukas, 2006). The history of tree rings in the water management context specifically is well reviewed by Meko and Woodhouse (2011). However, the potential for application in a risk management context has only more recently been developed (e.g., Bell et al., 2011). Using the Monsoon Asia Drought Atlas (MADA) (Cook et al., 2010a) and North American Drought Atlas (NADA) (Cook et al., 2010b), this study makes an important first connection between paleoclimate variability and modern risk management in agriculture by applying tree-ring-based climate reconstructions to the pricing of index insurance contracts. In the following sections we apply tree-ring data to estimating prices in a model index insurance contract, and discuss the implications of this simple example for established and new index insurance schemes.

2. Methods

The price of an index insurance premium is shaped by two components: first, the expected value of the payout; and second, the costs the insurer bears in administering the contract, capturing an economic profit, and borrowing the 'value at risk' of the contract. Both of these price components can be improved (made more accurate) by the use of richer data sets more representative of true climate variability. Our contracts are priced on the Palmer Drought Severity Index (PDSI), a drought measure widely used in agriculture (Dai et al., 2004; Heim, 2002) that expresses soil moisture as a normalized departure from a locally-averaged water balance. Tree rings have previously been used to reconstruct other environmental signals such as temperature or stream-flow, upon which corresponding climate index products could be developed.

Formally, the price premium is calculated as:

$$C_{\text{contract}} = E(R) + r \cdot [VAR - E(R)] \tag{1}$$

where $E(R)$ is the expected payout, VAR is the 'value at risk' – the maximum expected payout (such as for a 1 in 100 year event), and r is a target rate of return or the opportunity cost of funds for the insurer. Administrative costs other than the VAR are not sensitive to the use of climate information and are not treated explicitly here for simplicity. This is a simple and stylized pricing formula utilized in many index insurance pilots and in World Bank Index insurance training materials (see for example, IRI, 2009; Osgood et al., 2007); for the purposes of our analysis it provides a clear view into how the two key drivers of contract price (expected payout and value at risk) respond to changes in available climate information. The variable r is the interest rate paid by the insurer; because in an index insurance program, all insured contracts can be expected to pay out at the same time (via spatially pervasive drought), the insurer cannot count on premiums paid from other contracts to cover payouts and must instead borrow enough money to cover the maximum payout. In this study we adopt a typical linear payout structure, with payouts triggered at some dry PDSI Z_{trigger} and increasing up to the largest possible payout at the exit PDSI Z_{exit}:

$$R = \max\left(0, \min\left(\frac{Z_{\text{trigger}} - Z}{Z_{\text{trigger}} - Z_{\text{exit}}}, 1\right)\right) \cdot R_{\text{exit}} \tag{2}$$

where Z is the observed PDSI and R_{exit} is the payout at Z_{exit}. The expected payout for the contract in a given year is calculated as the integral:

$$E(R) = \int_{-\infty}^{Z_{\text{trigger}}} p(Z) \cdot \max\left(0, \min\left(\frac{Z_{\text{trigger}} - Z}{Z_{\text{trigger}} - Z_{\text{exit}}}, 1\right)\right) \cdot R_{\text{exit}} \tag{3}$$

where $p(Z)$ is the probability of a PDSI value of Z, and the bounds $-\infty$ to Z_{trigger} reflect the PDSI range over which the insurance contract pays out due to drought. The probability $p(Z)$ is drawn from the Gaussian distribution (μ, σ) estimated from the climate