Weather Index Insurance and Common Property Resources

Haimanti Bhattacharya and Daniel E. Osgood

With weather index insurance expanding and common property resources diminishing in low-income agricultural areas, it is essential to understand the potential effects of such insurance on resources that serve as vital input bases for low-income households. Using simple analytical constructs, we illustrate how index insurance may increase or decrease use of common property resources depending on common implementation characteristics such as binding constraints and multiple sources of income in a multi-temporal decision context. This analysis of how index insurance might assist low-income families without degrading the commons can be informative for insurance administrators and policymakers.

Key Words: agriculture, common property resource, weather index insurance

Since many low-income households worldwide rely on common property resources such as pastures and water bodies, maintaining the health of those resources is vital for their survival. However, reductions in uncertainty through programs providing insurance, an often critical element in efforts to improve human welfare, can damage those vital resources. Works by Sandler and Sterbenz (1990) and McCarthy (2000) show that when agents are risk-averse, production risk and uncertainty reduce the use of common property resources and thus conserve these assets. Thus, risk-mitigation tools such as insurance can intensify exploitation of common property resources and potentially exhaust them. If the reduction in risk needed to keep low-income households from failing destroys the environmental resources on which they depend, tools like weather index insurance, intended for development and adaptation, could backfire.

Weather index insurance is a risk-mitigation tool that is rapidly gaining popularity in low-income agricultural areas around the world as part of efforts to enhance the welfare of low-income households. The distinguishing characteristic of weather index insurance is that the insurance payoff triggers are based on weather indicators such as rainfall and satellite-based greenness indices that clients cannot manipulate. The insurance is designed to reduce risks posed by adverse weather for clients while addressing problems associated with moral hazard and adverse selection for lenders relative to traditional yield-based insurance (Turvey 2001, Barnett, Barrett, and Skees 2008, Hellmuth et al. 2009). Since credit is often constrained in low-income regions and insurance could reduce defaults following damaging states of nature, links to credit often play a central role in projects aimed at improving the lives of low-income individuals.

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Despite concerns about limited demand for index insurance (Banerjee and Duflo 2011, Cole et al. 2012, Giné and Yang 2009, Hazell et al. 2010), several recently established index insurance projects for low-income developing countries are growing dramatically, scaling up quickly from only a few hundred clients to tens of thousands of clients in two or three years (Oxfam 2011, Syngenta Foundation for Sustainable Agriculture 2011). In India, subsidized index insurance expanded to cover millions of farmers in less than ten years (Clarke et al. 2012). Given the dramatic growth of such projects, the potential for both desired outcomes and unintended negative consequences is large. Some index insurance projects have directly targeted common property pastoralists (Barrett et al. 2008b, Hellmuth et al. 2009) so it is important to understand the potential consequences that these types of tools may have on common property resources.

Research to date pertaining to weather index insurance has primarily focused on hurdles to its implementation, such as insurance uptake (Cole, Tobacman, and Topalova 2007, Giné, Townsend, and Vickery 2007, 2008) and the performance, benefits, and drawbacks of products for protected farmers (Barrett et al. 2008a, Kalavakonda and Mahul 2005). None of the studies have assessed potential effects of the insurance on the common property resources used in production processes.

Most closely related to our work is Müller et al. (2011). Their numerical bio-agricultural simulation model analyzed plausible impacts of rainfall-based weather index insurance on the sustainability of private property range land. Although they did not address common property resource issues, their ecological simulation modeling shows that high strike levels (frequent insurance payouts) can lead to adoption of less sustainable grazing practices while low to medium strike levels can enhance farmers' well-being without impairing sustainable practices for private range lands. Given the complexity of the dynamic simulation models, it is difficult to know what is missing from traditional theoretical analyses. If we are to design insurance programs that will improve the health of common property resources rather than degrade them, we need to thoroughly understand the fundamental forces driving the outcomes.

We use simple economic models that depict some typical decision-making scenarios in low-income households (e.g., binding constraints and engaging in multiple production activities) to illustrate why the impacts of index insurance on common property resources are not unambiguously negative. We find that index insurance can enhance the welfare of low-income households and improve the health of common property resources, thus offering the possibility of environmentally beneficial economic development and adaptation.

Analytical Framework

We analyze the potential impact of weather index insurance on a common property resource that a fixed number (N) of homogeneous individuals can use. Restricting access to a fixed N distinguishes the common-property-right regime from an open-access regime in which everyone has access to the resource. This is a form of informal regulation since access to the common property resource by outside-group members is prohibited. It is a widely observed practice for numerous common property resources, including water, pastures, and forests, throughout the world, and several inter-group clashes have been attributed to

maintaining these informal regulations (Fratkin 1997, Swallow and Bromley 1995), which are often intensively enforced.

Even if households optimize their returns, the common-property-resource regime retains the basic incentive problem of non-ownership—a household does not fully internalize the cost of exploitation of the resource, which can limit the household's incentive to optimize long-run returns from the resource. In principle, common property resources can be managed efficiently to obtain the economically optimal outcome of profit maximization, but the economically inefficient outcome of rent dissipation is also quite probable; the outcome depends on the type of informal regulation imposed and characteristics of the agents. Several studies (Ostrom 1990, Libecap 1989) have shown that an efficient solution is feasible for groups with a fixed number of homogeneous members.

In our model, we assume a fixed number of homogeneous agents who maximize their joint net revenue from a pasture. Thus, if weather index insurance has any negative effects on common property resources, our analysis will provide the most conservative estimate of such effects. If we relax the assumption of homogeneous users or assume that *N* tends to infinity and individuals engage in noncooperative optimization, our analysis is likely to find substantial rent dissipation or even the classic open-access case of complete rent dissipation and degradation of the common property resource (McCarthy 2000, Ostrom 1990, Libecap 1989) even in the absence of any insurance. In such cases, any negative effect of weather index insurance on a common property resource will be all the more aggravated. Thus, our assumption of a finite number of homogeneous users of the resource provides a helpful frame in which to examine use of common property resources.

We analyze decisions of a representative household. The total effect on a common property resource would be simply an amplified version (multiplied by *N*) of the effect of decision-making of an individual household.

The strength of this simplified yet generic[1] model set-up is its ability to highlight the decision-making problem for a household facing uncertainty, which can be applied to many different contexts. For example, in our discussion of decision-making under uncertainty when a household undertakes two farming activities, we label the activities as crop farming and animal farming for illustrative purposes. One can apply the analysis to any two activities in which one relies on a private property resource and the other on a common property resource. Similarly, uncertainty, which is represented in our model by rainfall, can easily be redefined as some other type of uncertainty, such as outbreak of a disease, that affects households' decisions.

A central feature of many production activities is multi-temporal decision-making. A number of studies have used dynamic models to analyze the impacts of risk on household decisions. Of particular interest are works analyzing the impacts of insurance using bio-economic dynamic simulations, especially for livestock production (see, for example, McAllister et al. (2006), Barrett et al. (2006), and Quaas and Baumgärtner (2008)). Since the complexity of dynamic models makes it difficult to identify the fundamental drivers of the results, we take a complementary approach and investigate the dynamic problem

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[1] We do not parameterize the production functions. The only assumption used is concavity. We impose no restrictions on the price of inputs and outputs of the farming activity or on the insurance premium and payoff.

through the most elemental framing possible to examine the fundamental question of how weather index insurance may help or hurt common property resources.

We collapse the decision-making problem, converting it from a multi-temporal optimization to a repeated single-period problem: in the face of uncertainty regarding weather, a user of a common property resource faces the same decision-making problem every season or year. We determine whether a hypothetical initial equilibrium in the absence of insurance is perturbed by introduction of weather index insurance through a simple, largely static optimization framework. Following Weitzman (1974), we examine a two-period model in which there is *ex ante* decision-making in the first period and nature's *ex post* outcome determines the payoff in the second period. This is perhaps the simplest possible representation of a dynamic problem under uncertainty that can be used to shed light on features that drive the impacts of provision of weather index insurance on common property resources.

In the model, we categorize nature in two discrete states based on rainfall; the "good" state corresponds to a normal amount of rainfall and the "bad" state to an extreme amount (very large or very small). The rainfall outcome is determined stochastically by nature; $\alpha = p(R \leq R_1^*) + p(R \geq R_2^*)$ is the probability of the bad state of nature. R denotes actual rainfall and R_1^* (R_2^*) denotes the benchmark for below-normal (above-normal) rainfall.[2] We assume that each household has the same prior belief about the probability of the bad state of nature, α.

Decision-making under Uncertainty with a Single Farming Activity

To present a starting point in which the effect of index insurance on a common property resource can be ambiguous, we model a simplistic but realistic analytical construct for household decision-making: a household engaged in a single production activity that uses a common property resource faces weather uncertainty, a binding credit constraint, and a binding sustenance (minimum consumption) constraint. Binding constraints or thresholds often shape household decision-making. In this construct, the insurance implementers are primarily interested in enhancing the well-being of low-income households. Thus, we incorporate constraints on credit and sustenance since both are vital for low-income households around the world.

Based on works like Miranda (1991), Coyle (1999), and McCarthy (2000), we use a traditional constant absolute risk-aversion assumption to analyze the behavior of risk-averse agents via means and variances in consumption. We consider the following decision-making problem for a household:

(1) $$\underset{x}{Max.}\, U = E(y) - \frac{\rho}{2}\,\mathrm{var}(y)$$

subject to

(2) $$c_s x = \overline{C} \text{ and } p_l^s g_l(x, k_l) = \overline{Y}$$

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2   We recognize that there are situations in which only above-normal or below-normal rainfall is bad for crops and/or animal farming. We define the bad state of nature in a general way so that the bad state of nature can easily be redefined to fit a specific location more precisely without affecting the analysis. For simplicity, we consider two discrete states of nature. In reality, there can be multiple states (and, theoretically, a continuum of states) to consider when making a decision. Binary states are often used to capture the essence of the problem of weather uncertainty.

where

(3) $$E(y) = \alpha p_l^s g_l(x, k_l) + (1 - \alpha) p_h^s g_h(x, k_h) - c_s x$$

denotes the *ex ante* expected consumption of the household,

(4) $$\mathrm{var}(y) = \alpha[p_l^s g_l(x, k_l) - c_s x - E(y)]^2 + (1 - \alpha)[p_h^s g_h(x, k_h) - c_s x - E(y)]^2$$

denotes the variance in consumption, and U is the utility function of a household based on consumption, ρ is the coefficient of absolute risk aversion, $\overline{Y}$ is the sustenance constraint—the minimum consumption need in the bad state of nature, $\overline{C}$ is the credit constraint, c_s is the cost per unit of purchased farming input, x is the number of farming inputs purchased, $g(\cdot)$ is the production function for the farming activity, k represents inputs from common property resources used in the farming activity, p^s is the price per unit of output, subscript l represents low returns (bad state of nature), andsubscript h represents high returns (good state of nature).

We recognize that the utility function of a household may not always reflect this quadratic construct in practice. A household may simply maximize expected consumption, which corresponds to a linear specification of the utility function, without taking into account the variance in consumption across different states of nature. When the credit constraint is strictly binding, decision-making will be primarily shaped by the credit constraint regardless of whether we represent the utility function in terms of simply expected consumption or use both means and variances in consumption. Therefore, qualitative inferences drawn from this analysis will not be perturbed by use of a linear or quadratic specification of the utility function.

We assume that

(5) $$\partial g(\cdot) / \partial i > 0, \ \ \partial^2 g(\cdot) / \partial i^2 < 0 \ \ \ i = x, k.$$

Due to constraints on labor and biological growth in the real world, we can assume the typical structure of a concave production function. In this expression, x represents the number of animals that a household decides to stock, and the common property resource is a shared pasture or water source on which the household relies for raising the stock. Let x^* denote the optimal input level (stock of animals) that solves the optimization problem.

Decision-making in the Presence of Index Insurance

We next consider the effect of introducing weather index insurance in the household decision-making problem with β as the insurance payoff and γ as the insurance premium. We assume that the price of weather index insurance is exogenous, which is typical of such projects to date; premiums have been determined by the financial institutions offering the insurance based on the cost of carrying the risk (Hellmuth et al. 2009).

First we consider an insurance structure in which a household receives the insurance payoff, β, following a bad state of nature and zero otherwise. Under this structure, the premium and payoff are independent of the input decisions of the household. This insurance structure can be represented as

(6) $$\text{Insurance payoff} = \begin{cases} \beta & \text{if } R \leq R_1^* \text{ or } R \geq R_2^* \\ 0 & \text{if } R_1^* < R < R_2^* \end{cases}.$$

This type of insurance could be used to provide uniform assistance to all covered households to help them meet their basic sustenance requirements in bad states of nature, which is the objective of many welfare programs run by governments and development organizations. Such programs are relatively inflexible but are probably easier to implement and therefore less costly than ones that involve careful monitoring of inputs.

Under this weather insurance structure, the household faces the following decision-making problem.

(7) $$\underset{x}{Max}.U = E(y) - \frac{\rho}{2}\text{var}(y)$$

subject to credit (equation 8) and sustenance (equation 9) constraints.

(8) $$c_s x + \gamma = \overline{C}$$

(9) $$p_l^s g_l(x, k_l) + \beta = \overline{Y}$$

In this case,

(10) $$E(y) = \alpha(p_l^s g_l(x, k_l) + \beta) + (1 - \alpha)(p_h^s g_h(x, k_h) - c_s x - c_c z - \gamma, \text{ and}$$

(11) $$\text{var}(y) = \alpha\{p_l^s g_l(x, k_l) + \beta - c_s x - \gamma - E(y)\}^2 + (1 - \alpha)\{p_h^s g_h(x, k_h) - c_s x - \gamma - E(y)\}^2.$$

Let $x_{i1}{}^*$ denote the optimal input level (animal stock) that solves the optimization problem in the presence of this index insurance. By comparing the household decision-making problem in the absence of insurance with the decision-making problem in the presence of this type of insurance, we can easily infer that, due to the binding credit constraint ($\overline{C}$), the household will have to reduce the production input (animal stock) to purchase the index insurance (pay the premium, γ). That is,

(12) $$x_{i1}{}^* < x^* \text{ as } x_{i1}^* = (\overline{C} - \gamma)/c_s \text{ and } x^* = \overline{C}/c_s.$$

The binding credit constraint requires the household to replace some (or all) of the production activity with the index insurance premium. We refer to this as the *substitution effect* of the index insurance.

The substitution effect implies that the reduced production input (animal stock) in the presence of the insurance will unambiguously reduce the household's use of the common property resource. Therefore, we can infer that the index insurance defined by this analytical set-up will be unambiguously beneficial for the health of the common property resource.

Turning now to the sustenance constraint, $\overline{Y}$, we can infer that a household will purchase this type of index insurance only if the magnitude of the insurance payoff, β, is large enough to offset forgone consumption required by the reduction in inputs, x, in the bad state of nature:

(13) $$\beta \geq \{p_l^s g_l(x^*, k_l) - p_l^s g_l(x_{i1}^*, k_l)\}.$$

If the payoff more than offsets forgone consumption, the insurance can enhance the well-being of the household in the bad state of nature. We refer to this effect of the index insurance as the *income effect*.

It is important to note here that a low-income household with access to a common property resource may drop out of a production activity if that activity cannot satisfy the sustenance constraint in the bad state of nature. When the magnitude of the insurance payoff is large enough, households can satisfy a sustenance constraint in the bad state of nature that could not be satisfied

without insurance, allowing them to return to or remain in the production activity. In that case, insurance will result in increased use of the common property resource. Thus, in aggregate, the *income effect* of index insurance can have a detrimental effect on the health of the common property resource if it outweighs the benefit from the *substitution effect*.

The empirical question, then, is whether the increase in environmental pressure from fewer households dropping out of production (the income effect of the insurance) is outweighed by the reduction in environmental pressure from households that reduce animal stocks (the substitution effect of the insurance). Hypothetically, both effects could occur simultaneously and can result in an ideal outcome in which index insurance enhances both household welfare and the health of the resource. Thus, it is valuable to investigate these quantitative tradeoffs carefully through simulation and empirical analysis of actual implementation scenarios.

Now we consider an alternative insurance structure that reflects index insurance for pastoralists provided through a slightly different set-up. Assume an insurance structure in which premiums and payoffs are based on the number of units of inputs (for example, the number of animals stocked by an animal-producing household). Each household pays a premium, γ, for each unit of input and receives an insurance payout, β, for each unit of input in the bad state of nature:

$$(14) \qquad \text{Insurance payoff} = \begin{cases} \beta x & \text{if } R \le R_1{}^* \text{ or } R \ge R_2{}^* \\ 0 & \text{if } R_1{}^* < R < R_2{}^* \end{cases}.$$

This structure, if implemented with a sign-up process that is effective and flexible enough to accurately reflect the number of animals actually stocked, is similar to livestock insurance programs in place in Kenya (Barrett et al. 2008b).

The household now faces the following decision-making problem:

$$(15) \qquad \underset{x}{Max}.U = E(y) - \frac{\rho}{2}\text{var}(y)$$

subject to credit (equation 16) and sustenance (equation 17) constraints.

$$(16) \qquad c_s x + \gamma x = \overline{C}$$

$$(17) \qquad p_l^s g_l(x, k_l) + \beta x = \overline{Y}$$

In this case,

$$(18) \qquad E(y) = \alpha\{p_l^s g_l(x, k_l) + \beta x\} + (1 - \alpha)p_h^s g_h(x, k_h) - c_s x - \gamma x, \text{ and}$$

$$(19) \qquad \text{var}(y) = \{\alpha\{p_l^s g_l(x, k_l) + \beta x - c_s x - \gamma x - E(y)\}^2 +$$
$$(1 - \alpha)\{p_h^s g_h(x, k_h) - c_s x - \gamma x - E(y)\}^2\}.$$

Let $x_{i2}{}^*$ denote the optimal input level (animal stock) that solves the optimization problem in the presence of this index insurance. By comparing the household decision-making problem in the absence of insurance with the decision-making problem in the presence of this insurance, we can again infer that the household will have to reduce the production input (animal stock) due to the binding credit constraint, $\overline{C}$, to purchase the insurance. That is,

(20) $x_{i2}* < x*$ as $x_{i2}^* = \overline{C} / (c_s + \gamma)$ and $x^* = \overline{C} / c_s$.

Thus, the effect of a reduction in x is beneficial to the common property resource. It is worth noting that the reduction in x under this insurance structure is due to the increased unit cost of the input.

Turning to the sustenance constraint, $\overline{Y}$, we can again infer that a household will purchase the index insurance only if the insurance payoff offsets forgone consumption caused by the reduction of x:

(21) $\beta x_{i2}^* \geq \{p_l^s g_l(x^*, k_l) - p_l^s g_l(x_{i2}^*, k_l)\}$.

Again, if insurance payoffs can bring drop-out households back to the production activity, the presence of insurance will increase the use of the common property resource.

In this analytical set-up in which households engage in a single production activity and face binding credit and sustenance constraints, purchasing insurance will unambiguously reduce production activity, which is beneficial for the health of the common property resource. However, the net effect on the resource is not unambiguous since the potential decline in drop-outs arising from the income effect of the insurance can adversely affect the common property resource.

Even in a more simplistic analytical set-up in which there is no credit or sustenance constraint, a reduction in risk from provision of insurance can unambiguously increase the inputs and lead to greater use of the common property resource, a result also noted in prior studies (see, for example, Sandler and Sterbenz (1990) and McCarthy (2000)). Consider a household facing the following optimization problem:

(22) $\underset{x}{Max.}\,U = E(y) - \dfrac{\rho}{2}\text{var}(y)$

where U is the utility function, $E(y)$ is expected consumption, $\text{var}(y)$ is variance in consumption, ρ is the coefficient of absolute risk aversion,

(23) $E(y) = \alpha p_l^s g_l(x, k_l) + (1 - \alpha)p_h^s g_h(x, k_h) - c_s x$, and

(24) $\text{var}(y) = \alpha[p_l^s g_l(x, k_l) - c_s x - E(y)]^2 + (1 - \alpha)[p_h^s g_h(x, k_h) - c_s x - E(y)]^2$

$$= \alpha(1 - \alpha)\{p_l^s g_l(x, k_l) - p_h^s g_h(x, k_h)\}^2.$$

If risk is reduced in terms of lower variance in consumption (i.e., $|p_l^s g_l(x, k_l) - p_h^s g_h(x, k_h)|$ declines), then, given our assumptions, the optimal input use (x^*) would have to increase unambiguously to satisfy the first-order condition for optimization,

(25) $\left[\begin{array}{l} \alpha p_l^s \dfrac{\partial g_l(x,k_l)}{\partial x} + (1-\alpha)p_h^s \dfrac{\partial g_h(x,k_h)}{\partial x} \\[4mm] -\rho\alpha(1-\alpha)\left\{ \begin{array}{l} p_l^s g_l(x,k_l) \\ -p_h^s g_h(x,k_h) \end{array} \right\}\left\{ p_l^s \dfrac{\partial g_l(x,k_l)}{\partial x} - p_h^s \dfrac{\partial g_h(x,k_h)}{\partial x} \right\} \end{array} \right] = c_s.$

This unambiguous negative effect on the common property resource holds only in specific cases like this one, which represents an overly simplistic analytical construct for analyzing decision-making by low-income households. With the introduction of basic constraints such as credit and sustenance, which are fairly

common realistic constraints for low-income households around the world, the risk-reduction tool no longer has an unambiguous negative effect on the common property resource.

Decision-making under Uncertainty with Two Farming Activities

Contrasting substitution and income effects from credit and sustenance constraints is not the only channel that gives rise to ambiguous insurance effects. The effect of index insurance on the commons can be ambiguous even if we do not consider the income effect of fewer households dropping out of production. We illustrate this point by analyzing decision-making when a household engages in two farming activities and only one of the activities uses the common property resource.

It is common for households in low-income rural areas to engage in more than one production activity, in part as a risk-diversification strategy. We therefore relax the assumption of a single activity and analyze a case in which the household engages in crop and animal farming. For clarity in our illustration, we assume that the household's crop farming activity relies on private property resources while its animal farming relies on a common property resource— pasture and water. As a result, the household's animal stocking decision will affect its use of the common property resource.

In this context, the household faces the following decision-making problem:

(26) $$\underset{x,z}{Max.}U = E(y) - \frac{\rho}{2} \text{var}(y)$$

subject to credit (equation 27) and sustenance (equation 28) constraints.

(27) $$c_s x + c_c z = \overline{C}$$

(28) $$p_l^s g_l(x, k_l) + p_l^c f_l(z) = \overline{Y}$$

In this case,

(29) $$E(y) = \alpha p_l^s g_l(x, k_l) + \alpha p_l^c f_l(z) + (1-\alpha) p_h^s g_h(x, k_h) +$$
$$(1-\alpha) p_h^c f_h(z) - c_s x - c_c z, \text{and}$$

(30) $$\text{var}(y) = \alpha(1-\alpha)\{\{p_l^s g_l(x,k_l) - p_h^s g_h(x, k_h)\} + \{p_l^c f_l(z) - p_h^c f_h(z)\}\}^2.$$

In these equations, c_s is stocking cost per unit animal, c_c is the cost of crop farming per unit of the composite input set, $g(\cdot)$ is the production function for animal farming, $f(\cdot)$ is the production function for crop farming, x is the number of animals stocked, k is inputs from the common property resource, z is crop farming inputs, p^s is the price per unit of animal product (or the animal itself), p^c is the price per unit of crop farm product, subscript l denotes low returns from a bad state of nature, and subscript h denotes high returns from a good state of nature. We also assume that

(31) $$\frac{\partial g(\cdot)}{\partial i} > 0, \quad \frac{\partial^2 g(\cdot)}{\partial i^2} < 0, \quad \frac{\partial f(\cdot)}{\partial i} > 0, \quad \frac{\partial^2 f(\cdot)}{\partial i^2} < 0, \quad i = x, z, k.$$

Let x^* and z^* denote the optimal level of animal stock and the crop inputs that solve this optimization problem.

Decision-making in the Presence of Index Insurance

Under our first insurance structure (equation 6), a household engaged in two farming activities faces the following decision-making problem:

(32) $$Max._{x,z}U = E(y) - \frac{\rho}{2}\text{var}(y)$$

subject to credit (equation 33) and sustenance (equation 34) constraints.

(33) $$c_s x + c_c z + \gamma = \overline{C}$$

(34) $$p_l^s g_l(x, k_l) + p_l^c f_l(z) + \beta = \overline{Y}$$

In this case,

(35) $$E(y) = [\alpha(p_l^s g_l(x, k_l) + p_l^c f_l(z) + \beta) + (1 - \alpha)(p_h^s g_h(x, k_h) + p_h^c f_h(z))] - c_s x - c_c z - \gamma, \text{ and}$$

(36) $$\text{var}(y) = \alpha(1 - \alpha)\{\{p_l^s g_l(x, k_l) - p_h^s g_h(x, k_h)\} + \{p_l^c f_l(z) - p_h^c f_h(z)\} + \beta\}^2.$$

Let x_{i1}^* denote the optimal animal stock and z_{i1}^* denote the optimal level of crop inputs that solve the optimization problem in the presence of this form of index insurance. We can infer from the binding credit constraint that the household will have to reduce x and/or z to purchase insurance. However, the effect of this insurance on x_{i1}^* is ambiguous. The adjustment in x will depend on the relative productivity and variance of the two production activities. Consider a case in which variance in productivity and expected returns are greater for animal farming than for crop farming. The household can reduce its use of crop inputs (z) to buy index insurance, leaving its animal stock (x) unchanged, or it can reduce crop inputs enough to increase its stock of animals. When the animal stock remains unchanged, stress on the common property resource also does not change. However, an increase in the animal stock will adversely affect the common property resource. This negative effect is akin to theoretical findings in prior studies (for example, Sandler and Sterbenz (1990) and McCarthy (2000)) in which risk can reduce use of common property resources and risk-mitigation tools can adversely affect those resources.

Alternatively, consider a case in which the expected returns from animal farming are smaller than the expected returns from crop farming and, in the absence of insurance, animal farming is used as a self-insuring device for meeting the sustenance constraint in the bad state of nature. In this scenario, the household can replace some of its animal stock with index insurance as long as the insurance payoff is greater than foregone returns from the animal stock in the bad state of nature. This substitution effect will have a positive effect on the common property resource.

Under the second insurance structure (equation 14), a household engaged in two farming activities faces the following decision-making problem:

(37) $$Max._{x,z}U = E(y) - \frac{\rho}{2}\text{var}(y)$$

subject to credit (equation 38) and sustenance (equation 39) constraints.

(38) $$c_s x + c_c z + \gamma x = \overline{C}$$

(39) $$p_l^s g_l(x, k_l) + p_l^c f_l(z) + \beta x = \overline{Y}$$

In this case,

$$(40) \quad E(y) = [\alpha(p_l^s g_l(x, k_l) + p_l^c f_l(z) + \beta x) + (1 - \alpha)(p_h^s g_h(x, k_h) + \\ p_h^c f_h(z))] - c_s x - c_c z - \gamma x, \text{ and}$$

$$(41) \quad \text{var}(y) = \alpha(1 - \alpha)\{\{p_l^s g_l(x, k_l) - p_h^s g_h(x, k_h)\} + \{p_l^c f_l(z) - p_h^c f_h(z)\} + \beta x\}^2.$$

Let x_{i2}^* represent the optimal animal stock and z_{i2}^* the optimal level of crop inputs that solve the optimization problem in the presence of this form of index insurance. As under the first insurance structure (equation 6), the binding credit constraint's effect on the animal stock decision is ambiguous. It depends on the mean return and the variance of return for each production activity.

In sum, when households engage in more than one production activity, the effect of index insurance on the commons is not unambiguous even if we ignore the income effect of the insurance (i.e., the possibility that fewer households will drop out of production because they have insurance). It will depend on the substitution effect based on the relative expected returns and the variance in returns from the two activities. Thus, it is also plausible to find conditions in which index insurance would not exacerbate the stress on common property resources when households engage in more than one production activity.

We acknowledge that several alternative analytical models could identify scenarios in which the effect of index insurance on common property resources is not necessarily negative. For example, index insurance can ease the credit constraint by reducing risk of default in the bad state of nature, which may lead to an increase or decrease in the production activity that relies on the common property resource (this again will depend on the relative productivity of the activities). Hence our broad qualitative inference that the effect of index insurance is not unambiguous remains unchanged. We provide illustrative analytical examples that demonstrate that index insurance can benefit low-income households without increasing stress on a common property resource, which can help those who design and implement index insurance for sustainable development of low-income areas where use of such resources is vital.

Summary and Conclusion

Prior studies have suggested that risk-averse agents facing production uncertainty reduce the use of common property resources and hence that risk-reduction tools like insurance can be expected to intensify the use of common property and threaten the sustainability of the commons. Weather index insurance is considered to be a tool that can potentially weaken poverty traps and is being introduced in many low-income agricultural areas where numerous households rely on common property resources to sustain their livelihoods. We construct analytical models to determine if weather index insurance is unambiguously detrimental to a common property resource under various household decision-making constructs and insurance structures and find that potential impacts of weather index insurance on common property resources are not unambiguously negative (or positive).

It is thus important for policymakers and insurance program administrators to carefully analyze where and how weather index insurance is implemented. For example, when households engage in a single production activity under binding credit and sustenance constraints, the impact of index insurance on common property resources depends on the balance between rising stress on the resource from fewer households dropping out of production and declining stress on the resource from households that reduce their production activity to buy insurance. However, when households engage in two production activities, the relative means and variances in returns of the production activities play an important role in determining the net effect of index insurance on the commons. Hence, critical to an insurance program's success in promoting sustainable development is careful study of the fundamental features of the households, including appropriately describing the households' decision-making processes. Otherwise, it is nearly impossible to uncover and rectify the drivers of unintended negative consequences of index insurance on common property resources. If we can anticipate and thus avoid insurance structures that increase stress on the commons, we may be able to implement risk-reduction tools that not only are effective in reducing poverty but also benefit the health of common property resources at the same time.

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