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Effects of subsidized crop insurance on crop choices

Jisang Yu[a,*], Daniel A. Sumner[b]

[a]*Department of Agricultural Economics, Kansas State University, Manhattan, KS 66506, USA*
[b]*Department of Agricultural and Resource Economics, University of California, Davis, CA 95616, USA*

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Abstract

This study focuses on how subsidized crop insurance affects crop choices. Crop insurance may change farm investments by reducing risks and providing subsidies. First, actuarially fair insurance reduces risks in crop production and marketing, holding the expected return constant. Second, insurance subsidies encourage farms to purchase crop insurance, which increases the expected return to insured risky crops. Farms also have many self-insurance mechanisms such as crop diversification or working off the farm. We derive conditions under which (1) unsubsidized and actuarially fair crop insurance or (2) insurance premium subsidies lead to more investment in a risky higher return crop. We then examine the role of self-insurance for these conditions. The impact of premium subsidies is decomposed into a direct profit effect and an indirect coverage effect. These effects are explained by substitutions between market insurance and self-insurance and between a risky crop and a safe crop. We discuss each effect as a combination of subsidy and risk effects. Numerical illustrations show that an insurance subsidy has a larger impact on risky crop investments compared to that of an input subsidy when farms are more risk-averse and have high costs of self-insurance. The framework provides a novel way to evaluate subsidized crop insurance programs.

JEL classifications: Q18, Q12, O12, O13

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1. Introduction

Subsidized crop insurance has been important in the United States for the last two decades and has been introduced in developing countries globally (Glauber, 2013; Mahul and Stutley, 2010; Miranda and Farrin, 2012). The World Development Report 2014 describes risk management as a powerful development instrument (World Bank, 2013). Evidence indicates that the availability of risk management tools, such as agricultural insurance, changes farm investment across crops in developed and developing countries, and such changes can facilitate capital accumulation and economic growth.[1]

A seminal work of Ehrlich and Becker (1972) models the interactions between market insurance, self-insurance, and self-protection. With an expected utility framework and a state-preference approach, they describe self-insurance as an action to reduce the size of losses in the bad state by redistributing income across states. They describe self-protection as an action to reduce the probability of the bad state. Market insurance pays indemnity when the bad state occurs and by doing so it increases income received in the bad state. They describe substitutability between market insurance and self-insurance and complementarity between market insurance and self-protection. In this article, we use their broad framework to focus on the substitutability between market insurance and self-insurance in the context of crop insurance and its impacts on agricultural production patterns.[2]

The relationship between crop insurance and crop choice—how crop insurance affects how much to produce among alternative crops—is an analogue to the relationship between market insurance and self-insurance. Crop choice can be thought of as an asset allocation among crops with different expected returns and "riskiness" of returns. Farmers with different self-insurance

*Corresponding author. Tel.: +1 785-532-3357; fax: +1 785-532-6925; *E-mail address*: jisangyu@ksu.edu (Jisang Yu).

[1] Morduch (1995) shows early empirical examples of how risk deters accumulation of human and material capital. The examples emphasize the importance of risk management for economic growth and development.

[2] Farmers manage risks in many ways and some of them would be considered as "self-protection" in the framework of Ehrlich and Becker (1972). For example, having irrigation facilities to reduce the variability of crop yields can be considered self-protection, since it changes the probability distribution of the states of nature, which is represented as crop yields, rather than transferring incomes from one state to another state. An analysis of the implications of self-protection is left for further research.

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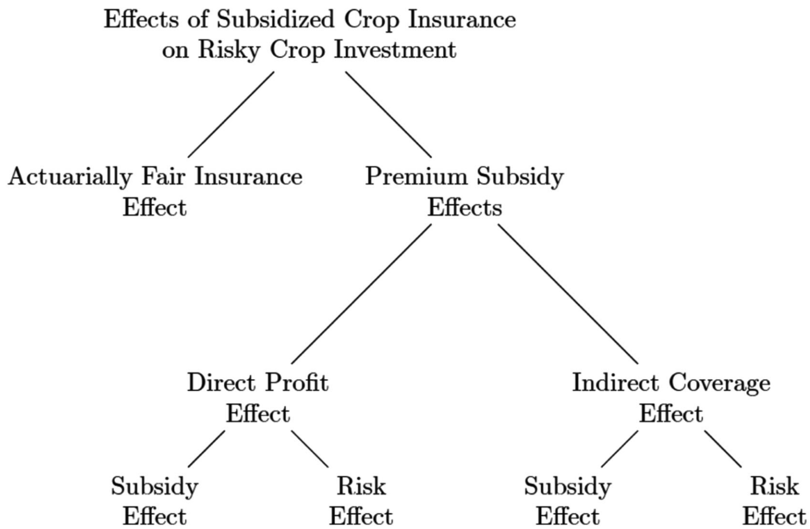

Fig. 1. Separation of the effects of subsidized crop insurance on risky crop investment.

options behave differently in their responses to crop insurance availability and premium subsidies.

We contribute to the literature in several ways. First, we provide an illuminating separation of the effects of subsidized crop insurance on crop choices by modifying and extending portfolio models. And then, motivated by the insights of Ehrlich and Becker (1972), we illustrate the important role of self-insurance cost on crop choices and how self-insurance interacts with subsidized crop insurance. Our illustration provides a novel way to evaluate impacts of subsidized crop insurance programs.

This article utilizes an expected utility maximization framework and examines crop choices when subsidized crop insurance becomes available.[3] The effects of subsidized crop insurance on crop choices are described as investments in two crops with different "riskiness", a risky crop and a safe crop. Fig. 1 summarizes the separations just mentioned and shows the logical structure of our framework. We separate the impact of subsidized crop insurance into (1) a change due to the provision of unsubsidized actuarially fair crop insurance and (2) an additional change due to crop insurance premium subsidies.

Moving down through Fig. 1, we see that the impact of premium subsidies is further separated into (a) a direct profit effect and (b) an indirect coverage effect. The direct profit effect is defined as that caused by higher profit from increases in the premium subsidy, for a given amount of insurance. The indirect coverage effect is defined as the impact of increases in insurance coverage caused by the premium subsidy increase. Note that Fig. 1 shows further that the direct profit effect and the indirect coverage effect each consist of a subsidy effect and a risk effect.

This article also highlights how these effects of crop insurance differ across farmers. When farmers may mitigate the portfolio risk, for example, by crop diversification, and the cost of such self-insurance differs across farms, the effects of subsidized crop insurance on crop choices differ accordingly. We compare subsidized crop insurance with an alternative policy, an input subsidy, to emphasize how farms with different accesses to or capabilities of self-insurance differ in their response to crop insurance.

The conceptual framework of this article also provides a better understanding of recent empirical studies that find positive production impacts of subsidized agricultural insurance in developing countries (e.g., Cai, 2016; Cai et al., 2015; Cole et al., 2017; Elabed and Carter, 2014; Karlan et al., 2014). For example, Cai (2016) studies a compulsory and heavily subsidized insurance program for tobacco producers in China and concludes that the program increased tobacco production by 16%. A randomized experiment of Cole et al. (2017) finds that the treatment group with free insurance has a higher probability of planting higher return and higher risk cash crops compared to the control group with a grant that is equal to the actuarially fair value of the free insurance. Note that the production impact estimated by Cai (2016) is an overall production effect of subsidized crop insurance, whereas the production impact estimated by Cole et al. (2017) is close to the effect of unsubsidized actuarially fair crop insurance. Understanding channels that cause these production effects is crucial to evaluate how various government-supported risk management tools affect farms.

The results of this article are useful in helping evaluate consequences of subsidized crop insurance policies. When self-insurance is readily available, as when diversification across crops is common or when off-farm jobs are nearby, we would expect more subsidy required to attract farms to government-supported crop insurance. Also, in those situations, subsidized

[3] Recent studies such as Babcock (2015) and Du et al. (2016) indicate that the predictions from the expect utility theory can be inconsistent with empirical data on crop insurance demand or coverage level choices. Despite the limitations, the expected utility theory still can provide insights into how subsidized crop insurance affects the crops farms choose.

government insurance programs have smaller impacts on which crops farms grow.

In the next section, we briefly link the contribution of this article to the literature on effects of crop insurance on farm resource allocation. Then, we develop a conceptual framework to examine the effects of actuarially fair and unsubsidized crop insurance and premium subsidies. Finally, we use a numerical simulation to illustrate how the effects of premium subsidies and those of a stylized input subsidy differ. The simulations highlight potential policy implications that are relevant to recent changes in U.S. farm policy and global expansion of agricultural insurance.

2. Effects of crop insurance on farm resource allocation

As described above, there have been several recent studies investigating the impacts of agricultural insurance provision in developing countries (e.g. Cai, 2016; Cai et al., 2015; Cole et al. 2017; Elabed and Carter, 2014; Karlan et al., 2014).[4] These studies find that the provision of insurance changes farmers' behavior toward investing more in crops with more risk and higher returns. Most of these empirical studies analyze data from controlled economic experiments of agricultural insurance with premium subsidies embedded. Therefore, it is difficult to clearly identify in these results the effect of providing better risk management tools from the effect of premium subsidies.

In the context of U.S. farm policy, empirical studies focusing on acreage response to the U.S. crop insurance program, such as Wu (1999) and Goodwin et al. (2004), suggest a positive effect of crop insurance on crop acreage. The positive acreage effect of the U.S. crop insurance program can be due to the risk reduction from the crop insurance availability or the crop insurance premium subsidies. Since the U.S. crop insurance is highly subsidized, it is difficult to distinguish these two potential sources.[5]

Theoretical studies by Eeckhoudt et al. (1997) and Hennessy (1998) show how the demand for insurance and the demand for a "risky" asset investment interact in expected utility maximization models and relatively abstract frameworks.[6] In the context of crop insurance and farm production, conceptual or simulation studies such as Ramaswami (1993), LaFrance et al. (2000), Young et al. (2001), Chambers and Quiggin (2002), Miao et al. (2014), Carter et al. (2016), and Miao et al. (2016) discuss crop insurance impacts on reallocation of farm resources.[7]

Eeckhoudt et al. (1997) and Hennessy (1998) model the simultaneous allocation between the quantity of a risky asset and the quantity of insurance. They derive conditions under which an increase in the quantity of insurance increases the quantity of investment in the risky asset and conditions under which an increase in the insurance premium decreases the quantity of investment in the risky asset. Eeckhoudt et al. (1997) focus on the separation of a direct effect and an indirect effect. We apply a similar separation to investigate the effect of premium subsidies considering an agricultural context in which farmers can self-insure. As noted in the introduction, we also build on Ehrlich and Becker's (1972) perspective on the interaction among market insurance, self-insurance, and self-protection; which is not considered by Eeckhoudt et al. (1997) and Hennessy (1998).

Ramaswami (1993) examines the effect of crop insurance on supply response in a model with single and multiple input production functions under an expected utility framework. The effect of insurance is decomposed into risk reduction and moral hazard. Ramaswami (1993) suggests that the direction of the effect of insurance on supply response is ambiguous. Chambers and Quiggin (2002) use the Arrow-Debreu state-contingent approach and investigate the linkage between a crop producer's insurance choice and production decisions when area-yield insurance is available. They provide a sufficient condition for the provision of area-yield insurance to induce a shift toward riskier production patterns. Again, effects of premium subsidies are not discussed in these studies.

There are only few explicit discussions on how premium subsidies in crop insurance affect crop choice (e.g., Goodwin and Smith, 2013; Miao et al., 2016; Yu et al., 2018). The interaction between crop insurance and self-insurance and its relationship with choice across crops remains to be fully characterized. We present a conceptual framework to understand how subsidized crop insurance affects crop choices and what role premium subsidies play. A numerical illustration is presented to compare crop insurance premium subsidy and input subsidy. Cost-effectiveness of premium subsidies on "risky" crop investment is derived from the comparison.

3. How subsidized crop insurance affects crop choices

This section presents a conceptual framework to explain the channels of impacts from subsidized crop insurance to crop choices and farm investments. The conceptual framework describes optimal farm portfolios under different crop insurance market environments. For simplicity, the model assumes that farmers have only two crops and crop production is the only available investment. Farmers can produce a crop with stable

[4] Macours (2013) provides a review on recent randomized experiments related to agricultural insurance. Miranda and Farrin (2012) review theoretical and empirical research on index insurance and provide a brief overview on major index insurance pilot programs in developing countries.

[5] Yu et al. (2018) directly estimate the acreage effect of crop insurance premium subsidies. Goodwin and Smith (2013) present preliminary empirical estimates indicating potential positive effect of premium subsidy.

[6] Eeckhoudt et al. (1997) also provide implications of their work on the demand for put options. Similarly, our work can be extended to provide implications for options markets.

[7] There is an extensive literature on the demand for crop insurance and the crop insurance product choices. Important papers include Goodwin (1993), Just et al. (1999), Innes (2003), Sherrick et al. (2004), Du et al. (2013), Babcock (2015), and Du et al. (2016).

returns, which is denoted as a "safe" crop, and can also produce a crop with variable returns, which is denoted as a "risky" crop.

The framework illustrates the effects of subsidized crop insurance by modifying the portfolio choice models and revisiting several propositions of Eeckhoudt et al. (1997), and Hennessy (1998) in the context of subsidized crop insurance. We extend and modify their models to discuss subsidized crop insurance and its interaction with self-insurance.

3.1. Farm asset allocation without crop insurance

Farmers allocate their initial capital asset, K_0, to the investment in the safe crop, K_s, with return $r_s K_s$, where r_s is a fixed parameter that determines the return from the safe crop. The alternative is to invest in the risky crop production, K_r, where the return from the risky crop production is represented by $r_r K_r$ and r_r is a positive random variable. The expected value of r_r is greater than r_s, since the risky crop has a higher expected rate of return than that of the safe crop. For simplicity, we assume linear return functions. One may use different functional forms for the returns from the two crops to incorporate increasing marginal costs or diseconomies of scope. However, our general discussion remains valid even without the linearization of the return functions.

To simplify, we assume there is no credit market available for farmers so that they cannot borrow or lend their initial capital assets. Even with the assumption that farms cannot save or borrow, our conceptual framework is general enough to discuss saving and borrowing behaviors. For example, investing in the safe crop can be interpreted as a saving with an interest rate r_s. Borrowing is not now represented but could be incorporated by eliminating the initial capital constraint and modifying the linear return functions. For a simple borrowing structure our general argument remains valid.[8]

Risk-averse farmers maximize their expected utility, $U = E(u(\cdot))$ where $u(\cdot)$ is increasing and strictly concave function. Therefore, the optimization problem of a representative risk-averse farmer can be written as

$$\begin{aligned} \max_{K_r}\ U(K_r) &= Eu(x(K_r)) \\ &= Eu(r_s(K_0 - K_r) + r_r K_r) \\ &\quad \text{subject to } K_r - K_0 \leq 0 \end{aligned}$$

and $x(K_r) = r_s(K_0 - K_r) + r_r K_r$ is the stochastic revenue that depends on the realization of r_r.[9]

As long as $E(r_r) > r_s$, it is clear that any agent with $u' > 0$ would invest at least some of the risky crop (Fishburn and Porter 1976). Therefore, the only relevant corner solution is $K_r{}^* = K_0$. From the Kuhn–Tucker condition, $K_r{}^* < K_0$ if and only if

$$Eu'(r_r K_0)(r_r - r_s) < 0\,. \tag{1}$$

The condition for $K_r{}^* < K_0$, which is described by (1), says that farmers allocate at least some of their initial capital to the safe crop if and only if the marginal benefit of investing in the safe crop exceeds the marginal benefit of investing in the risky crop at $K_r = K_0$. Obviously, as the rate of return of the safe crop increases, this condition is more likely to be satisfied.

Investment in the safe crop is a form of self-insurance as described in Ehrlich and Becker (1972). Self-insurance becomes cheaper as r_s increases relative to $E(r_r)$, and thus the demand for self-insurance, which is investment in the safe crop, increases. This follows directly from (1). If r_s is low enough, farmers would invest all of their resources in the risky crop since they do not have ability to self-insure. As described in Ehrlich and Becker (1972), this does not imply that farmers are risk loving. In this article, we focus on the effects of subsidized crop insurance when (1) is satisfied, that is, when farmers plant both crops. Note that when $Eu'(r_r K_0)(r_r - r_s) \geq 0$, the investment effects of actuarially fair crop insurance and premium subsidies are nonpositive since $K_r^* = K_0$ when crop insurance is not available.

In the following two subsections, effects of subsidized crop insurance are separated into (a) an actuarially fair insurance effect and (b) premium subsidy effects. More specifically, the effect of actuarially fair insurance is the difference between farm portfolios without crop insurance availability and that with the availability of actuarially fair insurance. The premium subsidy effects are additional effects from premium subsidies and are further separated into (a) a direct profit effect and (b) an indirect coverage effect.

3.2. Introduction of actuarially fair crop insurance

Actuarially fair insurance for the risky crop is introduced. Farmers can purchase an amount of actuarially fair insurance θ, per unit of K_r and obtain indemnity payments of $I(r_r)$, which depends on the realization of r_r. The actuarially fair premium is $\pi = E(I(r_r))$. The indemnity $I(r_r)$ is nonincreasing in r_r and decreasing in r_r for some r_r. More specifically, the indemnity, $I(r_r)$, is defined as

$$I(r_r) = \begin{cases} \overline{r_r} - r_r & \text{if } \overline{r_r} > r_r \\ 0 & \text{if } \overline{r_r} \leq r_r \end{cases},$$

where $\overline{r_r}$ is a threshold of the rate of return from the risky crop investment that defines the indemnity schedule of the crop insurance.

[8] For more sophisticated credit market structures and to analyze dynamic behaviors, future research is required. Note that Carter et al. (2016) investigate the different outcomes of agricultural index insurance across different agricultural risk and financial environments. They show that the effective index insurance contract to boost farm investment and technology adoption is contingent on how much of the overall risk is covariate and how much collateral is needed to access credit markets.

[9] The first-order conditions are $U_{K_r} = Eu'(x)(r_r - r_s) = \lambda, \lambda(K_r - K_0) = 0$, where λ is the Lagrangian multiplier.

When crop insurance is available, farmers face the following optimization problem:

$$\max_{K_r,\theta} U(K_r,\ \theta) = Eu(x(K_r,\ \theta)) = Eu(r_s(K_0 - (1+\theta\pi)K_r) + (r_r + \theta I(r_r))K_r) \text{ subject to } (1+\theta\pi) \times K_r - K_0 \leq 0 – \theta \leq 0.$$

The first-order conditions are

$$U_{K_r} = Eu'(x)(r_r - r_s + \theta(I(r_r) - r_s\pi)),$$

$$U_\theta = Eu'(x)(I(r_r) - r_s\pi)K_r.$$

The interior solution is characterized with $U_{K_r} = 0$ and $U_\theta = 0$.[10] For the most part of our analysis, we restrict the focus into the interior solutions.

For the following analysis, the sign of $U_{K_r\theta}$ is useful for comparative statics. Lemma 1 provides the condition for the positive $U_{K_r\theta}$.

Lemma 1. *Constant absolute risk aversion (CARA) or decreasing absolute risk aversion (DARA) preferences are sufficient for* $U_{K_r\theta} > 0$ *(Eeckhoudt* et al.*, 1997).*

Proof. Using Arrow–Pratt absolute risk aversion coefficient representation, $U_{K_r\theta}$ can be rewritten as

$$U_{K_r\theta} = -E[A(x)u'(x)(I - r_s\pi)(r_r - r_s)],$$

where $A(x) = -\frac{u''(x)}{u'(x)}$, which is the Arrow–Pratt absolute risk aversion coefficient. This can be rewritten as

$$U_{K_r\theta} = \int_0^{r_s\pi} u'(x)(I - r_s\pi)A(x)(r_s - r_r)dF(I(r)) + \int_{r_s\pi}^{I_h} u'(x)(I - r_s\pi)A(x)(r_s - r_r)dF(I(r_r))$$

with $I_h = I(0)$ and from the first-order condition,

$$\int_0^{r_s\pi} u'(x)(I - r_s\pi)dF(I(r_r)) + \int_{r_s\pi}^{I_h} u'(x)(I - r_s\pi)dF(I(r_r)) = 0. \quad (2)$$

For CARA and DARA preferences,

$$A(x|_{r_{r1}})(r_s - r_{r1}) < A(x|_{r_{r2}})(r_s - r_{r2}) \quad \text{for} \, \forall \, r_{r1} \text{ and } r_{r2},$$

where r_{r1} is any r_r with $I(r_r) \in [0,\ r_s\pi)$, and r_{r2} is any r_r with $I(r_r) \in [r_s\pi,\ I_h]$. Eq. (2) implies $U_{K_r\theta} > 0$. And increasing absolute risk aversion preferences are necessary for

$$A(x|_{r_{r1}})(r_s - r_{r1}) > A(x|_{r_{r2}})(r_s - r_{r2}) \quad \text{for} \, \forall \, r_{r1} \text{ and } r_{r2}$$

but not sufficient.

In a similar framework to that used here, Eeckhoudt et al. (1997) show that a sufficient condition for $U_{K_r\theta} \geq 0$ is that preferences are DARA, whereas in this framework CARA preferences are also sufficient. The condition under which $U_{K_r\theta} > 0$ determines other comparative statics results that are related to the demand for insurance and the effects of subsidized crop insurance on crop choices.

3.2.1. Insurance demand

The demand for actuarially fair crop insurance is positive if and only if

$$r_s\pi Eu'(x|_{\theta=0}) < Eu'(x|_{\theta=0})(I(r_r)). \quad (3)$$

Eq. (3) indicates that farmers purchase insurance if and only if the expected marginal benefit of indemnity payment, $Eu'(x|_{\theta=0})I(r_r)$, exceeds the marginal cost of crop insurance, $Eu'(x|_{\theta=0})r_s\pi$.[11] The marginal cost of crop insurance is the marginal benefit from self-insurance, which is through the investment in the safe crop, times the fair premium. Also note that at $\theta = 0$ the marginal cost of self-insurance is equal to the marginal benefit from the risky crop investment.

The substitutability between crop insurance and self-insurance can be examined by investigating changes of the demand for crop insurance with respect to changes in the rate of return from the safe crop, r_s.

Proposition 1. *When farmers purchase some insurance, the demand for actuarially fair insurance decreases with an increase in* r_s *if farmers have preferences that satisfy CARA or DARA and* $R(x) \leq 1$ *where* $R(x) = -\frac{u''(x)}{u'(x)}x$.

Proof. Using the implicit function theorem,

$$\frac{\partial\theta^*}{\partial r_s} = \frac{1}{J}(U_{K_r r_s}U_{K_r\theta} - U_{\theta r_s}U_{K_r K_r}),$$

where $J = U_{\theta\theta}U_{K_r K_r} - (U_{K_r\theta})^2$. Two second cross derivatives are

$$U_{K_r r_s} = -(1+\theta\pi)Eu'(x) - (K_0 - (1+\theta\pi)K_r)Eu'(x)A(x)(r_r - r_s + \theta(I(r_r) - r_s\pi))$$

[10] For the interior solution, the first-order condition can be rewritten as $Eu'(x)(r_r - r_s) = 0, Eu'(x)(I(r_r) - r_s\pi) = 0$. The two conditions indicate that farms equalize (a) marginal benefits from the risky crop investment and the safe crop investment, and (b) marginal benefits from the crop insurance indemnity and the safe crop investment weighted by the actuarially fair premium. We thank an anonymous referee for this point.

[11] Premiums for crop insurance can be smaller or larger than actuarially fair premiums due to poorly designed insurance contracts. If a premium, π', is set at a higher level compared to the actuarially fair premium, π (i.e., $\pi' > \pi$), condition (3) is less likely to be satisfied simply because $r_s\pi Eu'(x|_{\theta=0}) < r_s\pi' Eu'(x|_{\theta=0})$. And thus, to satisfy the condition on positive demand for crop insurance, it would require lower rates of return from the safe crop. Studies such as Goodwin (1994) and Goodwin and Ker (1998) show evidence that U.S. crop insurance premiums have not been actually fair for some crops.

and

$$U_{\theta r_s} = -K_r \pi Eu'(x) - (K_0 - (1+\theta\pi)K_r)K_r Eu'(x)A(x)(I(r_r) - r_s\pi).$$

The sufficient conditions for the sign of $U_{K_r r_s}$ to be negative are CARA or DARA with $R(x) \leq 1 U_{K_r r_s} U_{K_r r_s} = -Eu'(x)(1 - R(x) + \theta\pi + A(x)(K_r(r_r + \theta I(r_r)) + (K_0 - (1 + \theta\pi)K_r)r_r)) - (K_0 - (1+\theta\pi)K_r)\theta Eu'(x)A(x)(I(r_r) - r_s\pi)R(x) \leq 1$ and the sufficient conditions for the sign of $U_{\theta r_s}$ to be negative are CARA or DARA preferences. By Lemma 1, $U_{K_r\theta}$ is positive for CARA or DARA preferences. Therefore, under CARA or DARA and $R(x) \leq 1$, $\frac{\partial\theta^*}{\partial r_s} < 0$.

The substitutability between the crop insurance and the self-insurance holds if farmers with preferences that satisfy CARA or DARA with $R(x) \leq 1$. The substitutability is determined by (a) the change in the marginal utility from an additional unit of the risky crop investment and (b) the change in the marginal utility from an additional unit of the crop insurance coverage.[12]

As the rate of return from the safe crop investment increases, the marginal utility from an additional unit of the risky crop investment decreases for farms with CARA or DARA with $R(x) \leq 1$. The first term of $U_{K_r r_s}$, "$-(1 + \theta\pi)Eu'(x)$," represents losses in the marginal utility from the increased opportunity cost of investing in the risky crop due to the increase in the rate of return from the safe crop. This term is always negative regardless of risk preference. The second term, "$-(K_0 - (1+\theta\pi)K_r)Eu'(x)A(x)(r_r - r_s + \theta(I(r_r) - r_s\pi))$," represents changes in the marginal utility from the increased wealth due to the increase in the rate of return from the safe crop. Note that this term is zero for CARA and positive for DARA preferences and is represented by the net returns from each state and the risk preference. For farms with DARA preferences, the cost in terms of utility of accepting the risk decreases as the wealth increases. If the relative risk aversion of these farms is small enough, that is, $R(x) \leq 1$, the decrease in the cost of taking the risk is not large enough to compensate the losses in the marginal utility from the increased opportunity cost of investing in the risky crop. Thus, the trade-off between the safe crop investment and the risky crop investment becomes more favorable to the safe crop investment as the rate of return from the safe crop increases.

The increase in the rate of return from the safe crop investment also affects the marginal utility from an additional unit of the crop insurance coverage. The sufficient conditions for this marginal utility to decrease as the rate of return from the safe crop investment increases, that is, $U_{\theta r_s} < 0$, are CARA or DARA preferences. Regardless of risk preference, an increase in the rate of return from the safe crop investment increases the opportunity cost of crop insurance purchase. This is represented by the first term of $U_{\theta r_s}$. The second term, which represents the change in the marginal utility due to increased wealth, is zero for CARA preferences and negative for DARA preferences. Farms with DARA preferences value crop insurance less as their wealth increases.

[12] Following the language of Eeckhoudt et al. (1997), the change in the marginal utility from an additional unit of the crop insurance determines the direct effect and the change in the marginal utility from an additional unit of the risky crop investment determines the indirect effect. Note that the latter determines the demand for the crop insurance by changing the demand for the risky crop.

3.2.2. Effects of actuarially fair crop insurance on crop investment

For farmers who satisfy (3) and satisfy the interior solution condition, that is, $K_r^*(1 + \theta^*\pi) < K_0$, their portfolios are characterized with $U_{K_r} = 0$ and $U_\theta = 0$.[13]

The effect of actuarially fair crop insurance on the risky crop investment is defined as the difference between optimal K_r with and without crop insurance availability. Note that farmers with zero demand for actuarially fair crop insurance have the same optimal K_r with and without crop insurance availability. Thus, there is zero effect on the risky crop investment.

Proposition 2. *When farmers purchase some insurance, actuarially fair crop insurance induces more investment in the risky crop for farmers with preferences that satisfy CARA or DARA (similar to Hennessy, 1998).*

Proof. This can be shown by treating θ as exogenous parameter and showing $\frac{\partial K_r}{\partial\theta} > 0$. Using the implicit function theorem,

$$\frac{\partial K_r}{\partial\theta} = -\frac{U_{K_r\theta}}{U_{K_r K_r}}$$

and Lemma 1 states that CARA or DARA is sufficient for $U_{K_r\theta} > 0$.

Hennessy (1998) shows a similar result in a different setting. The difference between Proposition 2 and Hennessy (1998) is the availability of self-insurance. Because credit is not available and self-insurance is available only through the safe crop investment, Eq. (3) is necessary to have positive effect of actuarially fair crop insurance on the risky crop investment. In Hennessy (1998), any risk-averse agents with the indemnity $I(r_r)$ nonincreasing in r_r and decreasing in some r_r, purchase actuarially fair insurance and increase their investment in the risky crop, whereas Proposition 2 and Eq. (3) suggest that if self-insurance is cheap enough, the effect of actuarially fair crop insurance on the risky crop investment is zero.

Proposition 3. *An increase in the rate of return from safe crop investment reduces the effect of actuarially fair crop insurance on the risky crop investment if the farmers have CARA preferences or DARA with $R(x) \leq 1$ preferences.*

Proof. This can be shown by checking the sign of $\frac{\partial^2 K_r}{\partial\theta\partial r_s}$.

[13] The condition for the interior solution is $Eu'(\frac{r_r + \theta^0 I}{1+\theta^0\pi}K_0)(r_r - r_s + \theta^0(I(r_r) - r_s\pi)) < 0$, where θ^0 is defined by $Eu'(\frac{r_r + \theta^0 I}{1+\theta^0\pi}K_0)(r_r\pi - I) = 0$.

For farmers with CARA or DARA and $R(x) \leq 1$, actuarially fair crop insurance raises the risky crop investment more if the rate of return from the safe crop, r_s, is small. In other words, as self-insurance becomes more costly, the effect of actuarially fair crop insurance on the risky crop investment gets smaller.

Hennessy (1998) and Lemma 1 show that an increase in amount of insurance purchased increases investment in the risky crop. Proposition 1 shows that an increase in the rate of return from the safe crop, r_s, reduces the demand for insurance because of the substitutability between actuarially fair crop insurance and self-insurance through the safe crop investment. And since the demand falls, the investment effect becomes smaller as the rate of return from the safe crop decreases. Proposition 3 shows that the magnitude of effects of actuarially fair crop insurance on the risky crop investment is contingent on the cost of self-insurance.

3.3. Premium subsidy

This section focuses on how insurance premium subsidies affect the demand for insurance and investment across crops. Consider the premium subsidy, $0 < \gamma < 1$. The premium paid by farmers is now equal to $\pi(1-\gamma)$.

3.3.1. Effects of premium subsidy on insurance demand

The condition for positive insurance demand is now

$$r_s\pi(1-\gamma)Eu'(x|_{\theta=0}) < Eu'(x|_{\theta=0})I(r_r). \tag{4}$$

From (3) and (4), farmers who satisfy

$$r_s\pi(1-\gamma)Eu'(x|_{\theta=0}) < Eu'(x|_{\theta=0})I(r_r) < r_s\pi Eu'(x|_{\theta=0}) \tag{5}$$

purchase insurance only with the premium subsidy γ.[14] Note that the premium subsidy γ does not affect the distribution of indemnity payment.

For the farmers who satisfy (4) and satisfy the condition for investing some in the safe crop, that is, $K_r^*|_{K_s=0}(1+\theta^*|_{K_s=0}\pi(1-\gamma)) < K_0$, their portfolios are characterized by $U_{K_r} = 0$ and $U_\theta = 0$.[15]

Definition 1. *For the farmers who do not satisfy Eq.* (3)*, the premium subsidy γ is said to be effective if it satisfies Eq.* (5)*. In other words, the premium subsidy is effective if*

$$\gamma > \gamma_T = r_s\pi - \frac{Eu'(x|_{\theta=0})I(r_r)}{Eu'(x|_{\theta=0})}$$

and γ_T is the minimum effective premium subsidy.

Any premium subsidy γ that is less than γ_T has no effect on the farm portfolio. The threshold γ_T is increasing in r_s for CARA or DARA. This indicates that in environments where it is cheap to self-insure against farm portfolio risk, the minimum levels of effective premium subsidies are greater than in environments with expensive self-insurance.

The relationship between the minimum effective premium subsidy and the cost of self-insurance may explain low participation rates in the U.S. crop insurance program when the subsidy rate was relatively low. The U.S. farms have relatively more self-insurance options such as diversification, off-farm income, contracts, futures, and option.

3.2.2. Effects of premium subsidy on crop investment

Now, we provide a condition under which that subsidized crop insurance induces more investment in the risky crop. And then, we further separate the premium subsidy effect into two effects: (a) a direct profit effect and (b) an indirect coverage effect.

Proposition 4. *An increase in premium subsidy γ increases the amount of risky crop investment if farmers have preferences that satisfy CARA or DARA and $R(x) \leq 1$ when some insurance is purchased (similar to Eeckhoudt* et al.*, 1997; Hennessy, 1998).*

Proposition 4 is decomposed into Propositions 5 and 6. Therefore, the proof of Proposition 4 directly follows the proofs of Propositions 5 and 6.[16]

Eeckhoudt et al. (1997) and Hennessy (1998) both show that the optimal insurance purchase and the optimal investment on the risky asset decreases as the price of insurance increases in similar frameworks. For farmers who satisfy Eq. (4) and have preferences that satisfy CARA or DARA and $R(x) \leq 1$, the effect of premium subsidy on the risky crop investment is positive. To elaborate, there are two groups of farmers who satisfy Eq. (4): (a) farmers who have positive demands for actuarially fair crop insurance and (b) farmers who have zero demands for actuarially fair crop insurance but satisfy Eq. (5) with premium subsidy γ. In other words, by Definition 1, if farms have CARA or DARA with $R(x) \leq 1$ preferences, (a)

[14] Conditions (3) and (5) also provide an implication on how premium subsidies affect adverse selection in crop insurance participations. Without any premium subsidy, crop insurance includes farms that have large enough expected marginal benefit from indemnity payments or have high self-insurance costs. With greater premium subsidies, the distribution of crop insurance participants would be similar to the population distribution.

[15] Introducing the subsidy, γ, causes the condition for the interior solution to become $Eu'(\frac{r_r+\theta^* I}{1+\theta^*\pi(1-\gamma)}K_0)(r_r - r_s + \theta^*(I(r_r) - r_s\pi(1-\gamma))) < 0$ for θ^* that satisfies $Eu'(\frac{r_r+\theta^* I}{1+\theta^*\pi(1-\gamma)}K_0)(r_r\pi(1-\gamma) - I) = 0$.

[16] Clearly it follows from above that, when farms have preferences that satisfy CARA or DARA with $R(x) \leq 1$, the overall effect of premium subsidies on the risky crop investment is larger than the direct profit effect. This is consistent with use of the LeChatelier principle to show that long-run demand of an input is more elastic to the short-run demand of that input (Milgrom and Roberts, 1996). As an analogy between our decomposition and the LeChatelier principle, the indirect coverage effect can be interpreted as a long-run adjustment term in the context of a two-input production model.

farms with $\gamma_T = 0$ increase their risky crop investment as γ increases at any level of γ, and (b) farms with $\gamma_T > 0$ increase their risky crop investment as γ increases for γs that are greater than γ_T.

Subsidized crop insurance induces more investment in the risky crop when farmers have preferences that satisfy CARA or DARA and $R(x) \le 1$. Both actuarially fair crop insurance and premium subsidy increase investment in the risky crop. Now, we further separate the effects of the premium subsidy into two effects: (a) a direct profit effect and (b) an indirect coverage effect. The premium subsidy can induce more investment in the risky crop by increasing the profit per unit of investment with a given level of insurance coverage. This is defined as the direct profit effect. The premium subsidy also encourages farmers to purchase more insurance and by doing so, they may increase the risky crop investment. More precisely, the effects of the premium subsidy can be represented as[17]

$$\frac{\partial K_r}{\partial \gamma} = \left(1 - \frac{\partial K_r}{\partial \bar{\theta}} \frac{\partial \theta}{\partial \overline{K_r}}\right)^{-1} \left(\frac{\partial K_r}{\partial \gamma}_{\theta \text{ constant}} + \frac{\partial K_r}{\partial \theta} \frac{\partial \theta}{\partial \gamma}_{K_r \text{ constant}}\right), \quad (6)$$

where $\partial\bar{\theta}$ and $\partial\overline{K_r}$ indicate the exogenous changes in θ and K_r.

The term $\frac{\partial K_r}{\partial \gamma}_{\theta\ constant}$ represents a direct "profit effect" of the premium subsidy on the risky crop investment. The term $\frac{\partial K_r}{\partial \theta} \frac{\partial \theta}{\partial \gamma}_{K_r\ constant}$ represents an indirect "coverage effect" of the premium subsidy on the risky crop investment, which is through the increased insurance purchase.[18]

Proposition 5. *The direct profit effect is positive, that is,* $\frac{\partial K_r}{\partial \gamma}_{\theta\ constant} > 0$*, if farmers have preferences that satisfy CARA or DARA.*

Proof. By treating θ as an exogenous parameter, using the implicit function theorem,

$$\frac{\partial K_r}{\partial \gamma}_{\theta \text{ constant}} = -\frac{U_{K_r\gamma}}{U_{K_rK_r}}$$

and

$$U_{K_r\gamma} = r_s\theta\pi Eu'(x) - r_s\theta\pi K_r Eu'(x)A(x)(r_r - r_s + \theta(I(r_r) - r_s\pi(1-\gamma))). \quad (7)$$

The second term is zero for CARA and positive for DARA including minus sign. Thus, the sufficient conditions for $\frac{\partial K_r}{\partial \gamma}_{\theta \text{ constant}} > 0$ are CARA or DARA.

Proposition 6. *The indirect coverage effect is positive, that is,* $\frac{\partial K_r}{\partial \theta} \frac{\partial \theta}{\partial \gamma}_{K_r \text{ constant}} > 0$*, if farmers have preferences that satisfy CARA or DARA with* $R(x) \le 1$.

Proof. Similar to Proposition 5, by treating K_r as an exogenous parameter and using the implicit function theorem,

$$\frac{\partial \theta}{\partial \gamma}_{K_r \text{ constant}} = -\frac{U_{\theta\gamma}}{U_{\theta\theta}}$$

and

$$U_{\theta\gamma} = r_s\pi K_r Eu'(x) - r_s\theta\pi K_r^2 Eu'(x)A(x)(I(r_r) - r_s\pi(1-\gamma)). \quad (8)$$

The second term is zero for CARA and negative for DARA including the minus sign. We can rewrite (8):

$$U_{\theta\gamma} = r_s\pi K_r Eu'(x)(1 - R(x) + A(x)(r_s(K_0 - (1+\theta\pi(1-\gamma))K_r) + (r_r + r_s\theta\pi(1-\gamma))K_r)).$$

Thus, the sufficient conditions for $\frac{\partial \theta}{\partial \gamma}_{\theta \text{ constant}} > 0$ are CARA or DARA with $R(x) \le 1$.

The direct profit effect is a change in the risky crop investment holding the insurance purchase constant. This consists of a subsidy effect and a risk effect. The first term of (7), $r_s\theta\pi Eu'(x)$, is the subsidy effect and the second term of (7), $-r_s\theta\pi K_r Eu'(x)A(x)(r_r - r_s + \theta(I(r_r) - r_s\pi))$, is the risk effect. The subsidy effect, which is a change in the marginal utility from an increase in overall profit due to an increase in the subsidy rate, is positive regardless of preference. The risk effect is from a change in the marginal utility from a change in the risk preference caused by an increase in wealth due to the additional subsidy. This is zero for farms with CARA preferences and positive for DARA preferences. Note that farms with DARA preferences have lower costs of taking the risk as their wealth increases.

The indirect coverage effect derives from an increase in the amount of insurance purchased caused by an increase in the premium subsidy. The amount of insurance demanded rises as the cost of crop insurance for farmers falls, when market-based crop insurance and self-insurance are substitutes. The first term of (8), $r_s\pi K_r Eu'(x)$, represents a subsidy effect and the second term of (8), $-r_s\theta\pi K_r Eu'(x)A(x)(I(r_r) - r_s\pi)$, represents a risk effect. The subsidy effect, which is the first term of Eq. (8), $r_s\pi K_r Eu'(x)$, represents the marginal benefit from a unit increase in the insurance coverage level through the additional subsidy.[19] Similarly to the direct profit effect, the subsidy effect is positive regardless of preferences. The risk effect is zero for farms with CARA preferences and negative for farms with DARA preferences. As wealth increases, the crop insurance

[17] The derivation is from the total differentiation of the implicit function $K_r(\gamma,\ \theta(\gamma,\ K_r))$:$dK_r = \frac{dK_r}{d\gamma}d\gamma + \frac{dK_r}{d\theta}(\frac{d\theta}{d\gamma}d\gamma + \frac{d\theta}{dK_r}dK_r)d\theta$.

[18] This type of decomposition is parallel to the decomposition of Eeckhoudt et al. (1997), which defines the direct and indirect effects of a parameter shift. In their definition, the direct profit effect is classified as the direct effect and the indirect coverage effect is classified as the indirect effect. Hennessy (1998) has similar discussions in the context of Proposition 4 and decomposed the entire effect into a wealth effect and a substitution effect. Note that this decomposition is different from Eq. (6) both conceptually and mathematically.

[19] The empirical finding of Just et al. (1999) on small incentive from risk aversion suggests that this term may be substantial.

becomes less attractive if farms have DARA preferences. If farms have preferences that satisfy DARA and $R(x) \leq 1$, then the subsidy effect has a larger magnitude compared to that of the risk effect.

In our framework, the direct profit effect derives from the substitutability between the safe crop and the risky crop. The indirect coverage effect derives from the substitutability between market-based crop insurance and self-insurance through investing less in the safe crop. For those farmers who have preferences that satisfy DARA with $R(x) \geq 1$, market-based crop insurance and self-insurance may not be substitutes. If market-based crop insurance and self-insurance are not substitutes, the indirect coverage effect becomes negative. Since the direct profit effect of the premium subsidy is still positive, the magnitude of negative indirect coverage effect needs to be large to make the overall effect on the risky crop investment negative. Based on risk aversion of farms in developing countries, we expect this case is rare.

4. A comparison of the effects of a crop insurance subsidy to a stylized input subsidy: numerical illustrations

From the conceptual framework above, we show that the effects of premium subsidies consist of the two distinct effects, the direct profit effect and the indirect coverage effect. As (7) and (8) show, these two effects are determined by an interaction between the cost of self-insurance, r_s, and the degree of risk aversion. This section compares the effects of a premium subsidy on risky crop investments to the effects of a stylized farm input subsidy under alternative parameterizations of the cost of self-insurance and the degree of risk aversion.[20]

Consistent with the conceptual framework, numerical illustrations in this section assume linear returns to the crop investments.[21] Therefore, risk aversion is the only reason farmers may invest in both the risky crop and the safe crop. In the numerical illustrations, we vary the cost of self-insurance or the degree of risk aversion. Under the assumption of constant relative risk aversion (CRRA) preferences, the illustrations emphasize that farmers with higher costs of self-insurance or higher degrees of risk aversion are more responsive to the premium subsidy than to the stylized farm input subsidy. In other words, the difference between a risky crop investment under crop insurance and a risky crop investment under the stylized farm input subsidy is larger for farmers with higher costs of self-insurance or higher degrees of risk aversion.

[20] The functional form of the utility function and the parameters in the numerical simulations do not consider the rare case of negative effect of crop insurance subsidy on the risky crop investment. Empirical studies such as Cai (2016), Cai et al. (2015), Elabed and Carter (2014), Karlan et al. (2014), Goodwin et al. (2004), and Wu (1999) indicate that the overall effect of subsidized crop insurance is positive.

[21] Different functional forms can be considered but our general discussion remains valid even without the linearization of the return functions.

For illustrative purposes, we assume the following CRRA utility function:

$$u(x) = \frac{x^{1-R}}{1-R},$$

where x is stochastic income for each state and R is a coefficient of relative risk aversion. Following the setup in the previous sections, the expected utility maximization problem with the subsidized crop insurance is

$$\max_{K_r,\, \theta} U(K_r,\ \theta) = Eu(x(K_r,\ \theta))$$

$$\text{subject to } (1 + \theta\pi(1 + m - \gamma))K_r - K_0 \leq 0$$

$$-\theta \leq 0,$$

where m is the premium markup rate, γ is the premium subsidy rate, and

$$x(K_r,\ \theta) = r_s(K_0 - (1 + \theta\pi(1 + m - \gamma)K_r)) + (r_r + \theta I(r_r))K_r.$$

The markup rate and the subsidy rate are both measured in per unit of premium and they both range [0, 1). The insurance contract is specified as

$$I(r_r) = \max\{E(r_r) - r_r, 0\},$$

$$\pi = E(I(r_r)),$$

where $I(r_r)$ is the indemnity payout and π is the actuarially fair premium.[22]

For example, $m = 0.5$ and $\gamma = 0.2$ indicate the market price of the crop insurance is 150% of the actuarially fair premium and the government subsidy is 20% of the actuarially fair premium. In this case, a farmer pays 130% of the fair premium per unit of K_r. If all of K_r is insured (i.e., $\theta = 1$), the farmer receives 0.2π per unit of K_r as a subsidy. Of course, if the farmer only insures a half of his K_r, then he receives 0.1π per unit of K_r.

The alternative policy scheme, a farm input subsidy on K_r, is described by the following expected utility maximization problem:

$$\max_{K_r} U(K_r) = Eu(x(K_r)) = Eu(r_s(K_0 - (1 - \delta)K_r) + r_r K_r)$$

$$\text{subject to } (1 - \delta)K_r - K_0 \leq 0,$$

where δ is the input subsidy rate per unit of K_r. The input subsidy rate, δ, ranges [0, 1).[23]

[22] Recall that the actuarially fair premium rate π does not include administrative and operating costs or reinsurance costs.

[23] One can show that $\frac{\partial K_r}{\partial \delta}$ is positive when farms have CARA or DARA preferences by modifying Proposition 5, that is, the effect of the input subsidy is very similar to the direct profit effect with $\theta = 1$.

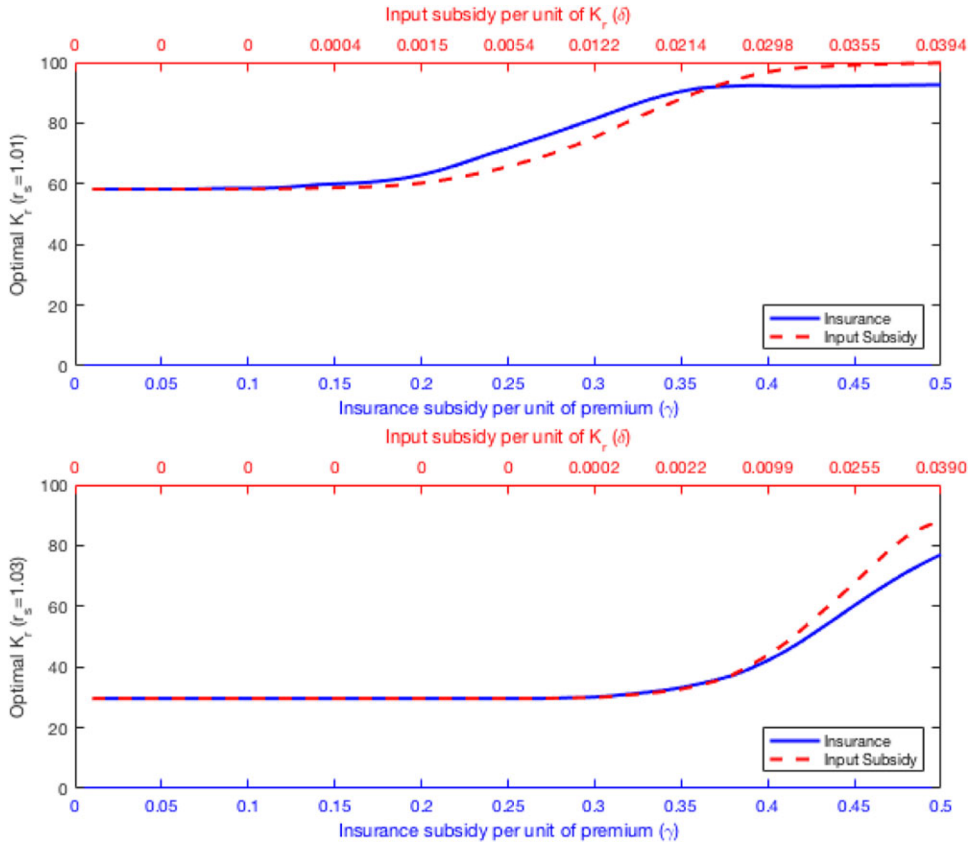

Fig. 2. Effects of premium subsidy and input subsidy ($\boldsymbol{R}(\boldsymbol{x}) = 1.7$). [Color figure can be viewed at wileyonlinelibrary.com]

Table 1
Parameters for the numerical illustration

Parameters	Values
Capital endowment, K_0	100
Mean of risky crop RoR, μ_{r_r}	1.05
Standard deviation of risky crop RoR, σ_{r_r}	0.2
Fair premium rate, π	0.079
Insurance markup rate, m	0.5
Premium subsidy rate, γ	[0, 0.5]
Safe crop RoR, r_s	{1.01, 1.03}
Risk aversion coefficient, R	{1.7, 2.7}

For a fair comparison between the two subsidy schemes in the numerical simulations, we set the input subsidy rate, δ, equal to $\pi\gamma\theta^*$. The product of the actuarially fair premium (π), the premium subsidy rate (γ), and the optimal insurance coverage level (θ) is equal to the amount of the premium subsidy per unit of K_r that farmers get when the subsidized crop insurance is available. In the numerical simulation, we compare impacts when each unit of K_r receives same amount of subsidy under the two policy schemes.

Table 1 describes the parameter specifications for the numerical illustrations. The range of the premium subsidy rates is from 0% to 50% of the fair premium.[24] When the rate of return from the risky crop, r_r, follows $N(1.05, 0.2^2)$ as described in Table 1, the fair premium rate is equal to 0.079 per unit of K_r.

Each Monte Carlo simulation consists of 100 repetitions of maximizing expected utility. In each repetition, expected utility is numerically approximated by drawing 1,000 samples of r_r from $N(\mu_{r_r},\ \sigma_{r_r}^2)$. We illustrate the simulation results for four cases: (a) a low rate of return from the safe crop and a low degree of risk aversion ($r_s = 1.01$ and $R = 1.7$), (b) a higher rate of return from the safe crop and a low degree of risk aversion ($r_s = 1.03$ and $R = 1.7$), (c) a low rate of return from the safe crop and a higher degree of risk aversion ($r_s = 1.01$ and $R = 2.7$), and (d) a higher rate of return from the safe crop and a higher degree of risk aversion ($r_s = 1.03$ and $R = 2.7$). We show the average of 100 optimal K_r^*s for these four cases.

Fig. 2 shows the optimal risky crop investments, K_r^*, for the two policy schemes when farmers are less risk-averse. The solid line illustrates the optimal K_r when subsidized crop insurance is offered and the dashed line illustrates the optimal K_r when the input subsidy is offered. The upper panel represents the case of the low rate of return from the safe crop investment, that is,

[24] This is lower than the actual subsidy rates in the U.S. crop insurance programs. For illustrative purposes, we focus on this range in order to avoid corner solutions.

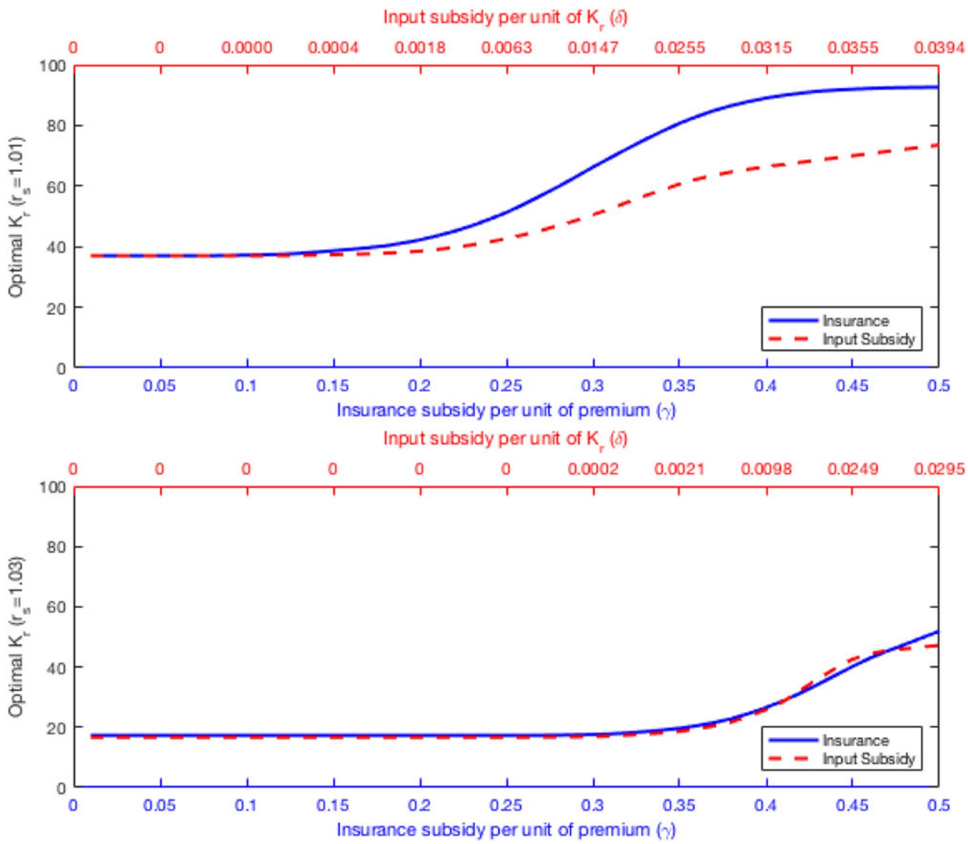

Fig. 3. Effects of premium subsidy and input subsidy ($\boldsymbol{R}(\boldsymbol{x}) = 2.7$). [Color figure can be viewed at wileyonlinelibrary.com]

higher cost of self-insurance. In this case, for the premium subsidy rates lower than 10% of the fair premium rate, farmers do not purchase any insurance. Thus, the amounts of subsidies per unit of K_r for both policy schemes are zero when the premium subsidy rates are set to be lower than 10%.

When premium subsidy rates are higher than 10%, optimal risky crop investments start to increase. The optimal risky crop investment under subsidized crop insurance increases more rapidly than the optimal risky investment under the input subsidy until the investment is constrained by the initial asset, K_0. When subsidized crop insurance is offered, farmers allocate their initial assets to three ways: (a) investment in the safe crop, (b) investment in the risky crop, and (c) the crop insurance premium. In the upper panel of Fig. 2, when the premium subsidy rate is higher than 35% of the fair premium, farmers stop investing in the safe crop. In that case, initial assets are allocated only to the risky crop investment and the crop insurance premium.[25] On the contrary, when the input subsidy is offered, farmers allocate their assets to only the safe crop and the risky crop. Both subsidy schemes can eliminate planting the safe crop. However, to derive farm investment out of the safe crop requires a larger input subsidy than crop insurance subsidy.

[25] Note that if they use some of their initial assets to purchase some amount of crop insurance, farmers cannot put all of their initial assets into the risky crop.

Similarly, the lower panel of Fig. 2 illustrates the optimal risky crop investments, K_r^*, when the rate of return from the safe crop is relatively high and farmers are less risk-averse. The cost of self-insurance is cheaper compared to the case of the upper panel of Fig. 2. Because of the lower cost of self-insurance, farmers do not buy crop insurance until the premium subsidy rate becomes greater than 30% of the fair premium. This is consistent with Definition 1, which indicates that the minimum threshold for effective premium subsidies is higher when the rate of return from the safe crop is higher. Comparing the lower panel with the upper panel of Fig. 2, we observe that the insurance premium subsidy is less effective when the cost of self-insurance is low.

Fig. 3 illustrates the optimal risky crop investments, K_r^*, when farmers are more risk-averse. We can use a comparison of the upper panel of Fig. 3 with the upper panel of Fig. 3 to examine the effect of more risk-aversion on responses to insurance subsidy versus input subsidy. In the upper panel of Fig. 3, similar to the case of the upper panel of Fig. 3, farmers do not purchase any insurance until the premium subsidy rate is above 10% of the actuarially fair premium. Comparing the vertical intercepts of the two figures indicates that when farmers receive no subsidy, the more risk-averse farmers invest less in the risky crop compared to the less risk-averse farmers. Then, also in the upper panel of Fig. 3, risky crop investment increases more rapidly as the subsidy rate increases for the subsidized crop insurance than for the farm input subsidy. Hence, when farmers are more risk-averse, the additional positive effect of insurance subsidy on risky crop investments is larger.

The lower panel of Fig. 3, compared with the upper panel of Fig. 3, shows that the insurance premium subsidy is less effective when the cost of self-insurance is low. However, since farmers are more risk-averse in Fig. 3, overall levels of risky crop investments are lower than those of Fig. 3. Also, the risky crop investments increase more slowly as the subsidy rate increases when self-insurance costs are low and the degrees of risk-aversion are high.

These numerical examples illustrate that insurance premium subsidies are more effective than alternatives when farmers are more risk-averse or self-insurance is more costly. Note that the direct profit effect of premium subsidies is similar to the effect of the input subsidy. Therefore, the difference between the effect of premium subsidies and the effect of input subsidies arises from the indirect coverage effect of crop insurance premium subsidies. The sign and the magnitude of the indirect coverage effect depend on the degree of risk aversion and the cost of self-insurance.

5. Concluding remarks

In this article, we separate effects of subsidized crop insurance on crop choices into the effect of unsubsidized actuarially fair crop insurance and the effects of premium subsidy. The effects of premium subsidy are further separated into the direct profit effect and the indirect coverage effect. These two effects of premium subsidy each consist of substitution effects and wealth effects. Fig. 1 summarizes the separate categories of these effects.

The degrees of the substitutability in production between the risky crop and the safe crop, and the substitutability between market-based crop insurance and self-insurance, determine the signs and the magnitudes of the direct profit effect and the indirect coverage effect. If the substitutability between crop insurance and self-insurance is smaller than the substitutability in production between the risky crop and the safe crop, the dominant driver of the impact of premium subsidy on crop choices is the direct profit effect. In such a case, policy-makers should expect that subsidized crop insurance functions similarly to simple input or output price subsidies.

We also investigate how the cost of self-insurance interacts with these effects of subsidized crop insurance. If the cost of self-insurance is cheap enough (as in high profitability from planting a safe crop), farmers have no incentive to participate in crop insurance programs. The cheaper the cost of self-insurance, the higher the subsidy rate that is required to encourage farmers to participate in crop insurance programs. This dampens the effects of premium subsidies on risky crop investments. A recent empirical study by Awondo et al. (2017) suggests that off-farm income, which is a kind of self-insurance mechanism in the language of Ehrlich and Becker (1972), reduces the cost of taking risks in maize production in Uganda.

Our numerical simulations illustrate how the effects of an insurance premium subsidy differ from those of an input subsidy. Farmers with high costs of self-insurance and high degrees of risk-aversion increase risky crop investments more when subsidies are offered in the form of crop insurance. Farmers with low costs of self-insurance and low degrees of risk-aversion behave similarly under the two subsidy schemes.

Our conceptual framework and numerical examples help policy-makers to recognize that premium subsidies may promote investments in risky crops by encouraging insurance purchases and by reducing "riskiness" of farm crop portfolios that include risky crops. However, in some situations and among some farmers, premium subsidies function mostly as direct production subsidies. We show that farmers whose cost of self-insurance is low enough would be unaffected by availability of subsidized crop insurance. For some farmers, providing subsidized crop insurance can lead to large differences in farm asset allocation compared to when other input subsidies are provided. Policy evaluators must consider these possibilities when making choices between crop insurance programs and alternative farm policies.

Self-protection, which in the language of Ehrlich and Becker (1972) reduces the variance of the rate of return from the risky crop in this simplified framework, would modify our results since self-protection provides another alternative to mitigate risks. Allowing intertemporal allocation of resources with credit market accessibility in the model also would have implications for the effects of subsidized crop insurance. Further research on effects of subsidized crop insurance when farmers have options for self-protection or intertemporal allocation of resources is needed.

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