Journal of Agricultural and Resource Economics 42(3):406–426 ISSN 1068-5502

Managing Catastrophic Risk in Agriculture through *Ex Ante* Subsidized Insurance or *Ex Post* Disaster Aid

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We consider a political economy in which government cares about risk-averse farmers' loss of income but incurs political cost if it provides monetary support to farmers. Farmers' expectations of government disaster aid and overconfidence (optimism bias) regarding their risk prevent farmers from purchasing full insurance under actuarially fair rates. Considering this conclusion, government prefers to subsidize farmers' purchases of insurance *ex ante* rather than solely relying on disaster aid *ex post*. The resulting subsidy rate depends on the political environment, the degree of systemic risk, the distribution of farmers' risk preferences, and the nature and distribution of farmers' risk perceptions.

Key words: agricultural (crop and livestock) insurance, agricultural risk, catastrophic risk, disaster relief, optimism bias, overconfidence, Stackelberg equilibrium, systemic risk

Introduction

Subsidized crop insurance has emerged to play a prominent role in U.S. agricultural policy as well as in the policy considerations and actions of legislators around the world (Mahul and Stutley, 2010; Goodwin, 2014). In the United States, the Federal Crop Insurance program has become the centerpiece of the agricultural safety net for crops, protecting $110 billion worth of liability and covering 90% of planted acres in 2014. Government spending on crop insurance was projected to exceed spending on farm commodity programs during fiscal years 2015–2025 (Congressional Budget Office, 2015). During the debate on the 2014 Farm Bill—legislation that authorizes agricultural, nutrition, and other programs over 2014–2018—the issue of public support for crop insurance underwent intense scrutiny, and the justification for crop insurance premium subsidies continues to be questioned in light of policy and budget issues (Goodwin and Smith, 2013; Glauber, 2013).

Crop insurance has received government support for a variety of reasons.[1] First, crop insurance risks are catastrophic (systemic) in nature, which may result in missing markets (Duncan and Myers, 2000). Second, information asymmetries (moral hazard and adverse selection problems), if present, may lead to market failure in the form of underinsurance (Nelson and Loehman, 1987). A third, stemming from the first, has been to discourage government use of ad hoc disaster payments, which

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The author acknowledges useful comments from Keith J. Collins, Thomas P. Zacharias, James Vercammen, Joseph W. Glauber, and GianCarlo Moschini on prior versions of the paper. The usual disclaimer applies. This research has been funded by National Crop Insurance Services (NCIS), Overland Park, Kansas (www.ag-risk.org).
Review coordinated by David K. Lambert.

[1] Congress, with the intent of replacing costly disaster aid payments, restructured the crop insurance program and increased premium subsidies with the Federal Crop Insurance Reform Act of 1994 (1994 Act) and the Agricultural Risk Protection Act of 2000 (ARPA). The 1994 Act increased subsidy rates primarily at the lower insurance coverage levels, while ARPA increased rates more at the higher coverage levels. Premium subsidy rates were further increased for certain insurable units of land in the Food, Conservation, and Energy Act of 2008. Over time, these progressive subsidy increases stimulated higher and more diverse participation, which—combined with better data—improved the program's actuarial performance by reducing adverse selection and enhancing underwriting and ratemaking (Collins and Bulut, 2011).

grew sharply in the 1980s and 1990s, were costly, and discouraged the purchase of crop insurance (U.S. Government Accountability Office, 1989; van Asseldonk, Meuwissen, and Huirne, 2002; Dismukes and Glauber, 2005, June; Innes, 2003). Fourth, somewhat contrary to the second, farmers may be overconfident (optimistically biased) in assessing—systematically underestimating—the risks of catastrophic production or revenue losses such as those caused by natural disasters (Just, 2002; Mahul and Stutley, 2010; Coble and Barnett, 2013).

The claim that farmers could be overconfident is supported by empirical studies (Sherrick, 2002; Umarov and Sherrick, 2005; Turvey et al., 2013). Du, Feng, and Hennessy (2017) empirically find that farmers reveal some aversion to incurring out-of-pocket premiums in their crop insurance coverage choices. The authors suggest that farmers may be prone to a cognitive bias in assessing the benefits of insurance. Overconfidence is not limited to agricultural decision-makers per se. For instance, Kunreuther and Michel-Kerjan (2013), Malmendier and Taylor (2015), and DellaVigna (2009) provide some evidence on overconfidence in flood insurance and other areas of economics, respectively. Finally, Bracha and Brown (2012) provide neuro-economic foundations for optimism bias in decision-making under risk. In particular, the authors propose a mental cost function to account for an individual's taste for accuracy and suggest that the individual can rationalize holding optimistic beliefs depending on the properties of the mental cost function. The authors also point out that the possibility of the illusion of control in chance events and suggest optimism bias is more likely to be observed in situations in which one's own competence is in question. Familiarity with the task at hand may feed into these feelings of competence and make rationalizing optimistic views easier.

Beyond these reasons, the qualitative and quantitative effects of political and economic determinants of the optimal subsidy rate (the effects of farmers' overconfidence, in particular) have not been analyzed within an equilibrium model. Without such an analysis, alternative policy proposals that call for reductions in premium subsidies can eschew farmers' equilibrium coverage demand response (see, for instance, U.S. Government Accountability Office, 2014, p. 22). Because the underlying tradeoff between insurance uptake and ad hoc disaster aid is not taken into account, the proposed potential savings may not materialize. In providing guidance to these policy proposals, econometric evaluations of price responsiveness of farmers' crop insurance demand have been of limited value for at least three reasons: First, these studies have fallen short of properly accounting for the endogeneity issue arising from the simultaneous choice of quantity of insurance and the attendant price (Woodard, 2016). Second, elasticity estimates of crop insurance demand obtained in an environment with significant subsidies may not extrapolate to an environment without any subsidy. Third, crop insurance demand may not be invariant to underlying political environment. In order to fill this gap in the existing literature, we develop a simple yet explicit theoretical framework that captures the essential aspects of government's decision on crop insurance premium subsidies. To that end, we combine the political economy framework as in Innes (2003) with the modeling of farmer's insurance coverage choice in the presence of systemic risk as in Duncan and Myers (2000) while improving upon both studies on several key dimensions.

Innes (2003) models *ex post* political behavior in times of financial distress as a constraint on government's *ex ante* policy choice and finds that an *ex ante* contract coupled with a participation fee can deter *ex post* disaster aid and correct for underproduction incentives that would otherwise occur. The *ex ante* contract takes the form of a price floor tailored to each farmer's productivity type, while government bears the positive difference between the floor and realized price. Nevertheless, such a policy package is not suitable to study farmers' insurance coverage choices in the nexus of government's subsidy-setting decision. To that end, we maintain the simple political process considered in Innes (2003) but introduce an explicit government objective function. This permits us to derive a disaster aid schedule in a closed form and identify the relevant range of political cost parameters that can support it. We also choose to focus on the risk-spreading role of insurance and consider production only implicitly. Accordingly, we move beyond the risk-neutrality approach found in Innes (2003) and adapt the modeling of risk-averse farmers' insurance coverage choices in

Duncan and Myers (2000). To this we add heterogeneous risk preferences and risk perceptions, which permits us to explicitly derive insurance coverage demands. These can then account for the observed heterogeneous uptake of insurance coverage. Because systemic risk is only implicitly considered in Innes (2003), we turn to the systemic risk modeling in Duncan and Myers (2000), to which we add explicit accounting of the components of systemic risk through a correlation modeling with roots in Bulut and Moschini (2006). Finally, all of these elements are brought together within a game-theoretic equilibrium framework.

In our framework, government considers offering insurance subsidies in order to bolster insurance protection in advance of a potential loss and reduce or eliminate the need for government to provide disaster aid later, both of which are subject to political cost. By doing so, government acts as the Stackelberg leader of the two-player game (figure 1b). We obtain the Stackelberg equilibrium of the game between government and farmers (Proposition 1) and numerically solve for the equilibrium premium subsidy rates for a set of parameter values in the base case and fourteen additional scenarios. The resulting premium subsidy rates then allow us to compute the equilibrium coverage demand response and the anticipated disaster aid schedules and to investigate the properties of the equilibrium. Our game-theoretic approach is novel within not only the literature examining government's support for agriculture but also the literature examining government's role in providing relief for catastrophic events in general (Shavell, 2014).[2]

The Model

We consider a large number (N) of farmers with their measure (size) normalized to 1 and denote the farm outcomes (yields for simplicity) with $\tilde{y}_i$, where i indexes farms $i = 1, 2, \ldots, N$. (The overstruck "$\sim$" refers to random variables throughout.) Farm yields are identically distributed with the same expected value and variance and positively yet imperfectly correlated across farms. The same correlation coefficient ($\rho_{\tilde{y}_i\tilde{y}_j}$) applies for each pair of farms. Farmers differ only in the dimension of risk preferences (λ)—to emphasize the risk-spreading role of insurance. Throughout, we assume that λ is a farmer's private information (hence, farmer's type) but that government knows its distribution function. We let $f(\lambda)$ denote the probability density function associated with the probability distribution for risk-aversion levels, where $f(\lambda)$ takes positive values over the interval $[\underline{\lambda}, \bar{\lambda}]$ and the parameters $\underline{\lambda}$ and $\bar{\lambda}$ are the minimum and maximum risk-aversion levels. The heterogeneity in risk preferences in turn underpins the heterogeneity in risk perceptions—more on this momentarily.

As in Duncan and Myers (2000), a typical member of a farmer population faces the prospect of a loss $\tilde{l}^0$—which refers to the prospect of farm outcome (yield or revenue) falling below a catastrophic threshold level—of loss amount l with probability p_l and no loss with probability $(1 - p_l)$ (see also footnote 22). The farmer's expected loss and the variance are $E(\tilde{l}^0) = p_l l$ and $\sigma^2_{\tilde{l}^0} = p_l(1 - p_l)l^2$, respectively. Based on $E(\tilde{l}^0)$ and $\sigma^2_{\tilde{l}^0}$, the farmer—who faces a risky activity without any government support or any insurance protection and is accurate in assessing his or her own risk—is assumed to have a linear mean-variance preference function:

$$U^0 = M - E(\tilde{l}^0) - 0.5\lambda\sigma^2_{\tilde{l}^0}, \tag{1}$$

where U^0 denotes utility, M is potential income, and λ is the farmer's risk-aversion level.[3]

[2] Our framework is in line with the type of principal-agent problems described in Guesnerie and Laffont (1984). In particular, our approach is similar to the mechanism design literature (such as Hueth, 2000) in allowing for heterogeneity across farmers and examining the government's choice among alternative policy options in supporting agriculture. In micro insurance markets, similar modeling efforts allowing consumer heterogeneity through risk-preference parameters are also emerging (Hofmann, 2009).

[3] The farmer's utility in equation (1) corresponds to the farmer's certainty equivalent under the assumption that the farmer's income is normally distributed and the farmer's utility can be represented with negative exponential utility function. Otherwise, equation (1) is approximately equal to the certainty equivalent based on the Arrow-Pratt approximation to risk premium.

In line with Bracha and Brown's (2012) optimism bias concept, we model overconfidence by rescaling the original probability of loss, p_l, downwards. The resulting definition is consistent with that in Just (2002)—an individual reporting distributions that are narrower than the true distribution.[4] We write the overconfidence in the farmer's own risk as $q_l = p_l(1 - \delta_l)$, where q_l denotes the farmer's perception (or subjective belief) of risk and $0 \leq \delta_l < 1$ represents the distortion with respect to true individual risk (based on objective probability, p_l). (Henceforth, superscripts "0" and "1" refer to calculations under accurate and perceived risk, respectively.) The perceived random variable $\tilde{l}^1$ is the farmer's loss at amount l with probability q_l. The farmer's expected loss and the variance are then $E(\tilde{l}^1) = q_l l$ and $\sigma^2_{\tilde{l}^1} = q_l(1 - q_l)l^2$, respectively. Based on $E(\tilde{l}^1)$ and $\sigma^2_{\tilde{l}^1}$, the farmer's preferences in equation (1) can be rewritten as

$$U^1 = M - E(\tilde{l}^1) - 0.5\lambda\sigma^2_{\tilde{l}^1}. \tag{2}$$

For a given risk-aversion level, the utility level given in equation (2) is higher than that in equation (1) because the farmer perceives a lower expected loss and a lower variance.

Menapace, Colson, and Raffaelli (2013) provide evidence that farmers are risk averse and that farmers who are more (less) risk averse perceive greater (smaller) farm losses. These findings are consistent with the suggested negative relationship between overconfidence and risk aversion in Umarov and Sherrick (2005, p. 17). Accordingly, we relate the distortion in the farmer's risk perception to the farmer's risk aversion and consider a negative relationship between the two. As risk aversion increases, the distortion (hence, overconfidence) monotonically declines to 0 and perceived risk approximates true risk.[5] As a result, the utility in equation (2) decreases in risk aversion because the penalty for experiencing risk increases and the farmer's perception becomes more accurate.

We now turn to the area in which a farmer operates. Because the area outcome combines the individual outcomes of large numbers of farmers, the individual farmer may feel somewhat detached from the area outcome and take a more objective view toward area risk.[6] In line with this view and for simplification, we postulate that the farmer's perception toward area risk remains accurate. In particular, the farmer's perception of the probability of area loss, q_L, and the correlation between area and farm losses, φ, equal their objective counterparts, p_L and ρ, respectively. Combining the notation for q_L and φ with q_l from earlier, it is possible to construct the perceived joint distribution

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[4] The farmer perceives a lower variance as small probabilities of loss are considered (i.e., $p_l < 0.5$).

[5] We specify the distortion as $\delta_l = \theta A(\lambda)$, where the parameter θ lies between 0 and 1 and sets the upper limit on the farmer's overconfidence and the function $A(\lambda)$ indexes overconfidence in terms of the degree of risk aversion. We write $A(\lambda) = (\overline{\lambda} - \lambda)/(\overline{\lambda} - \underline{\lambda})$, where $\underline{\lambda}$ and $\overline{\lambda}$ are the bounds as defined earlier. Notice that $A(\lambda)$ takes values between 0 (when $\lambda = \overline{\lambda}$) and 1 (when $\lambda = \underline{\lambda}$) and that $A(\lambda)$ is decreasing in λ, which in turn implies that δ_l takes values between 0 and θ, respectively, and δ_l decreases as λ increases. Implicit to the systematic optimism bias considered here is a mental cost function (individual's taste for accuracy) in line with Bracha and Brown (2012, p. 70), as referred to earlier. In that study, the mental cost function increases at an increasing rate as an individual adopts more optimistic probabilities than the objectively estimated one; it increases indefinitely when the perceived risk approaches 0. The formulation of bias here reflects the intuition that a more risk-averse individual can be expected to experience a higher mental cost from holding an optimistic view despite the presence of the objectively estimated risk.

[6] Despite weather being the common factor behind individual and area outcomes, these outcomes are positively yet imperfectly correlated and farmers may assign more weight than is warranted to their farm management efforts in influencing the outcome in their own farm. This is in line with Bracha and Brown's (2012) observation on the possibility of illusion of control under uncertainty and a greater potential for optimism bias in the context of one's own competence, as mentioned earlier.

of the individual and area losses.[7] Furthermore, in line with the political process described in U.S. Government Accountability Office (1989), we assume that a disaster declaration is necessary if government is to make *ex post* disaster payments and an area loss is necessary for government to declare a disaster. The farmer's assessment of the probability that a disaster will be declared—conditional on area loss—also remains accurate (e.g., its perceived level, $q_{D|L}$, equals its true level, $p_{D|L}$). The true level is assumed to be less than 1 based on the observation that disaster aid is subject to some degree of political uncertainty.[8]

We now introduce the elements of the government's objective function in a simple setup, in which an insurance option is not initially considered. In line with Innes (2003), we consider the simplest possible political process that can generate *ex post* disaster aid: The government is benevolent and cares about farmers' losses of income, yet the government incurs a political cost if it provides monetary support to farmers.[9] For a farmer who incurred a loss, the government's preferences can be written as

$$G(\tau;r) = B + V\left(w(\tau;r)\right) - C(\tau), \tag{3}$$

where $G(.)$ represents the government's net welfare, r indicates the event of loss and is defined as the ratio of the farmer's loss to the farmer's potential income (e.g., $r = l/M$), and $\tau \geq 0$ indicates a transfer such as disaster aid ($\tau < 0$ would indicate a tax and is ruled out here). In the objective function, B represents the government's utility in status quo from other segments in the economy, $V(.)$ represents the value that government receives from changes in the farmer's financial well-being (denoted with w depending on r and τ), and $C(.)$ is the political cost of providing $\tau > 0$ to an individual farmer.[10]

On the valuation side, $V(.)$ is specified as $V(.) = \psi\Lambda(w)$, where the parameter ψ represents the government's sensitivity to changes in the farmer's financial well-being and the function $\Lambda(.)$ indexes the changes in the farmer's financial well-being. A simple way to think about ψ is as some monetary value per farm (for example, the per farm net value added in the economy). Meanwhile, the function Λ has some properties that mimic the government's behavior in light of historical experience (see footnote 9). In the event of catastrophic losses in the farm economy, there is political urge to step in and provide financial assistance to farmers, yet these efforts are subject to diminishing marginal political pressure as farmers' financial well-being improves. In particular, Λ is increasing

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[7] As in Bulut, Collins, and Zacharias (2012), the actual joint distribution of the individual and the area losses is as follows: both individual and area see a loss with probability p_{lL}, individual sees a loss but area does not with probability p_{lN} ("basis risk"), individual does not see a loss but area does with probability p_{nL}, and neither individual nor area sees a loss with probability p_{nN}. In the perceived joint distribution, q_{lL} replaces p_{lL}, q_{lN} replaces p_{lN}, q_{nL} replaces p_{nL}, and q_{nN} replaces p_{nN} with the following formulations: $q_{lL} = q_l q_L + \varphi z_l z_L$; $q_{lN} = q_l(1-q_L) - \varphi z_l z_L$; $q_{nL} = (1-q_l)q_L - \varphi z_l z_L$; and $q_{nN} = (1-q_l)(1-q_L) + \varphi z_l z_L$, where z_l and z_L are the standard deviations and equal $z_l = \sqrt{q_l(1-q_l)}$ and $z_L = \sqrt{q_L(1-q_L)}$, respectively, and $\varphi z_l z_L$ is the covariance term. Note that the value of φ must be such that the respective probabilities are all non-negative. In particular, $q_{lN} > 0$ and $q_{nL} > 0$ hold, which in turn implies that $\varphi < \overline{\varphi} = \min\left\{\upsilon, \upsilon^{-1}\right\} \leq 1$, where υ is the short-hand notation for $\frac{\sqrt{q_l/(1-q_l)}}{\sqrt{q_L/(1-q_L)}}$. It is possible to verify that $q_l = q_{lL} + q_{lN}$ and $q_L = q_{lL} + q_{nL}$ hold. Parallel assumptions and formulations hold for the actual joint probabilities: simply replace q_l, q_L, and φ with p_l, p_L, and ρ; and use s_l and s_L instead of z_l and z_L, respectively. Notice that $z_L = s_L$ holds per se, as q_L equals p_L as mentioned. Similarly, φ equals ρ subject to the earlier non-negativity condition.

[8] The model treats disaster declaration probability as an exogenously given parameter, which may reflect common expectations based on historical experience. Goodwin and Vado (2007, p. 401) state, "In light of the consistency of agricultural disaster payments in U.S. agriculture, it is likely that farmers condition their production decisions based on an estimate of the probability that payments will be forthcoming in the event of poor production or market conditions."

[9] Government's interest in farmers' income losses has been revealed through the provision of persistent disaster assistance over time. In fiscal years 1989–2012—with the exception of 1991 and 2011—farmers received \$70.1 billion in total through various disaster assistance programs (Chite, 2012, p. 12; see also U.S. Government Accountability Office, 1989). Government's objective function can be viewed as originating from policy-makers' exogenous set of preferences or as a reduced form of a political equilibrium in which interest groups compete for influence through lobbying (see Innes, 2003, p. 321, footnote 9, and the references cited therein; see also Rausser and Goodhue, 2002, p. 2,081).

[10] The farmer's resulting income level is $M - l + \tau$, while the farmer's potential income is M. The percentage change then can be calculated as $w = -r + \frac{\tau}{M}$.

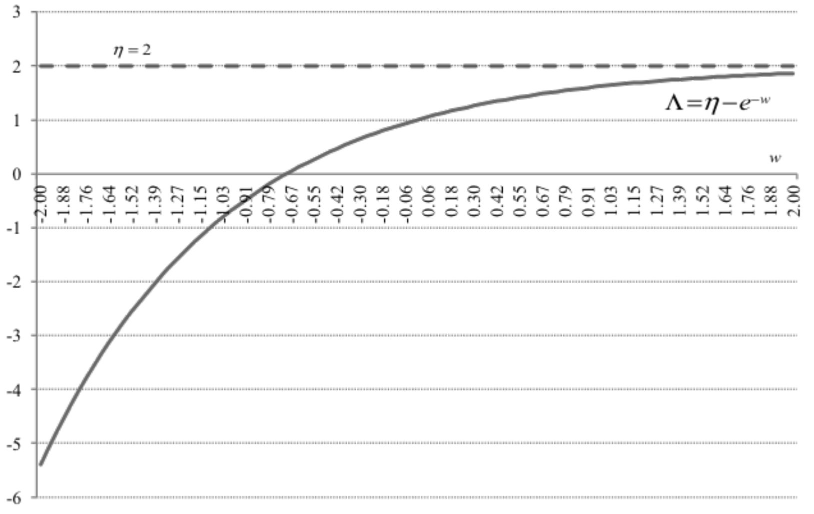

Figure 1a. Component of the Government's Objective Function That Indexes the Changes in Farmer's Financial Well-Being

Notes: The x-axis displays the percentage change in a farmer's financial well-being (w), while the y-axis displays the value of the indexing function ($\Lambda = \eta - e^{w}$ where $\eta = 2$). Notice that when $\Lambda = 1$ holds there is no change in a farmer's financial well-being ($w = 0$).

and concave in w. When there is no change in farmer's financial well-being ($w = 0$), $\Lambda = 1$ holds and so $\psi\Lambda$ becomes ψ. As w increases indefinitely, Λ approximates to a finite value above 1, denoted here by η, and so $\psi\Lambda$ goes to $\psi\eta$; as w decreases indefinitely, Λ and $\psi\Lambda$ approximate negative infinity. To obtain an explicit formulation for the government's disaster aid, we further specify Λ as $\Lambda = (\eta - e^{-w})$, where $\eta = 2$ holds. The preceding formulation is a simplified version of the expo-power function in Saha (1993, p. 906) and facilitates the aforementioned properties (figure 1a).

On the cost side, $C(.)$ is specified as $C(\tau) = K + k\tau$, where K represents the fixed political cost of providing funds $\tau > 0$, k is the marginal political cost, and $k\tau$ is the variable political cost incurred in extending that level of support. Fixed political cost arises because time must be spent in gathering support, deliberating, crafting legislative language, legislative maneuvering, and passing the bill. A sufficiently high fixed cost will ensure that the government does not provide any *ex post* disaster aid to a single farm when the neighboring farms are faring well. The marginal political cost, k, is defined as the political value (opportunity cost) of the government dollar that could be directed to another constituency.

Theoretical Analysis of the Government's Optimal Policy

We further consider a strategic interaction between the government and the farmer that consists of three stages (figure 1b). In stage 1, the government announces the *ex ante* insurance subsidy rate. In stage 2, the farmer makes an insurance coverage choice decision by taking the subsidy rate as given and anticipating the *ex post* disaster aid, which is contingent upon disaster declaration and consistent with the subsidy rate and the farmer's insurance coverage choice. In stage 3, random events unfold and payments are made according to the announced schedules. In this setup, the government is the natural Stackelberg leader and the farmer is the follower. Specifically, the government solves the problem of setting the subsidy rate by determining how the farmer will respond in stage 2 and the consequence of the farmer's response regarding possible *ex post* disaster aid and then using this

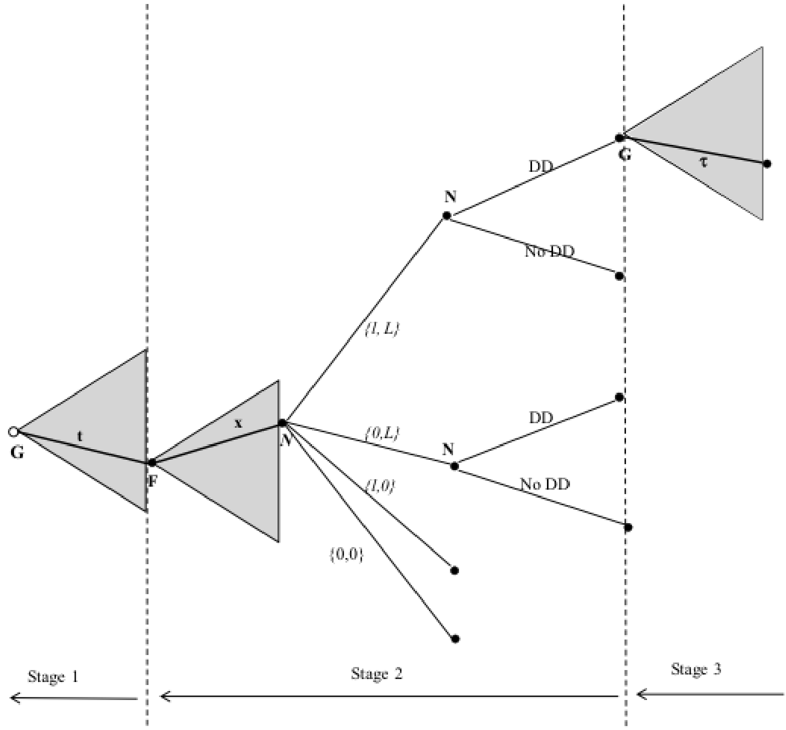

Figure 1b. Game Tree Representing Strategic Interaction between Government and a Farmer

Notes: "G" denotes "Government," "F" denotes "Farmer," "N" denotes "Nature," t indicates the premium subsidy rate being offered, x indicates the insurance coverage demand, and τ indicates the disaster assistance amount. Furthermore, $\{0,0\}$, $\{l,0\}$, $\{0,L\}$, and $\{l,L\}$ indicate respective loss events for the individual and the area and "DD" indicates a "Disaster Declaration" event. At each end node of the game tree, the government and the farmer realize some payoffs, which are not shown here (see text). Finally, the vertical dashed lines are used to indicate the three stages in the game. The horizontal arrows indicate that the model is solved backwards from Stage 3 to Stage 1.

response information to formulate its optimal stage 1 policy. The model is solved from stage 3 to stage 1 as follows.[11]

Stage 3

This is the *ex post* situation in which a farmer holds a positive level of insurance coverage $x \in (0,1]$ and the premium amount, πx, is initially subsidized at the rate of t, where π is the premium rate. In the event of loss, by taking insurance coverage x into account, the government's objective function in equation (3) can be rewritten as

$$G(\tau; r, x, t) = B + \psi(\eta - e^{-w(\tau,r,x,t)}) - K - k\tau, \tag{4}$$

where w is the percentage change in the farmer's well-being with positive insurance coverage and positive disaster aid.[12] From the maximization of the government's objective function (the first-order condition is necessary and sufficient), the *ex post* disaster aid is obtained as an affine function of coverage level $\check{\tau}_{xt} = l\omega + l\alpha x$, where $\omega = 1 - \ln(kM/\psi)/r$ indicates the fraction of the farmer's loss that would be paid through disaster aid in the absence of insurance, $\ln(.)$ denotes natural logarithm operator, and $\alpha = \frac{(1-t)\pi}{l} - 1$ represents the portion of loss (including the farmer paid premium) already covered by per unit of insurance coverage. Now, $\omega \in (0,1)$ holds depending on

[11] The game tree is structured similarly when the farmer holds an optimistically biased or accurate perception. The effect of biased perception shows up in stage 2 when the farmer makes insurance coverage choices.

[12] The farmer's resulting income level is $M - (1-t)\pi x - l(1-x) + \tau$, while the farmer's potential income is M. The percentage change then can be calculated as $w = -(1-t)\pi x/M - r(1-x) + \tau/M$.

the marginal political cost—given that the fixed cost is not too high. Note that ω is increasing in ψ and r; that is, a bigger disaster aid would be provided if the government attributed a higher value to the farmer's financial well-being or the farmer faced a bigger loss prospect relative to potential income. With the presence of insurance coverage, the loss event requires less disaster aid than the farmer would otherwise need. Furthermore, with a higher subsidy rate, the farmer pays less out-of-pocket insurance premium; the farmer's resulting loss is lower, again requiring less disaster aid. Accordingly, once evaluated at the actuarially fair rates, $\pi^f = p_l l$, $\alpha < 0$ and $|\alpha| < 1$ hold whenever the farmer pays some premium; that is, $t \in [0, 1)$.

The government extends some disaster aid whenever doing so would provide at least as much net welfare as not extending any amount in equation (4), which also requires accounting for the fixed cost. For an appropriate political cost environment,[13] we can state the following (Online Supplement C).[14]

LEMMA 1. *Assume that premium rates are actuarially fair; that is, $\pi = p_l l$. For a political cost environment $0 < K < \overline{K}$ and $k \in [\underline{k}_{x=1}, \bar{k}_K]$, there exists a coverage level x_* such that for all coverage levels beyond x_*, government's best response is not to extend any ex post disaster aid. Moreover, due to the presence of fixed cost, x_* remains lower than an upper bound $\bar{x}_*$, which in turn can be lower than the full insurance; that is, $x_* < \bar{x}_* \leq 1$ hold. Furthermore, $\bar{x}_*$ can be obtained as $\omega/(1 - (1 - t)p_l)$, where ω is as defined earlier. Finally, the following comparative static results hold: (i) x_* is decreasing in both k and K; (ii) x_* is decreasing in t; (iii) $\bar{x}_*$ is decreasing in k; and (iv) $\bar{x}_*$ is decreasing in t.*

In light of Lemma 1, the optimal *ex post* disaster aid in the presence of some insurance coverage with subsidy rate t is

$$\hat{\tau}_{xt} = \begin{cases} l\omega + l\alpha x > 0 & \text{if } k \in [\underline{k}_{x=1}, \bar{k}_K] \text{ and } x \leq x_* \\ 0 & \text{else if } k > \bar{k}_K \text{ or } x > x_*. \end{cases} \tag{5}$$

Stage 2

If the farmer anticipates receiving $\hat{\tau}_{xt} > 0$ from equation (5) in the event of loss, the expected loss with insurance coverage x can be written as $E(\tilde{l}^1_{x\hat{\tau}_{xt}}) = q_l l(1 - x) - q_{lL} q_{D|L} \hat{\tau}_{xt}$ and the variance of the farmer's loss is $\sigma^2_{\tilde{l}^1_{x,\hat{\tau}_{xt}}} = \sigma^2_{\tilde{l}^1_{\hat{\tau}}} - 2\Delta_1 x + x^2 \Delta_3$, where $\sigma^2_{\tilde{l}^1_{\hat{\tau}}}$ is the variance of farmer's loss when disaster aid is the only option, and the remaining terms account for additional risk reduction through insurance coverage.[15] Denote the farmer's resulting utility with $U^1_{x,\hat{\tau}_{xt}>0}$. If instead the farmer anticipates receiving no disaster aid (that is, $\hat{\tau}_{xt} = 0$ from equation 5) in the event of loss, then the farmer's expected loss with coverage is $E(\tilde{l}^1_x) = q_l l(1 - x)$ and the farmer's variance of the loss with coverage is $\sigma^2_{\tilde{l}^1_x} = \sigma^2_{\tilde{l}^1} - (x^2 - 2x)\sigma^2_{\tilde{l}^1}$. In the latter, $\sigma^2_{\tilde{l}^1}$ is from equation (2), and $(x^2 - 2x)\sigma^2_{\tilde{l}^1}$ is the perceived risk reduction through holding insurance coverage. Denote the farmer's resulting

[13] We rule out the possibility of transfers when the farmer has no loss or the farmer-paid premium is the only loss by assuming a high enough marginal political cost (k). We obtain that level as $\underline{k}_{x=1} = \psi e^{p_l r}/M$. In line with $\underline{k}_{x=1}$, the maximum fixed cost that can be accommodated in providing some *ex post* disaster aid is $\overline{K} = \psi(e^r - e^{p_l r}(1 + r(1 - p_l)))$. Meanwhile, k can take high enough values such that, based on marginal analysis alone, the government does not extend any *ex post* disaster aid. We obtain that level as $\bar{k} = \psi e^r/M$. When a fixed cost is present such that $0 < K < \overline{K}$, the government stops extending any disaster assistance at a k lower than $\bar{k}$. We denote that level with $\bar{k}_K$ and obtain it numerically (Online Supplement A, Part 1).

[14] Online Supplements are available online at www.jareonline.org

[15] The terms are obtained as $\sigma^2_{\tilde{l}_{\hat{\tau}1}} = \sigma^2_{\tilde{l}1} - 2q_{lL} q_{D|L}(1 - q_l)\omega l^2 + q_{lL}(1 - q_{lL}) q^2_{D|L} \omega^2 l^2$, $\Delta_1 = \sigma^2_{\tilde{l}1} + (\alpha - \omega) l^2 q_{D|L} q_{lL}(1 - q_l) - \alpha\omega l^2 q^2_{D|L} q_{lL}(1 - q_{lL})$, and $\Delta_3 = \sigma^2_{\tilde{l}1} + 2\alpha l^2 q_{D|L} q_{lL}(1 - q_l) + \alpha^2 l^2 q^2_{D|L} q_{lL}(1 - q_{lL})$. Recall $\sigma^2_{\tilde{l}1}$—the variance of the farmer's loss when neither option is available—from equation (2). The formulations reflect the trade-off between disaster aid and insurance protection in generating risk reduction. In particular, $\sigma^2_{\tilde{l}_{\hat{\tau}1}} \geq \Delta_1 \geq \Delta_3 > 0$ holds (Online Supplement D).

utility with U_x^1. It is possible to obtain the farmer's utility with insurance and possible disaster aid as

$$(6)\qquad U^1_{x,\hat{\tau}_{xt}\geq 0} = \begin{cases} U^1_{x,\hat{\tau}_{xt}>0} = M - (1-t)\pi x - E(\tilde{l}^1_{x\hat{\tau}_{xt}>0}) - 0.5\lambda\sigma^2_{\tilde{l}^1_{x\hat{\tau}_{xt}>0}} & \text{for } x \leq x_* \\ U^1_x = M - (1-t)\pi x - E(\tilde{l}^1_x) - 0.5\lambda\sigma^2_{\tilde{l}^1_x} & \text{for } x > x_*. \end{cases}$$

For a given coverage level, both parts of equation (7) decrease as risk aversion increases, which is in line with the farmer's utility in equation (2). Maximizing $U^1_{x,\hat{\tau}_{xt}>0}$ and U^1_x, separately, with respect to coverage level x yields the expressions

$$(7)\qquad \begin{aligned} \breve{x}^1_{\hat{\tau}} &= \frac{\Delta_1}{\Delta_3} + \frac{-\pi(1-t)(1-q_{lL}q_{D|L}) + (q_l - q_{lL}q_{D|L})l}{\lambda\Delta_3} \\ \breve{x}^1 &= 1 + \frac{-\pi(1-t)+q_l l}{\lambda\sigma^2_{\tilde{l}^1}}, \end{aligned}$$

respectively, where Δ_1 and Δ_3 are the variance-related terms from earlier (footnote 15). Now, $\breve{x}^1_{\hat{\tau}}$ is the coverage demand when a positive disaster aid amount can be anticipated (Online Supplement D); hence, $\breve{x}^1_{\hat{\tau}} \leq x_*$ holds throughout, and $\breve{x}^1$ is the coverage demand when no disaster aid amount can be anticipated (Online Supplement B). Observe that $\breve{x}^1_{\hat{\tau}} < \breve{x}^1 \leq 1$ holds; that is, the presence of disaster aid further reduces the farmer's coverage demand, which is already below the full insurance level. The latter is due to the farmer's optimism bias and holds at a sufficiently low—0, in particular—premium subsidy rate. The intuition for the finding of demand reduction stems from the fact that the farmer takes into account that some portion of his or her risk is already covered through the presence of disaster aid. Even if the farmer expects no disaster aid, he or she, being overconfident, already perceives the risk to be over-priced.[16]

The farmer's problem is to choose between $\breve{x}^1_{\hat{\tau}}$ and $\breve{x}^1$ in order to maximize the utility function in equation (7). To that end, evaluate $U^1_{x,\hat{\tau}_{xt}>0}$ at $\breve{x}^1_{\hat{\tau}}$ and U^1_x at $\breve{x}^1$ and denote the resulting values with $U^1_{x,\hat{\tau}_{xt}>0}(\breve{x}^1_{\hat{\tau}})$ and $U^1_x(\breve{x}^1)$, respectively. The argument of the higher of $U^1_{x,\hat{\tau}_{xt}>0}(\breve{x}^1_{\hat{\tau}})$ and $U^1_x(\breve{x}^1)$ will be the farmer's optimum solution. In the event that the preceding utility values are equal, the farmer will choose $\breve{x}^1_{\hat{\tau}}$ without loss of generality.

To characterize the farmer' best response (coverage level demand) in terms of risk aversion, we define some threshold levels: λ^1_*, λ^1_{**}, and $\underline{\lambda}^1$. First, recall from Lemma 1 that x_* does not depend on the farmer's risk aversion. Second, note that $\breve{x}^1$ is monotonically increasing in risk aversion whenever $\breve{x}^1$ remains less than full insurance (Online Supplement B). Finally, assume that the coverage demand $\breve{x}^1_{\hat{\tau}}$ is also monotonically increasing in risk aversion λ whenever $\breve{x}^1_{\hat{\tau}}$ remains less than x_*. There then exists a unique risk-aversion level such that $\breve{x}^1_{\hat{\tau}} = x_*$ holds, which then defines λ^1_*. As discussed earlier, the farmer with λ^1_* evaluates demanding x_* and anticipating the consistent disaster aid $\hat{\tau}_{x_*t} > 0$ versus relying solely on insurance coverage $\breve{x}^1$. If x_* is chosen at λ^1_*, then λ^1_{**} is defined as the highest risk aversion such that x_* can be still chosen (see footnote 17). If, instead, $\breve{x}^1$ is chosen at λ^1_*, then $\underline{\lambda}^1$ is defined as the lowest risk aversion such that $\breve{x}^1$ can still be chosen, if any. We can then conclude the following.

LEMMA 2. *Suppose that premium rates are actuarially fair, $\pi = p_l l$, political environment is such that $0 < K < \overline{K}$, and $k \in [\underline{k}_{x=1}, \bar{k}_K]$ holds. Recall $\breve{x}^1_{\hat{\tau}}$ and $\breve{x}^1$ from equation (7). Assume further that $\breve{x}^1_{\hat{\tau}}$ is monotonically increasing in risk aversion λ whenever $\breve{x}^1_{\hat{\tau}} \in (0, x_*)$. Note that the upper bound of risk aversion $\overline{\lambda}$ is sufficiently high (see footnote 17), and λ^1_*, λ^1_{**}, and $\underline{\lambda}^1$ are as defined earlier. Now let $\hat{x}^1_{\hat{\tau}}$ denote the overconfident farmer's optimal demand for insurance coverage in response to the government's ex post disaster aid in equation (5). Then, for a given premium subsidy rate $t \in [0,1]$, $\hat{x}^1_{\hat{\tau}}$ can be obtained for each risk-aversion level as follows:*

[16] In the expression for $\breve{x}^1_{\hat{\tau}}$ in equation (7), actuarially fair price $\pi^f = p_l l$ remains higher than the fair price from the farmer's point of view $(q_l l - q_{lL}q_{D|L}l)$,while the subsidy reduces the gap between the two.

1. *If the farmer with λ_*^1 strictly prefers x_* over $\check{x}^1$, then farmers with risk aversion less than λ_*^1 choose $\check{x}_{\hat{\tau}}^1$. Farmers with risk aversion of at least λ_*^1 and less than or equal to λ_{**}^1 choose the same coverage x_*. Farmers with risk aversion above λ_{**}^1 choose $\check{x}^1$.*

2. *If the farmer with λ_*^1 is indifferent between x_* and $\check{x}^1$, then that farmer is the only one choosing x_*. For remaining farmers, the choices are similar to (i).*

3. *If, on the contrary, the farmer with λ_*^1 strictly prefers $\check{x}^1$ over x^*, then there are two possibilities: either only the farmers with risk aversion less than $\underline{\lambda}^1$ choose $\check{x}_{\hat{\tau}}^1$ and all other farmers choose $\check{x}^1$, or all farmers choose $\check{x}^1$.*

Recall from Lemma 1 that x_* decreases as the subsidy rate t increases. Meanwhile, as x_* decreases, the unique risk-aversion level λ_*^1 such that $\check{x}_{\hat{\tau}}^1 = x_*$ holds also decreases—which follows from the monotonicity of the insurance coverage demand. Now, the upper bound of risk aversion is sufficiently high so that the most risk-averse farmer—with an accurate perception of risk—prefers insurance-only option $\check{x}^1$ at zero subsidy rate.[17] Then, Lemma 2 points out that by increasing subsidy rate, the government induces a higher portion of the farmer population to be content with the insurance only option.

Stage 1

The government takes the farmer's coverage demand $(\hat{x}_{\hat{\tau}}^1)$ from Lemma 2 into account; nevertheless, it will continue to use its own assessment of the farmer's probability of loss in welfare calculations. From the government's point of view, the farmer's true expected loss under insurance plus disaster aid is $E(\tilde{l}^0_{\hat{x}_{\hat{\tau}}^1 \hat{\tau}_{xt}}) = p_l l(1 - \hat{x}_{\hat{\tau}}^1) - p_{lL} p_{D|L} \hat{\tau}_{x=\hat{x}_{\hat{\tau}}^1, t}$, where $\hat{\tau}_{x=\hat{x}_{\hat{\tau}}^1, t}$ is from equation (5) after taking $\hat{x}_{\hat{\tau}}^1$ and t into account and the variance of the farmer's loss is $\sigma^2_{\tilde{l}^0_{\hat{x}_{\hat{\tau}}^1 \hat{\tau}_{xt}}} = \sigma^2_{\tilde{l}^0_{\hat{\tau}}} - 2\Xi_1 \hat{x}_{\hat{\tau}}^1 + (\hat{x}_{\hat{\tau}}^1)^2 \Xi_3$ (see footnote 17 on the formulations of $\sigma^2_{\tilde{l}^0_{\hat{\tau}}}$, Ξ_1, and Ξ_3). The government then arrives at the farmer's true financial well-being under the insurance plus disaster aid option as

$$U^0_{\hat{x}_{\hat{\tau}}^1 \hat{\tau}_{xt}} = M - (1-t)\pi \hat{x}_{\hat{\tau}}^1 - E(\tilde{l}^0_{\hat{x}_{\hat{\tau}}^1 \hat{\tau}_{xt}}) - 0.5\lambda \sigma^2_{\tilde{l}^0_{\hat{x}_{\hat{\tau}}^1 \hat{\tau}_{xt}}}. \tag{8}$$

The government evaluates *ex ante* the percentage change in the farmer's financial well-being as $w^0(\hat{x}_{\hat{\tau}}^1, \hat{\tau}_{xt}) = \frac{U^0_{\hat{x}_{\hat{\tau}}^1, \hat{\tau}_{xt}}}{M} - 1$. In light of this measure, the government's *ex ante* objective is to maximize its expected net welfare by choosing a subsidy rate $t \in [0,1]$—the expectation is taken over the distribution of farmer types in terms of risk aversion. Now, given a political cost environment, if the subsidy rate is such that case (i) applies in Lemma 2, then the value of government's *ex ante*

[17] After setting $t = 0$ and solving $U^1_{x_* < 1, \hat{\tau}_{xt} > 0} < U^1_{\check{x}^1}$ from equation (7) for risk aversion $(\bar{\lambda})$ yields the condition $\bar{\lambda} > \frac{p_{lL} p_{D|L} l(\omega + (p_l - 1)x_*)}{\sigma^2_{\tilde{l}^0_{x\hat{\tau}_{xt}}}}$. In the preceding expression, $\sigma^2_{\tilde{l}^0_{x\hat{\tau}_{xt}}}$ is the variance of the farmer's loss and can be obtained $\sigma^2_{\tilde{l}^0_{\hat{x}_{\hat{\tau}}^1 \hat{\tau}_{xt}}} = \sigma^2_{\tilde{l}^0_{\hat{\tau}}} - 2\Xi_1 \hat{x}_{\hat{\tau}}^1 + (\hat{x}_{\hat{\tau}}^1)^2 \Xi_3$, where $\sigma^2_{\tilde{l}^0_{\hat{\tau}}}$, Ξ_1 and Ξ_3 are based on true probabilities with formulations parallel to $\sigma^2_{\tilde{l}^1_{\hat{\tau}}}$, Δ_1, and Δ_3 in the text, respectively (Online Supplement D; footnote 15). Incidentally, the preceding condition on $\bar{\lambda}$ ensures that λ_{**}^1 exists.

objective function becomes

$$
\begin{aligned}
(9)\qquad G(t;\tilde{r}^0) = {} & B + \int_{\underline{\lambda}}^{\lambda_*^1} \Big(\psi(\eta - e^{-w^0(\check{x}_{\hat{\tau}}^1(t),\hat{\tau}_{xt})}) - kt\pi\check{x}_{\hat{\tau}}^1(t) - p_{D|L}p_{lL}(K + k\hat{\tau}_{xt})\Big) f(\lambda)d\lambda \\
& + \int_{\lambda_*^1}^{\lambda_{**}^1} \Big(\psi(\eta - e^{-w^0(x_*(t),\hat{\tau}_{xt})}) - kt\pi x_*(t) - p_{D|L}p_{lL}(K + k\hat{\tau}_{xt})\Big) f(\lambda)d\lambda \\
& + \int_{\lambda_{**}^1}^{\bar{\lambda}} \Big(\psi(\eta - e^{-w(\check{x}^1,\tilde{r}^0)}) - kt\pi\check{x}^1(t)\Big) f(\lambda)d\lambda,
\end{aligned}
$$

where $\tilde{r}^0$ indicates the prospect of loss. For subsidy rates resulting in cases (ii) and (iii) in Lemma 2, which tend be observed for high subsidy rates, the objective function can be similarly written. In all three cases, the political cost environment such that $0 < K < \bar{K}$ and $k \in [\underline{k}_x, \bar{k}]$ hold and the premium rate is actuarially fair, $\pi^f = p_l l$. On the margin, the government calculation involves weighing the direct effect of increasing the subsidy on the farmer's well-being against the savings that can be found by replacing expected *ex post* disaster aid with higher insurance coverage through subsidy, while incurring some political cost for both.

Having worked through the three-stage maximization process above, we can conclude the following:

PROPOSITION 1. *Suppose that the government's problem in equation (9) is continuous and concave in subsidy rate. Let* $\hat{t}^1 \in [0,1]$ *be the optimal solution to the government's problem in equation (9). Now, the triple* $(\hat{t}^1, \hat{x}_{\hat{\tau}}^1, \hat{\tau}_{xt})$ *forms the unique Stackelberg equilibrium, where* $\hat{x}_{\hat{\tau}}^1$ *is from Lemma 2 and* $\hat{\tau}_{xt}$ *is from equation (5) and evaluated at* $(\hat{x}_{\hat{\tau}}^1, \hat{t}^1)$.

In other words, the government's choice of the subsidy rate, the farmer's coverage demand choice, and disaster aid schedule are the best responses to each other in every subgame of the game depicted in figure 1b.[18] For instance, $\hat{t}^1$ induces the subgame consisting of stages 2 and 3. In that subgame, given $\hat{t}^1$, $\hat{x}_{\hat{\tau}}^1$ and $\hat{\tau}_{xt}$ are the best responses to each other. Similarly, after the uncertainty is resolved, $(\hat{t}^1, \hat{x}_{\hat{\tau}}^1)$ induces the subgame consisting of stage 3 only. In that stage, $\hat{\tau}_{xt}$ is the government's best response to $(\hat{t}^1, \hat{x}_{\hat{\tau}}^1)$ from equation (5). The existence and uniqueness of the equilibrium subsidy rate $\hat{t}^1$ follows so long as the continuity and concavity properties of the government's objective function can be maintained. Because no analytical closed-form solution can be obtained, $\hat{t}^1$ needs to be solved numerically. Once $\hat{t}^1$ is found, the equilibrium insurance coverage levels $\hat{x}_{\hat{\tau}}^1$ for all risk-aversion levels can be calculated. Using $\hat{t}^1$ and $\hat{x}_{\hat{\tau}}^1$, $\hat{\tau}_{xt}$ can then be determined.

On the other hand, the government's *ex ante* calculation of its expected net welfare solely from the anticipated *ex post* disaster aid is

$$
(10)\qquad G(\hat{\tau},\tilde{r}^0) = B + \int_{\underline{\lambda}}^{\bar{\lambda}} \psi(\eta - e^{-w(\hat{\tau},\tilde{r}^0)}) f(\lambda)d\lambda - p_{lL}p_{D|L}(K + k\hat{\tau}).
$$

Now, $\hat{\tau} = l\omega \geq 0$ is the optimal *ex post* disaster aid when insurance is not considered (obtained from equation 5 by setting $x = 0$ and $t = 0$). The variable $w_{\hat{\tau}}^0$ is the expected percentage change

[18] This result is consistent with Zermelo's theorem (see Propositions 9.B.1 and 9.B.2 in Mas-Colell, Whinston, and Green, 1995, p. 272, p. 276, respectively), as the game has two players and finite number of stages and is of perfect information (in the sense that each player knows the action previously taken by the other player at each stage.) The concavity of the government's objective function ensures the uniqueness of the equilibrium subsidy rate.

in the farmer's financial well-being in that case and equals $w^0_{\hat{\tau}} = \frac{U^0_{\hat{\tau}}}{M} - 1$, where $U^0_{\hat{\tau}}$ is the farmer's utility when disaster aid is the only option (obtained from equation 8 by setting $x = 0$ and $t = 0$; see also Online Supplement A, Part 2). Finally, $p_{lL}p_{D|L}(K + k\hat{\tau})$ is the expected cost of extending *ex post* disaster aid $\hat{\tau} > 0$. Note that the government's objective function in equation (10) remains the same whether farmers are accurate or optimistically biased about their risk because ω does not depend on the farmer's risk perception from earlier. In addition, government uses the objective (true) probabilities in its welfare calculation regardless of the farmer's perceptions.

Simulation Analysis of the Government's Optimal Policy

Numerical analysis is used to investigate the properties of the equilibrium in Proposition 1 to gain insight into the government choices between two options in providing financial support to a farmer at times of distress. The first option is having the farmer primarily covered through insurance *ex ante* and allowing for some amount of ad hoc disaster aid, if needed. The second option is to rely solely on ad hoc disaster aid, which happens after the farmer's loss; thus, it is an *ex post* instrument. To that end, the parameter values in the base case are chosen as follows.

The farmer's risk preferences are assumed to be distributed uniformly (using the probability density function $f(\lambda) = 1/(\bar{\lambda} - \underline{\lambda})$ for $\underline{\lambda} \leq \lambda \leq \bar{\lambda}$). The expectation operations in equations (9) and (10) are taken with respect to that distribution. The base case values for the parameters $\underline{\lambda}$ and $\bar{\lambda}$ are chosen in a manner consistent with Babcock, Choi, and Feinerman (1993).[19] The farmer's potential income is $M = \$58,845$. For the net value added to the U.S. economy, per farmer, $\psi = \$83,909$ holds.[20] Normalized value of the government's utility in status quo (perhaps from non-food related sectors) is $B = 0$. As mentioned before, the parameter η in the government's valuation function is set at $\eta = 2$. Probability of the farmer's loss is $p_l = 0.15$. In addition, given the level for M, a loss prospect amount is considered so that $r = 0.25$ holds.[21] As a function of the preceding loss prospect, the upper bound for per farm fixed cost is $\bar{K} = \$2,114$. Recall that a higher loss prospect amount (which determines r for a given level of potential income) would allow a higher amount of fixed costs. In the base case, the amount of fixed cost is set at one-quarter of $\bar{K}$; hence, $K = \$528$. Marginal political cost k varies between $\underline{k}_{x=1} = 1.4804$ and $\bar{k} = 1.8309$ (footnote 13).

Furthermore, the degree of systemic risk is measured by the primitive parameter $\rho_{\tilde{y}_i\tilde{y}_j}$ from earlier, which is set at $\rho_{\tilde{y}_i\tilde{y}_j} = 0.627$. Assuming farm yields are normally distributed,[22] the values for p_l and $\rho_{\tilde{y}_i\tilde{y}_j}$ determine a value for p_L, which is $p_L = 0.0953$. Note that $p_L < p_l$ holds due to the aggregation involved in arriving at p_L, and the value of p_L would approach that of p_l if the value of $\rho_{\tilde{y}_i\tilde{y}_j}$ increased toward 1. The value of correlation between the farmer's and area losses is determined as $\rho = 0.5$—consistent with the values of p_l and p_L and the joint distribution of the farmer and area losses. Note that the value of ρ, given the value of p_l, is found to be monotonically increasing function of $\rho_{\tilde{y}_i\tilde{y}_j}$. As such, the systemic risk effect henceforth is

[19] To index risk aversion, function $h(\lambda)$ is defined as the ratio of risk premium (the variance component of the farmer's utility function $0.5\lambda p_l(1 - p_l)l^2$) from equation (1) to the size of the loss (l), and $h^{-1}(.)$ is used to denote the inverse function. Note that $\underline{\lambda}$ is set to $\underline{\lambda} = 0.000001123$ so that $h(\underline{\lambda}) = 1/1000$, or $h^{-1}(1/1000) = \underline{\lambda}$ holds. Similarly, $\bar{\lambda}$ is set to $\bar{\lambda} = 0.000106621$ so that $h(\bar{\lambda}) = 1/10$, or $h^{-1}(1/10) = \bar{\lambda}$ holds.

[20] Farmer's potential income is based on farm household income in 2013 (\$/farm household). Net value added in actual 2012 dollars was forecasted at \$184.6 billion (U.S. Department of Agriculture, Economic Research Service, 2013), while the number of farms in 2012 was 2.2 million (U.S. Department of Agriculture, National Agricultural Statistics Service, 2013). Per farm value added then would be \$83,909.

[21] To provide some perspective, the highest value of countrywide loss costs (indemnities divided by liabilities) in the Federal Crop Insurance program over 1980–2012 is 0.152.

[22] As mentioned earlier, there is a threshold level of yield below which catastrophic loss happens with respect to mean yield. Only catastrophic loss is of interest here; hence, either catastrophic loss happens or it does not. Because the model ignores the rest, the word "loss" implicitly refers to catastrophic one (in line with Duncan and Myers, 2000, p. 844). The amount of loss prospect that a farm faces can be viewed as *Conditional Value at Risk (CVaR)*. As Hull (2009, pp. 451–453) puts it, *CvaR* answers the question of "if things do get bad, how much an individual can expect to lose?" or the "expected shortfall."

represented by the correlation coefficient pertaining to losses, ρ; any change in ρ should be understood as originating from a change in $\rho_{\tilde{y}_i\tilde{y}_j}$. Moreover, the conditional probability of disaster declaration under accurate perception is $p_{D/L} = 0.455$, half of an upper bound considered for this parameter (Online Supplement A, Part 2). Finally, the upper limit on the overconfidence (denoted with θ as in footnote 5) is restricted to 50% (e.g., $\theta = 0.5$). In line with the distribution of λ given earlier, the error in a farmer's perception is distributed uniformly between 0 and θ (see the formulation in footnote 5). Given that $\theta = 0.5$, the average error in that case would be $\theta/2 = 0.25$.

The preceding government's net welfare functions in equations (9) and (10) are simulated using the base case parameter values.[23] (Note that setting $\theta = 0$ in equation 9 would yield the government's objective function under farmers' no overconfidence case.) A sensitivity analysis with respect to key parameter values r, p_l, ρ, $p_{D|L}$, K, $\bar{\lambda}$, and θ is also done by assigning higher and lower values to them than those considered in the base case, which resulted in fourteen additional scenarios. (The details of the sensitivity analysis are available upon request.) The following highlights the main findings of the simulation analysis.

When farmers are not overconfident and yet hold disaster aid expectations and no premium subsidies are provided under actuarially fair premium rates, the aggregate insurance coverage demand can be reduced by more than 45% (compared to the full insurance benchmark in which aggregate insurance coverage demand equals 1; figure 2c). Given the anticipated fall out in demand, subsidy is used to induce farmers to participate or buy higher insurance coverage. In the base case, focusing on the lower end of the marginal political cost range, the equilibrium subsidy rate of nearly 17% is found (figure 2b), which is approximately equal to the implicit coverage of *ex post* disaster aid.[24] By offering such a subsidy rate, government is ensuring farmers' full participation (figure 2c). Nevertheless, the resulting subsidy rate is even less than a third of the current average subsidy rate in the crop insurance program.[25] The reason for a rather modest value is the medium level of parameters that determine the systemic risk in the base case. When a high degree of systemic risk is considered, the subsidy rate at the lower end of marginal political cost is found to be nearly 73%. In fact, the equilibrium subsidy rate is obtained as a convex function of the degree of systemic risk (figure 3a). Apart from the effects of systemic risk, the subsidy rates appear to be fairly robust in other scenarios (may change within a few basis points, if any).

On the other hand, when farmers are overconfident and, on top of that, hold disaster aid expectations and no premium subsidies are provided under actuarially fair premium rates, the decline in aggregate demand from full insurance level is even larger, exceeding 75% (again compared to the full insurance benchmark; figure 2c). (A higher value for the upper bound of the risk-aversion parameter would somewhat ameliorate the demand.) Accordingly, the subsidy rates to induce farmers are found to be markedly higher than those when farmers are not overconfident. In particular, focusing on the lower end of marginal political cost range, the equilibrium subsidy rate

[23] The procedure used to find the maximum of the government's net welfare function in equation (9) is a grid search with five main steps. In step 1, two sets of parameter values are obtained: (i) 5,000 values for the marginal political cost and (ii) 5,000 values for the subsidy rate between 0 and 1. In step 2, the critical level of insurance coverage level (x_*) from Lemma 1 is computed for a given marginal political cost and a subsidy rate. In step 3, in line with the bounds specified in footnote 19, 3,000 values for risk-aversion levels are sampled by generating an equidistributed sequence (the Neiderreiter sequence, in particular) as described in Miranda and Fackler (2002, pp. 92–94). In step 4, for a given marginal political cost and a subsidy rate, the expected value of the government's net welfare function—which incorporates the resulting value of x_*—is computed as the sample mean based on the prior draws for risk-aversion levels (Quasi-Monte Carlo integration). In step 5, the subsidy rate that yields the maximum value of government's net welfare is selected over all the values for subsidy rates for each marginal political cost level. The underlying programs are written using MATLAB software.

[24] Denoting the implicit coverage of *ex post* disaster aid under farmers' accurate perceptions with y^0, it is possible to obtain $y^0 = p_{lL}p_{D|L}\omega/p_l$ and verify that $y^0 < 1$; that is, the disaster assistance implicitly covers only a portion of farmer's risk (Online Supplement A, Part 2). The same conclusion holds when farmers are optimistically biased. In that case, the implicit coverage of *ex post* disaster aid is denoted with y^1. Similarly, it is possible to obtain $y^1 = q_{lL}q_{D|L}\omega/q_l$ and verify that $y^1 < 1$ holds (Online Supplement A, Part 3).

[25] The average subsidy rate in the crop insurance program, based on 2013 total premium and total subsidy amount, is calculated as 61.8%.

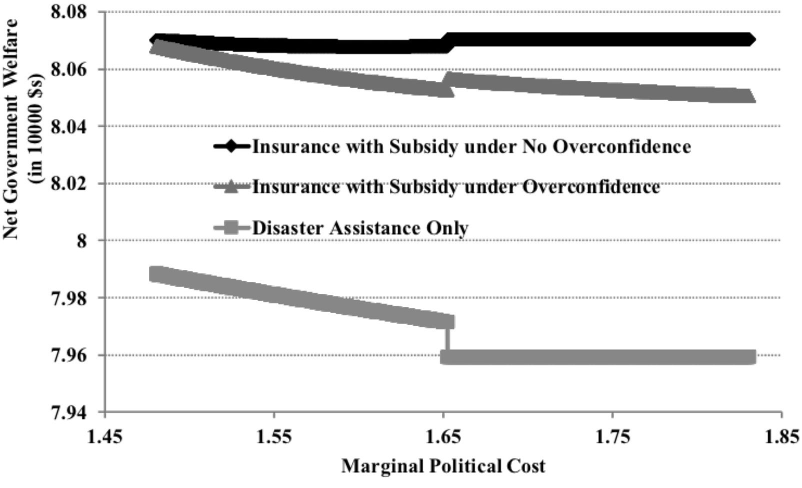

Figure 2a. Government's Net Welfare Levels

Notes: The x-axis displays marginal political cost (k), while the y-axis displays the government's net welfare levels. The levels under insurance are the top and middle graphs with diamond- and triangular-shaped data markers (when farmers are not overconfident and overconfident, respectively) and the level under disaster assistance option is the bottom graph with square-shaped data markers. The y-axis is in $10,000s and can be put into context by recalling that the parameter ψ, per farm monetary value, in the government's objective function takes the value of $83,309. The base case parameter values apply. In particular, $\theta = 0$ and $\theta = 0.5$ hold, when farmers are not overconfident and overconfident, respectively.

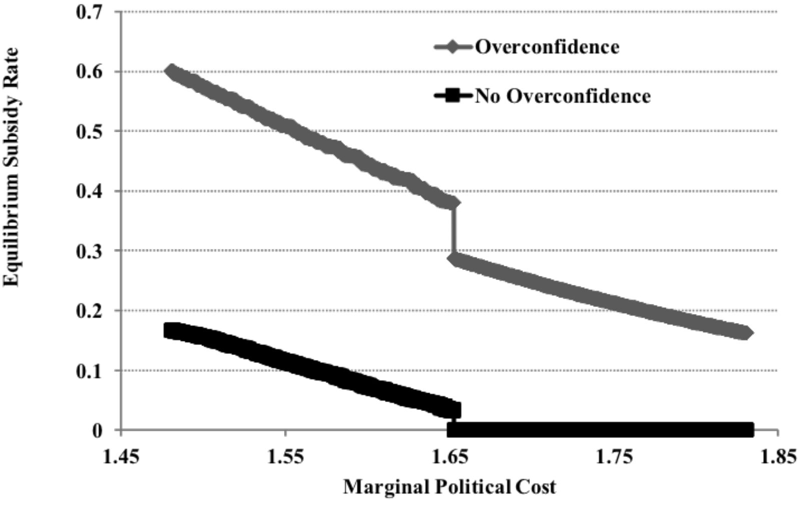

Figure 2b. Equilibrium Premium Subsidy Rates

Notes: The x-axis displays marginal political cost (k), while the y-axis displays the equilibrium subsidy rates when farmers are overconfident and not overconfident (the top and bottom graphs with diamond- and square-shaped data markers, respectively). The base case parameter values apply. In particular, the maximum overconfidence parameter takes the value of $\theta = 0$ when farmers are not overconfident and $\theta = 0.5$ when they are overconfident.

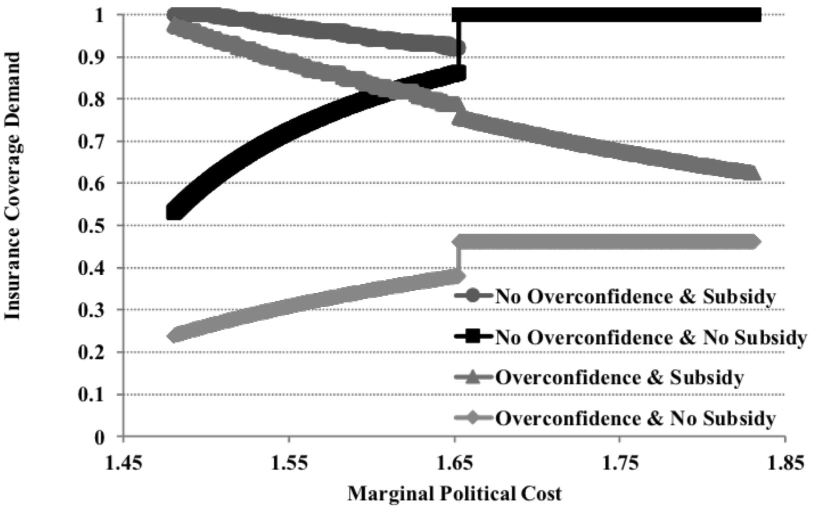

Figure 2c. Aggregate Insurance Coverage Demands

Notes: The x-axis displays marginal political cost (k), while the y-axis displays aggregate insurance coverage demands. When farmers are not overconfident, depending on whether a subsidy provided or not, the demands are the graphs with circle- and square-shaped data markers, respectively. Similarly, when farmers are overconfident, depending on whether a subsidy provided or not, the demands are the graphs with triangular- and diamond-shaped data markers, and respectively. The base case parameter values apply. In particular, $\theta = 0$ and $\theta = 0.5$ hold, when farmers are not overconfident and overconfident, respectively.

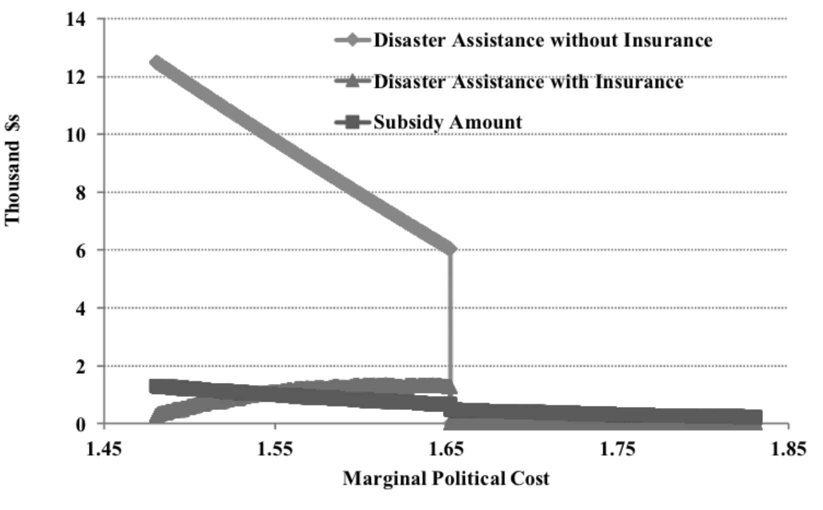

Figure 2d. *Ex Post* Disaster Aid Amounts with and without Insurance versus *Ex Ante* Subsidy Amount under Insurance Option

Notes: The x-axis displays marginal political cost (k), while the y-axis displays *ex post* disaster aid amounts in case of a loss with and without insurance (the graphs with triangular- and diamond-shaped data markers, and respectively) and the *ex ante* subsidy amount under insurance option (the graph with square-shaped data markers). Note that the y-axis is in \$1,000s and can be put it into context by recalling that, the amount of farmer's loss prospect, l, is \$14,711. The base case parameter values apply. In particular, the maximum overconfidence parameter takes the value of $\theta = 0.5$. A separate figure for the case when farmers are not overconfident, $\theta = 0$, is available upon request.

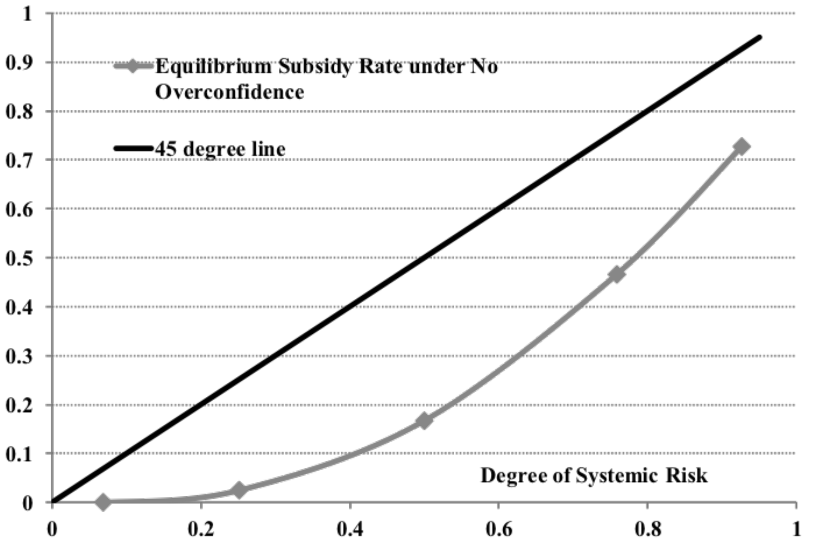

Figure 3a. Effect of Degree of Systemic Risk on Equilibrium Premium Subsidy Rate

Notes: The x-axis displays the degree of systemic risk, while the y-axis displays the equilibrium subsidy rate (the graph with diamond-shaped data markers) along with the 45-degree line (the solid line). The degree of systemic risk is measured by the correlation coefficient (ρ). Furthermore, $p_{D|L}$ is indexed to ρ as $p_{D|L} = \rho \bar{p}_{D|L}$ in this particular scenario, where $\bar{p}_{D|L}$ is an upper bound for $p_{D|L}$ (Online Supplement A, Part 2). The marginal political cost is at its minimum $\underline{k}_{x=1} = 1.48$ and the remaining parameters maintain their values at the base case. Finally, farmers are not overconfident; hence, $\theta = 0$ holds.

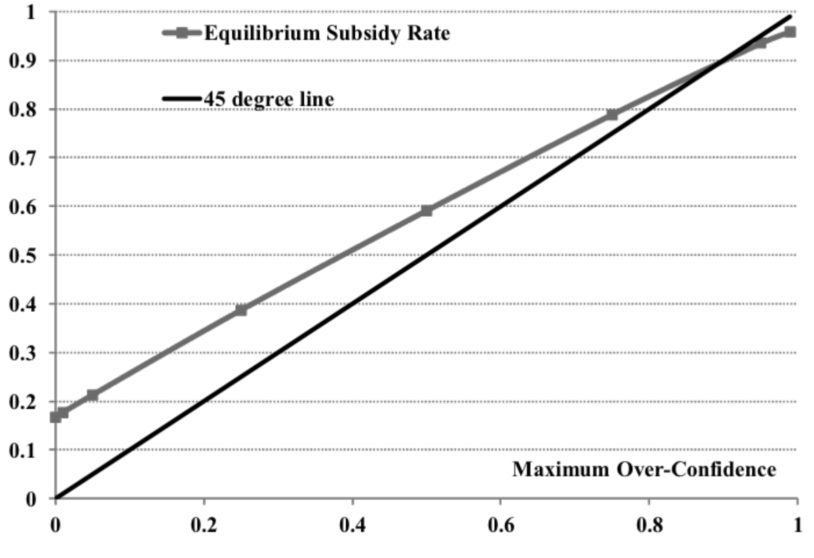

Figure 3b. Effect of Maximum Overconfidence Parameter on Equilibrium Subsidy Rate

Notes: The x-axis displays the maximum overconfidence parameter (θ), while the y-axis displays the equilibrium premium subsidy rate (the graph with square-shaped data markers) along with the 45-degree line (solid line). When $\theta = 0$, the equilibrium premium subsidy rate corresponds to the intercept value and is obtained when farmers are not overconfident. When $\theta > 0$, the equilibrium premium subsidy rate is obtained when farmers are overconfident. The marginal political cost is at its minimum $\underline{k}_{x=1} = 1.48$ and the other parameters maintain their values at the base case.

increases to nearly 60% in the base case (figure 2b), which is in line with the current average subsidy rate in the crop insurance program (footnote 25). The upper end value of overconfidence parameter and the resulting error in farmers' perceptions are also critical. In fact, the equilibrium subsidy rate is obtained as an increasing yet concave function of the maximum value of overconfidence parameter θ (figure 3b).

Summary and Conclusions

We have developed a political economy model for government's support of agriculture within a game theoretic (Stackelberg) equilibrium framework: government cares about farmers' loss of income as well as its political cost and acts as the Stackelberg leader, while farmers act as followers (figure 1b). We have used this model to examine government's preference for crop insurance support in the form of subsidies versus ad hoc disaster aid, where both are subject to a political cost, while farmers may have a form of overconfidence (optimism bias).

By solving and simulating the Stackelberg equilibrium of the model (Proposition 1) for a set of parameter values in the base case and fourteen additional scenarios, we show that expected utility-maximizing, risk-averse farmers can underinsure (relative to full insurance) while facing actuarially fair premiums. In the absence of subsidies, the fallout in the aggregate demand can be as large as 45%–75%, depending on whether farmers are overconfident, in the base case (figure 2c) and can reach up to 100% in certain scenarios in which high levels of systemic risk are considered. The reason for underinsurance is that both disaster aid expectations and overconfidence drive a wedge between the actuarially estimated price and the price that is "fair" from farmers' point of view (footnote 16).[26] We thus shed some light on farmers' reluctance to pay actuarially fair premiums. As a corollary, we show that crop insurance demands vary with the values of political cost parameters (equation 7; figure 2c). These observations may have implications for econometric studies of the price elasticity of crop insurance demand.

With that anticipation of farmers' best responses, we show that government actually prefers to subsidize agricultural insurance rather than solely rely on *ex post* disaster aid (figure 2a).[27] In subsidizing the insurance option, government takes four main factors into account: (i) the political environment; (ii) the degree of systemic risk; (iii) the distribution of risk preferences among farmers; and (iv) the nature and distribution of farmers' risk perceptions. In particular, the equilibrium subsidy rate is obtained as a decreasing and affine function of marginal political cost (figure 2b), increasing and convex function of the degree of systemic risk (figure 3a), and increasing and concave function of the overconfidence parameter (figure 3b). The average premium subsidy rate as currently seen in the crop insurance program (footnote 25) can be obtained in the base case (with medium levels of systemic risk and farmers' overconfidence) as well as in other scenarios considered. These findings may stimulate further research into measuring systemic risk more accurately and extensively. Currently, research has been limited to a few locations and crops (Zulauf and Orden, 2014, p. 13). Our modeling of farmers' overconfidence and related findings may also stimulate

[26] The fair price from farmers' point of view is similar to the "reference price" concept introduced in Thaler (2008). In that article, reference price arises from the perceived merits of a transaction. Whenever reference price is less than actual price, upon paying the latter, buyers derive some "transactional disutility," which is tantamount to what is modeled as farmers' aversion for out-of-pocket payments in Du, Feng, and Hennessy (2017).

[27] In the absence of a fixed political cost consideration, the functions depicted in figures 2a, 2b, 2c, and 2d would be continuous up to $k = 1.83$, the upper bound of marginal political cost values. As explained in footnote 13 and referenced in the text, $k = 1.83$ is the value of marginal political cost beyond which—based on variable political cost consideration alone—disaster aid is no longer desirable from the government's point of view. Once a fixed political cost consideration is present, such as the level considered in the base case, the government stops extending disaster aid at a lower level of marginal political cost than the prior level (hence, $k = 1.65$ becomes the threshold value instead of $k = 1.83$). The sum of fixed and variable political costs has become high enough to deter any disaster aid. (Notice that in figure 2d the disaster assistance without insurance drops to 0 at $k = 1.65$.) At the equilibrium, farmers anticipate that and do not expect any disaster aid beyond $k = 1.65$. As a result, the functions in the figures see a jump on that particular level and remain continuous afterwards. (The figures in the absence of a fixed political cost are available upon request.)

further research into better understanding farmers' decision processes as to crop insurance choices and the role of framing and education in this context, which may involve experimental analyses.

In the political economy equilibria we have found here, neither government nor farmers have any incentive to change their behavior. Nevertheless, given that government's net welfare is higher when farmers are accurate in their perceptions (figure 2a), government may benefit from investing in risk-management education activities in order to influence farmers' risk perceptions and promote insurance culture on agricultural production (Mahul and Stutley, 2010, p. 166; Bracha and Brown, 2012, p. 72). Despite the fact that disaster aid does not depend on the accuracy of farmers' perceptions (equation 10) and insurance options can be susceptible to perception issues (such as the form of overconfidence considered here), we show that government-supported insurance program can still be preferable (Shavell, 2014, p. 233). The underlying reason is that disaster aid implies an implicit coverage level, which is not tailored to the individual farmer's risk management needs (footnote 24). By subsidizing insurance, government alleviates the risk-averse farmers' reluctance to pay premiums in the presence of free disaster aid and at the same time induces them to cover their risks through a more customized risk management tool. The *ex ante* political cost arising from insurance subsidy appears to be much smaller than the would be *ex post* political cost arising from disaster aid in the absence of the insurance option (figure 2d). Our analysis indicates that disaster aid can be used at much lower capacity in the future but may not be eradicated when farmers are overconfident.[28]

To further explain government's preference for insurance option over ad hoc disaster aid, future research can investigate several considerations that are not modeled here:

1. Insurance with sufficient coverage can facilitate credit use (Ifft, Kuethe, and Morehart, 2013) and ease borrowers' liquidity constraints via higher advance rates in loans (Jensen, 2017).

2. The availability and predictability of insurance options from year to year (relative to ad hoc disaster aid and emergency loan programs) helps farmers with long-term business planning (U.S. Government Accountability Office, 1989, pp. 28–30) and may encourage investment in the farm sector.

3. The *ex ante* insurance option (to the extent that it deters ad hoc disaster aid) may result in production efficiency gains (Innes, 2003). As mentioned earlier, the *ex ante* contract proposed in Innes (2003) differs somewhat from crop insurance options currently offered to farmers. The study also recommends buying out some low-productivity farms. The latter (to some extent) is facilitated by Conservational Reserve Program (CRP), as environmentally sensitive land may correlate with low-productivity land.

4. The expectations of potential favorable treatment by the World Trade Organization (WTO) may have contributed to the global growth of agricultural insurance over the last twenty-five years (Glauber, 2015). However, these expectations do not appear to have any basis from the WTO perspective toward explaining governments' preference for *ex ante* insurance over ad hoc disaster aid, as both options are treated similarly within the context of relief from natural disasters (Innes, 2003, p. 327; Glauber, 2015, pp. 8, 23–25)).

5. Insurance options can perform better relative to disaster aid in terms of accuracy and speed of payments (U.S. Government Accountability Office, 1989, p. 25, p. 30). In fact, during the 2012 drought experience, insurance delivery systems proved to be effective in dealing with

[28] Examples of replacing ad hoc disaster assistance aid with agricultural insurance programs that are supported by the government through provision of insurance subsidies can be found in some countries such as Spain (Mahul and Stutley, 2010, p. 62). In the United States, with the record-high participation rate in crop insurance and after many years of Congress passing ad hoc disaster legislation to deal with weather-induced losses in agriculture, there were no calls for crop disaster legislation after 2012, a major drought year. Nevertheless, some livestock disaster assistance programs were authorized in the 2014 Farm Bill and were implemented.

the claim load and met the expectations of policy-makers and the farm sector in that regard. Furthermore, since 2014, improper payment rates (a standardized measure of waste and abuse in federal spending programs) associated with the crop insurance program stood at about half of the government-wide average (Manzano, 2017).

6. Certain features—(i) liability is established ahead of time and based on the value of production, (ii) payments are made only when there is a legitimate loss with respect to the liability, and (iii) farmers pay a portion of the premium and need to incur a deductible before any payment is triggered—can make insurance options more politically palatable than direct income support. For instance, direct payments, which were repealed by the 2014 Farm Bill, were naturally free to farmers and did not even require production.

[Received June 2016; final revision received June 2017.]

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Online Supplement A

Part 1: On the Range of Political Cost Parameters (k, K)

Denote the realized (actual) value of random variable $\tilde{l}^0$ with l_a, then $l_a = l$ in case of loss and $l_a = 0$ in case of no loss. Similarly, one can denote the random variable for the ratio of amount of loss to farmer's potential income with $\tilde{r}^0 = \tilde{l}^0/M$ and the actual (realized) value for the ratio with r_a (that is, $r_a = l_a/M$). In case of loss, one can refer to r_a as r so that $r_a = r = l_a/M = l/M$, otherwise $r_a = 0$. Seperately, r is defined as the ratio of the farmer's loss prospect to the farmer's potential income (that is, $r = l/M$ and $r > 0$), whenever the farmer faces a positive loss prospect.

In the case of no farmer loss (that is, $l_a = 0$ and so $r_a = 0$), if the government considers making a transfer, the farmer's resulting income level would be $M + \tau$, while the farmer's potential income is M. The percentage change can then be calculated as $w(\tau, 0) = \tau/M$. Rewriting the government's objective function in equation (3) after substituting $w(\tau, 0)$ yields $G(\tau; r) = B + \psi(\eta - e^{-w(\tau,0)}) - (K + k\tau)$, where $B = 0$ and $\eta = 2$ hold. From the first-order condition (FOC) of the maximization of the preceding function with respect to τ (the FOC would be necessary and sufficient in the absence of fixed political cost) yields $\breve{\tau}_{r_a=0} = -M \ln\left(\frac{kM}{\psi}\right)$. One can verify that if $\underline{k} = \frac{\psi}{M}$, then $\breve{\tau}_{r_a=0} = 0$ holds, while if $k > \frac{\psi}{M}$, then $\breve{\tau}_{r_a=0} < 0$ holds. Note that $\breve{\tau}_{r_a=0} < 0$ is ruled out, as government is not interested in taxing farmers (implicitly, τ is in absolute value in equation 3). Thus, for any $k \geq \frac{\psi}{M}$, the marginal political cost is high enough to deter *ex post* disaster aid to the farmer when the farmer does not have a loss. However, if $k < \frac{\psi}{M}$ were to hold, then $\breve{\tau}_{r_a=0} > 0$ would hold in the absence of fixed cost $K > 0$, but the latter needs to be taken into account. Regardless of the value of the fixed cost, one can rule out the possibility of such transfers when the farmer has no loss by assuming a high enough marginal political cost, $k \geq (\psi/M)$.

In the case of a farmer loss (that is, $l_a > 0$ and so $r_a > 0$), the government's problem is to maximize its objective function in equation (3) by choosing a non-negative level of transfer. The farmer's resulting income level is $M - l + \tau$, while the farmer's potential income is M. The percentage change then can be calculated as $w(\tau, r) = -r + \tau/M$. Rewriting the government's objective function in equation (3) after substituting $w(\tau, r)$ yields $G(\tau; r) = B + \psi(\eta - e^{-w(\tau,r)}) - (K + k\tau)$, where $B = 0$ and $\eta = 2$ continue to hold. Solving the FOC from the maximization of the preceding function, which would be necessary and sufficient in the absence of fixed political cost, yields $\breve{\tau} = M\left[r - \ln\left(\frac{kM}{\psi}\right)\right]$. In addition to the lower bound defined earlier, now define an upper bound of $\bar{k} = \frac{\psi e^r}{M}$ for the marginal political cost. Note that $\breve{\tau} \geq 0$ so long as $k \leq \bar{k}$, and $\breve{\tau}$ is monotonically decreasing in k as k increases within $[\underline{k}, \bar{k}]$. Furthermore, $\breve{\tau}$ is increasing in ψ, $\breve{\tau}$ is increasing in r, and $\breve{\tau}$ does not depend on the farmer's risk p_l. As before, even though $\breve{\tau}$ becomes negative when $k > \bar{k}$, it will be set to 0 as discussed earlier. One can then state that $\breve{\tau} = M\left[r - \ln\left(\frac{kM}{\psi}\right)\right] > 0$ holds when $k < \bar{k}$ and $\breve{\tau} = 0$ holds when $k \geq \bar{k}$. The preceding expression can be rearranged as $\breve{\tau} = l\omega$, where $\omega = 1 - \frac{1}{r}\ln(\frac{kM}{\psi})$.

In addition to the variable cost, the government should account for the fixed cost. In order for government to extend $\breve{\tau} > 0$ to the farmer, the government's net welfare with a farm loss and no transfer, $G(0, r) = B + \psi(\eta - e^{-w(0,r)})$, should be less than its net welfare with a farm loss and the optimal transfer, $G(\breve{\tau} > 0, r) = B + \psi(\eta - e^{-w(\breve{\tau},r)}) - (K + k\breve{\tau})$. The preceding condition can be expressed as $K < \psi e^r(1 - e^{-\breve{\tau}/M}) - k\breve{\tau}$. Denote the right side of the preceding inequality with K_k, which is the implied maximum level of fixed cost that can be accommodated; that is, K_k shows the additional net value gained by extending $\breve{\tau} > 0$ to the farmer as opposed to the fixed cost of doing so. For a high enough political cost, $k = \bar{k}$, $\breve{\tau} = 0$; that is, marginal political cost is so high, based on marginal analysis alone, that the government does not extend any *ex post* disaster aid. Conversely, for a given fixed cost level, there exists a marginal political cost level, denoted $\bar{k}_K$, such that for all marginal political cost levels beyond $\bar{k}_K$, government does not find extending $\breve{\tau} > 0$ beneficial. Upon evaluating K_k from earlier at $\underline{k}$, one can obtain an upper bound to fixed cost $\overline{K}_{\underline{k}} = \psi(e^r - (1+r))$ such that $\underline{k} = \bar{k}_K$; that is, the government is indifferent between $\check{\tau} > 0$ and $\check{\tau} = 0$ only at the lower end of the marginal political cost range considered. However, if $k = \bar{k} = \frac{\psi e^r}{M}$, then $\check{\tau} = 0$, which in turn implies that $K_{\bar{k}} = 0$. In order to accommodate a $K > 0$, $\bar{k}_K < \bar{k}$ must hold. Moreover, one can establish that K_k is a strictly convex and monotonically declining function of k when $k \in [\underline{k}, \bar{k}_K]$. Thus, for all $K \leq \overline{K}_{\underline{k}}$, $\bar{k}_K$ lies in the domain $[\underline{k}, \bar{k})$ and $\bar{k}_K$ is a decreasing function of K.

We summarize the foregoing as follows. Suppose that the amount of fixed political cost of providing a farmer with *ex post* disaster assistance, K, is not prohibitively high (that is, $0 < K \leq \overline{K}_{\underline{k}}$). For all marginal political cost values that are beyond $\bar{k}_K$ and less than $\bar{k}$ (that is, $k \in (\bar{k}_K, \bar{k}]$), the mere presence of fixed political cost prevents government from extending disaster assistance to farmers. It follows, then, that for all $0 < K \leq \overline{K}_{\underline{k}}$,

$$\hat{\tau} = \begin{cases} \check{\tau} = l\omega > 0 & k \in [\underline{k}, \bar{k}_K] \\ 0 & k > \bar{k}_K, \end{cases} \tag{A1}$$

where ω indicates the fraction of the farmer's loss paid through disaster assistance and is defined as $\omega = 1 - \frac{1}{r}\ln(\frac{kM}{\psi})$.

Now consider the possibility of the farmer holding insurance coverage x in the *ex post* situation. The farmer's resulting income level is $M - (1-t)\pi x - l(1-x) + \tau$ and potential income is M. The percentage change can be calculated as $w(r,\tau,x,t) = -(1-t)\pi x/M - r(1-x) + \tau/M$, which is used in government's *ex post* problem in equation (4). From the FOC of the maximization of the preceding problem, the disaster assistance is obtained as $\check{\tau}_{xt} = M\left[r(x,t) - \ln\left(\frac{kM}{\psi}\right)\right]$, where $r(x,t)$ is the ratio of loss with insurance coverage x to the potential income and can be written as $r(x,t) = \frac{(1-t)\pi x + l(1-x)}{M} = \frac{(1-t)\pi x}{M} + r(1-x)$. Note the distinction between r as a parameter and $r(x,t)$ as a function of x and t. Now the expression for $\check{\tau}_{xt}$ can be recollected as $\check{\tau}_{xt} = l\omega + l\alpha x$, where ω is as defined earlier and $\alpha = \left((1-t)\frac{\pi}{l} - 1\right)$. Evaluating $\check{\tau}_{xt}$ at the minimum marginal political cost $\underline{k}$ would yield $\check{\tau}(x,t) = Mr(x,t) = (1-t)\pi x + l(1-x)$; that is, the optimal disaster assistance pays out the portion of the farmer's loss not covered by insurance plus the farmer-paid premium.

Suppose that the only loss incurred is the farmer-paid premium (that is, set $l_a = 0$ and so $r_a = 0$ for the moment). Then, $r(x,t)$ from earlier would reduce to $r(x,t)|_{r_a=0} = \frac{(1-t)\pi x}{M}$. The preceding ratio is at its maximum when $x = 1$ and $t = 0$, which amounts to the full premium divided by the farmer's potential income. The assumption that the premium paid was actuarially fair ($\pi = p_l l$) yields $r(x=1,t=0)|_{r_a=0} = \frac{p_l l}{M} = p_l r$. Then, the disaster assistance $\check{\tau}_{xt}$ from earlier would reduce to $\check{\tau}_{xt}|_{r_a=0} = M\left[p_l r - \ln\left(\frac{kM}{\psi}\right)\right]$. Ignoring the fixed cost for a moment, at $k = \underline{k}$, the government would like to pay the farmer's actuarially fair premium back so that $\check{\tau}_{xt}|_{r_a=0} = p_l l$. This could be prevented with the mere existence of fixed cost of providing funds. Nevertheless, based on marginal analysis alone, in order to prevent any government transfer in this case, it is sufficient to revise the minimum level of marginal political cost upward to $\underline{k}_{x=1} = \frac{\psi e^{p_l r}}{M}$ (that is, $\underline{k}_{x=1} > \underline{k}$). Notice that at $\underline{k}_{x=1}$, the optimal disaster assistance (when the farmer's only loss is the premium paid) is set to 0 (that is, $\check{\tau}_{xt}|_{r_a=0} = 0$ as desired).

Going back to earlier, when insurance is absent, an upward revision in the minimum of marginal political cost from $\underline{k}$ to $\underline{k}_{x=1}$ requires that the maximum fixed cost that can be accommodated be revised as well. When $k = \underline{k}_{x=1} = \frac{\psi e^{p_l r}}{M}$ holds, $\check{\tau} = l\omega = l(1-p_l)$. Plugging in the preceding values, one obtains $\overline{K}_{\underline{k}_{x=1}} = K_{\underline{k}_{x=1}} = \psi e^r(1 - e^{-l(1-p_l)/M}) - \underline{k}_{x=1} l(1-p_l)$. Rearranging the terms yield $\overline{K}_{\underline{k}_{x=1}} = K_{\underline{k}_{x=1}} = \psi[e^r - e^{p_l r}(1 + r(1-p_l))]$, which is referred to as $\overline{K}$ in the article. Q.E.D. ■

Part 2: Obtaining the Variance of Farmer Loss When Disaster Assistance Is the Only Option and Farmer Has Accurate Perceptions (No Overconfidence)

Suppose that $k \in [\frac{\psi}{M}, \bar{k}_K]$ so that the *ex post* disaster amount is positive (that is, $\hat{\tau} > 0$ in equation 5) after setting $x = 0$ and $t = 0$ (hence, the insurance option is absent), which is reproduced here as $\hat{\tau} = \omega l$ and $\omega = 1 - \frac{1}{r}\ln(\frac{kM}{\psi})$. From $E(\tilde{l}^0_{\hat{\tau}}) = (p_{lL} + p_{lN})l - p_{lL}p_{D|L}\hat{\tau}$, one obtains the farmer's expected loss as

(A2) $$E(\tilde{l}^0_{\hat{\tau}}) = p_l l - p_{lL}p_{D|L}\omega l$$

and the farmer's expected squared loss as $E\left((\tilde{l}^0_{\hat{\tau}})\right)^2 = p_{lL}(l - p_{D|L}\hat{\tau})^2 + p_{lN}(l-0)^2 + p_{nL}0^2 + p_{nN}0^2$. From the variance formula, $\sigma^2_{\tilde{l}^0_{\hat{\tau}}} = E\left((\tilde{l}^0_{\hat{\tau}})^2\right) - \left(E(\tilde{l}^0_{\hat{\tau}})\right)^2$, $\sigma^2_{\tilde{l}^0_{\hat{\tau}}} = p_{lL}(l - p_{D|L}\hat{\tau})^2 + p_{lN}l^2 - \left(p_l l - p_{lL}p_{D|L}\hat{\tau}\right)^2$. Upon rearranging the terms, using $\sigma^2_{\tilde{l}^0} = p_{lL}(1-p_{lL})l^2 + p_{lN}(1-p_{lN})l^2 - 2p_{lL}p_{lN}l^2$ and substituting $\hat{\tau} = l\omega > 0$, one can obtain $\sigma^2_{\tilde{l}^0_{\hat{\tau}}} = \sigma^2_{\tilde{l}^0} - 2p_{lL}p_{D|L}(1-p_l)\omega l^2 + p_{lL}(1 - p_{lL})p_{D|L}{}^2\omega^2 l^2$. Rearranging the terms yields

(A3) $$\sigma^2_{\tilde{l}^0_{\hat{\tau}}} = \sigma^2_{\tilde{l}^0} - 2p_{lL}p_{D|L}(1-p_l)\omega l^2 + p_{lL}(1-p_{lL})p_{D|L}p_{D|L}\omega^2 l^2.$$

Using $E(\tilde{l}^0_{\hat{\tau}})$ and $\sigma^2_{\tilde{l}^0_{\hat{\tau}}}$, the farmer's utility under the disaster aid option and perfect information is

(A4) $$U(\hat{\tau}, \tilde{r}^0) = U^0_{\hat{\tau}} = M - E(\tilde{l}^0_{\hat{\tau}}) - 0.5\lambda\sigma^2_{\tilde{l}^0_{\hat{\tau}}}.$$

The farmer's *ex ante* utility calculation takes into account the possibility of *ex post* disaster aid in the event of loss.

From the previous section, consider the marginal political cost level $\underline{k}_{x=1} = \frac{\psi e^{p_l r}}{M}$, which lies within the domain of interest. When $k \geq \underline{k}_{x=1}$, $\omega \leq (1 - p_l)$ holds, which in turn implies that $\sigma^2_{\tilde{l}^0_{\hat{\tau}}} < \sigma^2_{\tilde{l}^0}$ in equation (A3); hence, there is a risk reduction. Notice that as k increases, ω decreases, then risk reduction obtained from disaster assistance also decreases. In particular, because $\bar{k}_K < \bar{k}$ and $\omega > 0$ at $k = \bar{k}_K$ hold, some risk-reduction—however small that may be—can still be found at $k = \bar{k}_K$.

To see the effect of marginal political cost on $\sigma^2_{\tilde{l}^0_{\hat{\tau}}}$, one can write

(A5) $$\frac{\partial \sigma^2_{\tilde{l}^0_{\hat{\tau}}}}{\partial k} = \frac{\partial \omega}{\partial k}\left(\underbrace{-(1-p_l) + (1-p_{lL})p_{D|L}\omega}_{\otimes}\right)p_{lL}p_{D|L}2l^2.$$

Recall that $\frac{\partial \omega}{\partial k} = -\frac{1}{rk} < 0$ so that $\frac{\partial \hat{\tau}}{\partial k} = \frac{\partial \omega}{\partial k}l = -\frac{M}{k}$ holds. In the following, one can determine the sign of the term indicated with $\otimes$.

Recall that $\omega \leq 1$: ω takes the value of 1 at the lower bound $\underline{k}$ and gets very small as k approaches $\bar{k}$. Notice that $(1 - p_{lL}) > (1 - p_l)$, and yet $(1 - p_l) > (1 - p_{lL})p_{D|L}\omega$ could hold as ω gets closer to 0; that is, less disaster assistance can be paid due to the higher marginal political cost. In that case, the term indicated with $\otimes$ has a negative sign, which in turn determines the sign of $\frac{\partial \sigma^2_{\tilde{l}^0_{\hat{\tau}}}}{\partial k}$ as positive. Whereas if $(1 - p_l) < (1 - p_{lL})p_{D|L}\omega$ were to hold (say for a sufficiently high $p_{D|L}$ and for relatively low values of k so that ω is closer to 1), then the term indicated with $\otimes$ is positive and one could sign $\frac{\partial \sigma^2_{\tilde{l}^0_{\hat{\tau}}}}{\partial k}$ as negative. That is, at the lower range of marginal political cost (perhaps) increasing the disaster assistance would increase the risk. Finally, when $(1 - p_l) = (1 - p_{lL})p_{D|L}\omega$, the term indicated with $\otimes$ is 0, therefore $\frac{\partial \sigma^2_{\tilde{l}^0_{\hat{\tau}}}}{\partial k} = 0$. This can be summarized as

(A6) $$\frac{\partial \sigma^2_{\tilde{l}^0_{\hat{\tau}}}}{\partial k} \begin{cases} < 0 & \text{if} \quad (1-p_l) < (1-p_{lL})p_{D|L}\omega \\ = 0 & \text{if} \quad (1-p_l) = (1-p_{lL})p_{D|L}\omega \\ > 0 & \text{if} \quad (1-p_l) > (1-p_{lL})p_{D|L}\omega. \end{cases}.$$

These findings could be re-expressed in terms of marginal political cost as follows. Substituting the expression for ω in equation (A6) and solving for k yields $k_c = \underline{k}e^{r\left(1-\frac{(1-p_l)}{(1-p_{lL})p_{D|L}}\right)}$.

Now one could consider imposing an upper limit to $p_{D|L}$, denoted with $\bar{p}_{D|L}$, such as

(A7) $$p_{D|L} \leq \bar{p}_{D|L} = \frac{(1-p_l)}{(1-p_{lL})} < 1.$$

Based on the preceding assumption, one obtains $k_c \leq \underline{k}$, which indicates that such a level of marginal political cost is already outside of the domain of interest. Therefore, the assumption in equation (A7) implies that $\frac{\partial \sigma^2_{\tilde{l}^0_{\hat{\tau}}}}{\partial k} \geq 0$ and $\sigma^2_{\tilde{l}^0_{\hat{\tau}}} < \sigma^2_{\tilde{l}^0}$ at $k = \underline{k}$, when $\omega = 1$. Because $\frac{\partial \sigma^2_{\tilde{l}^0_{\hat{\tau}}}}{\partial k} \geq 0$, the risk-reduction $(\sigma^2_{\tilde{l}^0} - \sigma^2_{\tilde{l}^0_{\hat{\tau}}})$ declines as the marginal political cost increases.

Nevertheless, recall the marginal political cost level $\underline{k}_{x=1} = \frac{\psi e^{p_l r}}{M}$ from Online Supplement A, Part 1. One can verify that when $k \geq \underline{k}_{x=1}$, $\omega \leq (1-p_l)$. For $k = \underline{k}_{x=1}$, $\omega = (1-p_l)$ holds, in particular. Then $(1-p_l) > (1-p_{lL})p_{D|L}\omega$ holds in equation (A6) as $(1-p_{lL})p_{D|L}$ discounts $\omega = (1-p_l)$, which in turn implies $\frac{\partial \sigma^2_{\tilde{l}^0_{\hat{\tau}}}}{\partial k} > 0$. Thus, when $k \geq \underline{k}_{x=1}$, $\frac{\partial \sigma^2_{\tilde{l}^0_{\hat{\tau}}}}{\partial k} > 0$ holds regardless of the assumption given in equation (A7). To reiterate, $\sigma^2_{\tilde{l}^0_{\hat{\tau}}}$ behaves as expected with respect to marginal political cost in the domain of interest, $k \geq \underline{k}_{x=1}$, without any regard to placing an upper bound on $\bar{p}_{D|L}$ per se.

Notice that the expected loss with disaster assistance $\hat{\tau}$ is positive; that is, $E(\tilde{l}^0_{\hat{\tau}}) > 0$ for all $k \in [\frac{\psi}{M}, \bar{k}_K]$ because the maximum amount of potential disaster assistance ($\hat{\tau} = l$) is when the marginal political cost is at its minimum, $\underline{k} = \frac{\psi}{M}$, and $E(\tilde{l}^0_{\hat{\tau}}) > 0$ is increasing with k. Rearrange the terms in the farmer's expected loss with disaster assistance as $E(\tilde{l}^0_{\hat{\tau}}) = p_l l(1-y^0)$, where $y^0 = \frac{p_{lL}p_{D|L}\omega}{p_l}$ indicates that the implicit coverage implied by disaster assistance. Because $y^0 < 1$, the disaster assistance by itself cannot fully eliminate the farmer's risk. The disaster assistance does not protect against basis risk per se (denoted with subscript "lN," see footnote 7). Q.E.D. ■

Part 3: Obtaining the Variance of Farmer Loss When Disaster Assistance Is the Only Option and Farmer Is Overconfident

From equation (5) after setting $x = 0$ and $t = 0$ and Online Supplement A, Part 1, recall that $\hat{\tau} = \omega l$, where $\omega = 1 - \frac{1}{r}\ln(\frac{kM}{\psi})$ and $\omega \in (0,1]$ over the domain of $k \in [\frac{\psi}{M}, \bar{k}_K)$. Notice that $\hat{\tau}$ does not depend on a farmer's perceived risk, whether it is p_l or q_l.

When disaster assistance is the only option and the farmer can be overconfident, the farmer's expected loss is $E(\tilde{l}^1_{\tau}) = q_{lL}(l - q_{D|L}\hat{\tau}) + q_{lN}(l-0) + q_{nL}0 + q_{nN}0$, which can be re-expressed as

(A8) $$E(\tilde{l}^1_{\tau}) = q_l l - q_{lL}q_{D|L}\omega l.$$

The farmer's expected squared loss is $E\left((\tilde{l}^1_{\tau})^2\right) = q_{lL}(l - q_{d|L}\hat{\tau})^2 + q_{lN}(l-0)^2 + q_{nL}0^2 + q_{nN}0^2$. Combining the preceding two expressions in the variance formula $\sigma^2_{\tilde{l}^1_{\tau}} = E\left((\tilde{l}^1_{\tau})^2\right) - \left(E(\tilde{l}^1_{\tau})\right)^2$, one obtains the variance of the farmer's loss as $\sigma^2_{\tilde{l}^1_{\hat{\tau}}} = q_{lL}(1-q_{lL})(l - q_{D|L}\hat{\tau})^2 + q_{lN}(1-q_{lN})(l-0)^2 - 2q_{lL}q_{lN}(l - q_{D|L}\hat{\tau})l$. Using $\sigma^2_{\tilde{l}^1} = q_{lL}(1-q_{lL})l^2 + q_{lN}(1-q_{lN})l^2 - 2q_{lL}q_{lN}l^2$ and substituting $\hat{\tau} = \omega l$, one arrives at

$$\text{(A9)} \qquad \sigma^2_{\tilde{l}^1_{\hat{\tau}}} = \sigma^2_{\tilde{l}^1} - 2q_{lL}q_{D|L}(1-q_l)\omega l^2 + q_{lL}(1-q_{lL}){q_{D|L}}^2\omega^2 l^2.$$

Based on $E(\tilde{l}^1_\tau)$ and $\sigma^2_{\tilde{l}^1_\tau}$, one can then write the farmer's preference under the disaster aid option as

$$\text{(A10)} \qquad U^1_{\hat{\tau}} = M - E(\tilde{l}^1_{\hat{\tau}}) - 0.5\lambda\sigma^2_{\tilde{l}^1_{\hat{\tau}}},$$

which represents the farmer's perceived utility (financial well-being). In line with equation (2), as risk aversion increases, the farmer's perception of risk gets more accurate; hence $E(\tilde{l}^1_\tau)$ and $\sigma^2_{\tilde{l}^1_\tau}$ increase toward their actual values. Combining these with the increasing pain of tolerating risk, one obtains that $U^1_{\hat{\tau}}$ decreases as risk aversion increases.

Furthermore, taking the first derivative of $\sigma^2_{\tilde{l}^1_{\hat{\tau}}}$ with respect to marginal political cost yields

$$\text{(A11)} \qquad \frac{\partial \sigma^2_{\tilde{l}^1_{\hat{\tau}}}}{\partial k} = \frac{\partial \omega}{\partial k}\left(\underbrace{-(1-q_l) + (1-q_{lL})q_{D|L}\omega}_{\otimes}\right) q_{lL}q_{D|L}2l^2.$$

Recall (from Online Supplement A, Part 1) that $0 < \omega < 1$ whenever $k \in (\underline{k}, \bar{k}_K]$; $0 < \omega < (1-p_l)$ and whenever $k \in (\underline{k}_{x=1}, \bar{k}_K]$; and ω is decreasing in marginal political cost. Consider the following upper bound for $q_{D|L}$ for the moment: $q_{D|L} \leq \bar{q}_{D|L} = \frac{(1-q_l)}{(1-q_{lL})} < 1$. Combining $q_{D|L} \leq \bar{q}_{D|L}$ with $\omega \leq 1$, one signs the term indicated with $\otimes$ in equation (A11) as negative, which in turn signs $\frac{\partial \sigma^2_{\tilde{l}^1_{\hat{\tau}}}}{\partial k}$ as positive. That is, as marginal political cost increases the risk-reduction ability of *ex post* disaster aid is decreasing. Furthermore, recall the marginal political cost level $\underline{k}_{x=1} = \frac{\psi e^{p_l r}}{M}$ from earlier. Notice when $k \geq \underline{k}_{x=1}$, $\omega \leq (1-p_l)$ holds; particularly for $k = \underline{k}_{x=1}$, $\omega = (1-p_l)$ holds. Then, $(1-q_l) > (1-p_{lL})p_{D|L}\omega$ holds in equation (A11), as $(1-p_{lL})p_{D|L}$ discounts $\omega = (1-p_l)$, which in turn implies $\frac{\partial \sigma^2_{\tilde{l}^1_{\hat{\tau}}}}{\partial k} > 0$. Thus, when $k \geq \underline{k}_{x=1}$, $\frac{\partial \sigma^2_{\tilde{l}^1_{\hat{\tau}}}}{\partial k} > 0$ holds, regardless of the earlier restriction on $q_{D|L}$. To reiterate, $\sigma^2_{\tilde{l}^1_{\hat{\tau}}}$ behaves as expected with respect to marginal political cost in the domain of interest, $k \geq \underline{k}_{x=1}$, without any need to place an upper bound for $q_{D|L}$ per se.

Rearranging the terms in the farmer's expected loss with disaster assistance as $E(\tilde{l}^1_\tau) = q_l l(1 - y^1)$, where $y^1 = \frac{q_{lL}q_{D|L}\omega}{q_l}$ indicates the perceived implicit coverage of disaster aid. In comparing y^1 with y^0 (actual implicit coverage of disaster aid) from the previous section, the disaster aid continues to be inadequate to fully eliminate the farmer's risk because $y^1 < 1$. Based on the base case parameter values, one can numerically observe that y^1 monotonically increases over y^0 as risk aversion decreases. Note that for the most risk-averse farmer—with accurate perception of risk—$y^1 = y^0$ continues to hold. Q.E.D. ■

Online Supplement B: Coverage Demand in the Absence of Disaster Assistance When Farmer Is Overconfident

If the farmer holds x units of coverage with individual insurance only, the farmer's expected loss with individual coverage is

$$E(\tilde{l}_x^1) = q_l(l - xl). \tag{A12}$$

The variance of the loss of the farmer with x units of coverage is $\sigma^2_{\tilde{l}_x^1} = E\left((\tilde{l}_x^1)^2\right) - \left(E(\tilde{l}_x^1)\right)^2$. Now one can obtain

$$E\left((\tilde{l}_x^1)^2\right) = q_{lL}(l - xl)^2 + q_{lN}(l - xl)^2 + q_{nL}0 + q_{nN}0 \tag{A13}$$

and $\left(E\left((\tilde{l}_x^1)\right)\right)^2 = (q_l l)^2(1-x)^2$. Combining equations (A12) and (A13) yields

$$\sigma^2_{\tilde{l}_x^1} = (1-x)^2\sigma^2_{\tilde{l}^1}, \tag{A14}$$

where $\sigma^2_{\tilde{l}^1} = q_l(1-q_l)l^2$, the variance of the farmer's loss without insurance, is from equation (2).

After substituting $\sigma^2_{\tilde{l}_x^1}$ with $E\left((\tilde{l}_x^1)^2\right) - \left(E(\tilde{l}_x^1)\right)^2$, the farmer's utility function in equation (2) can be written as

$$U(x,t,\tilde{r}^1) = M - (1-t)\pi x - E(\tilde{l}_x^1) - 0.5\lambda\left(E\left((\tilde{l}_x^1)^2\right)\right) + 0.5\lambda\left(E(\tilde{l}_x^1)\right)^2. \tag{A15}$$

The utility function is concave in x, which follows from the linearity of the expected loss and convexity of the variance of the farmer's loss. (Notice that the variance term enters negatively in the objective function.) The farmer's objective is to maximize the preceding utility function. The necessary and sufficient FOC is

$$\frac{\partial U}{\partial x} = -\pi(1-t) - 0.5\lambda\frac{\partial\left(E\left((\tilde{l}_x^1)^2\right)\right)}{\partial x} + \left[\lambda E(\tilde{l}_x^1) - 1\right]\frac{\partial E(\tilde{l}_x^1)}{\partial x} = 0. \tag{A16}$$

Note that

$$\frac{\partial E(\tilde{l}_x^1)}{\partial x} = -q_l l. \tag{A17}$$

$$\tfrac{\partial}{\partial x}\left(E(\tilde{l}_x^1)^2\right) = -2q_{lL}l(l-xl) - 2q_{lN}l(l-xl) = -2q_l(1-x)l^2. \tag{A18}$$

Substituting equations (A17) and (A18) into the FOC and solving for x, one can obtain

$$\check{x}^1 = 1 + \frac{q_l l - (1-t)\pi}{\lambda q_l(1-q_l)l^2}, \tag{A19}$$

which corresponds to that in equation (7).

Regarding the monotonicity of $\check{x}^1$ with respect to risk aversion, first observe that as long as $t < \theta$ and the premium is actuarially fair, $\pi = p_l l$, then one obtains $\check{x}^1 = 1 + \frac{q_l l-(1-t)\pi}{\lambda q_l(1-q_l)l^2} < 1$; and when $t \in [\theta, 1]$ and the premium is actuarially fair, $\pi = p_l l$, then one obtains $\check{x}^1 = 1$. In addition, observe that

$$\frac{\partial q_l l}{\partial \lambda} = l\frac{\partial}{\partial \lambda}(-\delta_l) = l\theta p_l\frac{\partial}{\partial \lambda}(-A(\lambda)) = l\theta p_l\frac{1}{(\bar{\lambda} - \underline{\lambda})} > 0. \tag{A20}$$

Thus, $q_l l$ increases toward $p_l l$, as λ increases. Because $p_l < 0.5$, the perceived variance $q_l(1-q_l)l^2$ increases toward $p_l(1-p_l)l^2$; hence the entire denominator $\lambda q_l(1-q_l)l^2$ increases as λ increases. Combining these two effects, $\frac{q_l l-(1-t)\pi}{\lambda q_l(1-q_l)l^2}$ becomes less negative as λ increases: as a result, $\check{x}^1 = 1 + \frac{q_l l-(1-t)\pi}{\lambda q_l(1-q_l)l^2}$ increases to 1, as long as $t < \theta$ and the premium is actuarially fair, $\pi = p_l l$. Thus, $\check{x}^1$ is monotonically increasing in risk aversion for that range of subsidy rates. Again, for all subsidy rates at and above θ, $\check{x}^1$ is bounded by 1, per actuarial standards; hence, it is nondecreasing. To sum up, $\frac{\partial \check{x}^1}{\partial \lambda} > 0$ whenever $\check{x}^1 \in (0,1)$.

Finally, if one replaces the perceived probabilities (q) with the actual probabilities (p) (see footnote 7) in the formulation of $\check{x}^1$ in equation (A19), one would obtain

(A21) $$\check{x}^0 = 1 + \frac{p_l l - (1-t)\pi}{\lambda p_l(1-p_l)l^2} = 1 + \frac{p_l l - (1-t)\pi}{\lambda \sigma^2_{\tilde{l}0}}.$$

It is straightforward to see that the coverage demand under no confidence is monotonic in risk aversion. Q.E.D. ■

Online Supplement C: Proof of Lemma 1

Assume $K < \bar{K}$ and $k \in [\underline{k}_{x=1}, \bar{k}_K]$ so that disaster assistance would pay a fraction of loss $\omega > 0$ if the insurance option were not present. In the *ex post* loss situation—in which a farmer happens to hold coverage level x with subsidy rate t, based on the marginal analysis alone—government considers extending $\check{\tau}_{xt} = l(\omega + \alpha x) \geq 0$ from equation (5) and Online Supplement A, Part 1. Recall that $\omega = 1 - \frac{1}{r}\ln(\frac{kM}{\psi})$ and $\alpha = (1-t)\frac{\pi}{l} - 1$ from equation (5). From $\check{\tau}_{xt} = l(\omega + \alpha x) = 0$, one obtains

(A22) $$\bar{x}_* = \frac{\omega}{-\alpha}.$$

At the actuarially fair premium rate (that is, $\pi = p_l l$), $\alpha = (1-t)p_l - 1$. Then $\bar{x}_* = \frac{\omega}{-\alpha} = \frac{\omega}{1-(1-t)p_l}$ as claimed in Lemma 1. In addition, if $k = \underline{k}_{x=1}$ and $t = 0$ hold, then $\omega = -\alpha = (1-p_l)$ holds, which would imply $\bar{x}_* = 1$.

Differentiating $\bar{x}_*$ with respect to marginal political cost, one obtains $\frac{\partial \bar{x}_*}{\partial k} = \frac{\frac{\partial \omega}{\partial k}}{-\alpha} < 0$ as $\frac{\partial \omega}{\partial k} = -\frac{1}{rk} < 0$ from Online Supplement A, Part 1, and $-\alpha > 0$ from above. In addition, differentiating $\bar{x}_*$ with respect to the subsidy rate, one obtains $\frac{\partial \bar{x}_*}{\partial t} = -\frac{\omega}{(-\alpha)^2}\frac{\partial(-\alpha)}{\partial t} < 0$ as $\frac{\partial(-\alpha)}{\partial t} = \frac{\pi}{l}$, which becomes $\frac{\partial(-\alpha)}{\partial t} = p_l$ at the actuarially fair premium rate. Thus, the claims regarding $\bar{x}_*$ in Lemma 1 follow.

Based on the marginal analysis alone, if $x = \bar{x}_*$, then $\check{\tau}_{xt} = l(\omega + \alpha x) = 0$, meaning that the presence of insurance at such a level $x = \bar{x}_*$ and given subsidy rate, t, is the perfect substitute for anything that government could do in terms of *ex post* this disaster aid, $\check{\tau} = l\omega$, in the absence of insurance. Taking the presence of such insurance into account, government does not extend any *ex post* disaster aid.

In Online Supplement A, Part 1, one obtains $G(0, r(x,t)) = B + \psi(\eta - e^{r(x,t)})$ and $G(\hat{\tau}_{xt}, r(x,t)) = B + \psi(\eta - e^{r(1-\omega)}) - (K + k\hat{\tau}_{xt})$. Suppose that there exists an $x_* \in (0,1]$ such that $G(0, r(x,t)) = G(\hat{\tau}_{xt}, r(x,t))$ holds at $x = x_*$, so that government is indifferent between $\check{\tau}_{xt} > 0$ and providing nothing in the *ex post* situation. From the definition of $\bar{x}_*$, $\check{\tau}_{x=1,t=0} = 0$ holds, and $x_* < \bar{x}_*$ as claimed in Lemma 1.

The equation $G(0, r(x,t)) = G(\hat{\tau}_{xt}, r(x,t))$ translates to

(A23) $$-\psi e^{r+r\alpha x} + \psi e^{r-r\omega} + K + kl\omega + kl\alpha x = 0,$$

where x_* denotes the coverage level that satisfies equation (A23). In the following, by appealing to implicit function theorem, one can establish that x_* can be expressed as a function of (k,K).

Now re-express equation (A23) as $F(x,k,K;o)=0$, where o represents the remaining parameters, such as ψ. First, find the partial derivatives:

(A24)
$$\frac{\partial F}{\partial x} = -\psi \alpha r e^{r+r\alpha x} + kl\alpha$$
$$\frac{\partial F}{\partial K} = 1$$
$$\frac{\partial F}{\partial k} = -r\frac{\partial \omega}{\partial k}\psi e^{r-r\omega} + l\omega + kl\frac{\partial \omega}{\partial k} + l\alpha x = 0$$
$$\frac{\partial F}{\partial t} = -\psi e^{r+r\alpha x}\frac{\partial \alpha}{\partial t}rx + klx\frac{\partial \alpha}{\partial t}.$$

Clearly, $\frac{\partial F}{\partial K}$ is continuous. Now focus on $\frac{\partial F}{\partial k}$. Because $\frac{\partial \omega}{\partial k} = -\frac{1}{rk}$, $\frac{\partial \psi e^{r(1-\omega)}}{\partial k} = -r\frac{\partial \omega}{\partial k}\psi e^{r-r\omega} = \psi e^{r(1-\omega)}\frac{1}{k}$. Recall that $\omega = 1-\frac{1}{r}\ln(\frac{kM}{\psi})$. One can obtain $r(1-\omega) = \ln(\frac{kM}{\psi})$. The following relationship will be useful:

(A25)
$$\frac{\psi}{M}e^{r(1-\omega)} = k.$$

Then, $\frac{\partial \psi e^{r(1-\omega)}}{\partial k} = \psi e^{r(1-\omega)}\frac{1}{k} = M$. Moreover, $kl\frac{\partial \omega}{\partial k} = -\frac{kl}{rk} = -M$ for all $k \in [\underline{k}_{x=1}, \bar{k}_K)$. Thus, $\frac{\partial F}{\partial k} = l\omega + l\alpha x > 0$ for all $k \in [\underline{k}_{x=1}, \bar{k}_K)$, whenever $\hat{\tau} = l(\omega + \alpha x) > 0$. The latter requires $x < \bar{x}_*$, as discussed earlier.

Now turn to $\frac{\partial F}{\partial t}$. From the definition of $\alpha = (1-t)\frac{\pi}{l} - 1$, $\frac{\partial \alpha}{\partial t} = -\frac{\pi}{l}$. At the actuarially fair premium, $\frac{\partial \alpha}{\partial t} = -p_l$. Because $l\omega + l\alpha x > 0$ as $x \le x_*(k,K,t) < \bar{x}_*(k,t) = \frac{\omega}{1-(1-t)p_l} \le 1$, αx is less negative than $-\omega$. Using the expression in equation (A25), one obtains $\frac{\partial F}{\partial t} = \underbrace{\frac{\partial \alpha}{\partial t}}_{=-p_l} rx \underbrace{\left(-\psi e^{r+r\alpha x} + \psi e^{r(1-\omega)}\right)}_{<0} > 0.$

Now focus on $\frac{\partial F}{\partial x}$ in equation (A24). Assuming actuarially fair premium rates, $\alpha = (1-t)p_l - 1$. Recall that if $x \le x_* < \bar{x}_* \le 1$, then $-\omega < \alpha x$. Combining that with equation (A25), one obtains $\frac{\partial F}{\partial x} = l\alpha \underbrace{(-\frac{\psi}{M}e^{r+r\alpha x} + \frac{\psi e^{r-r\omega}}{M})}_{<0} > 0$ for all $k \in [\underline{k}_{x=1}, \bar{k}_K)$ and $t \in [0,1]$ at the actuarially fair premium $\pi = p_l l$.

Because the function F has continuous partial derivatives $\frac{\partial F}{\partial x}$, $\frac{\partial F}{\partial k}$, $\frac{\partial F}{\partial k}$, $\frac{\partial F}{\partial t}$, and $\frac{\partial F}{\partial x} \neq 0$ in the domain of interest, the implicit function theorem applies. One can then write the implicit function $x_* = f(k,K)$. Because $\frac{\partial F}{\partial x_*} > 0$ as found above, one can obtain

$$\frac{\partial x_*}{\partial k} = \frac{-\frac{\partial F}{\partial k}}{\frac{\partial F}{\partial x_*}} = \frac{-l(\omega + \alpha x)}{\frac{\partial F}{\partial x_*}} < 0,$$
$$\frac{\partial x_*}{\partial K} = \frac{-\frac{\partial F}{\partial K}}{\frac{\partial F}{\partial x_*}} = \frac{-1}{\frac{\partial F}{\partial x_*}} < 0,$$
$$\frac{\partial x_*}{\partial t} = \frac{-\frac{\partial F}{\partial t}}{\frac{\partial F}{\partial x_*}} < 0.$$

Q.E.D. ■

Online Supplement D: Coverage Demand in the Presence of Disaster Assistance When Farmer Is Overconfident

For a given insurance coverage level, x, the optimal *ex post* disaster aid is formulated in equation (5): $\breve{\tau}_{xt} = l\omega + l\alpha x$, where $\omega = 1 - \frac{1}{r}\ln(\frac{kM}{\psi})$ and $\alpha = (1-t)\frac{\pi}{l} - 1$. Focus on the part of the farmer's objective function in equation (7), where $\breve{\tau}_{xt} > 0$; that is, whenever $x \leq x_*$, one writes

$$\text{(A26)} \qquad U^1_{x\hat{\tau}_{xt}} = M - (1-t)\pi x - E(\tilde{l}^1_{x\hat{\tau}_{xt}}) - 0.5\lambda\left(E\left((\tilde{l}^1_{x\hat{\tau}_{xt}})^2\right)\right) + 0.5\lambda\left(E(\tilde{l}^1_{x\hat{\tau}_{xt}})\right)^2.$$

The FOC for the maximization of the preceding utility is

$$\text{(A27)} \qquad \frac{\partial U^1_{x\hat{\tau}_{xt}}}{\partial x} = -\pi(1-t) - 0.5\lambda\frac{\partial\left(E\left((\tilde{l}^1_{x\hat{\tau}_{xt}})^2\right)\right)}{\partial x} + \left[\lambda E(\tilde{l}^1_{x\hat{\tau}_{xt}}) - 1\right]\left(\frac{\partial E(\tilde{l}^1_{x\hat{\tau}_{xt}})}{\partial x}\right) = 0.$$

Recall that the farmer's expected loss with insurance and disaster assistance is

$$\text{(A28)} \qquad E(\tilde{l}^1_{x\hat{\tau}_{xt}}) = q_{lL}(l - lx - q_{D|L}\hat{\tau}_{xt}) + q_{lN}(l - lx) + q_{nL}0 + q_{nN}0,$$

which can be rearranged as $E(\tilde{l}^1_{x\hat{\tau}_{xt}}) = q_l(l-lx) - q_{lL}q_{D|L}\hat{\tau}_{xt}$. The farmer's expected squared loss in the same case is

$$\text{(A29)} \qquad E\left((\tilde{l}^1_{x\hat{\tau}_{xt}})^2\right) = q_{lL}\left(l - lx - q_{D|L}\hat{\tau}_{xt}\right)^2 + q_{lN}(l-lx)^2 + q_{nL}0^2 + q_{nN}0^2.$$

From equations (A28) and (A29), one obtains

$$\text{(A30)} \qquad \frac{\partial E(\tilde{l}^1_{x\hat{\tau}_{xt}})}{\partial x} = -q_l l - q_{lL}q_{D|L}\frac{\partial\hat{\tau}_{xt}}{\partial x}.$$

$$\text{(A31)} \qquad \frac{\partial\left(E\left((\tilde{l}^1_{x\hat{\tau}_{xt}})^2\right)\right)}{\partial x} = q_{lL}2\left(l - xl - q_{D|L}\hat{\tau}(x,t)\right)\left(-l - q_{D|L}\frac{\partial\hat{\tau}_{xt}}{\partial x}\right) + q_{lN}2(l-lx)(-l).$$

Because $\breve{\tau}_{xt} = l\omega + l\alpha x$, where $\alpha = (1-t)\frac{\pi}{l} - 1$ from equation (5), one obtains

$$\text{(A32)} \qquad \frac{\partial\hat{\tau}_{xt}}{\partial x} = l\alpha.$$

Plugging that expression back in equations (A30) and (A31) yields

$$\text{(A33)} \qquad \frac{\partial E(\tilde{l}^1_{x\hat{\tau}_{xt}})}{\partial x} = -q_l l - q_{lL}q_{D|L}l\alpha.$$

Alternatively, rearranging equation (A28) yields $E(\tilde{l}^1_{x\hat{\tau}_{xt}}) = \underbrace{(q_l - q_{lL}q_{D|L}\omega)l}_{=\zeta_0} + \underbrace{x(-q_l - q_{lL}q_{D|L}\alpha)l}_{=\zeta_1}.$

Using the newly defined terms ζ_0 and ζ_1, one can write

$$\text{(A34)} \qquad E(\tilde{l}^1_{x\hat{\tau}_{xt}}) = \zeta_0 + \zeta_1 x.$$

It immediately follows (and verifies equation A33) that

$$\text{(A35)} \qquad \frac{\partial E(\tilde{l}^1_{x\hat{\tau}_{xt}})}{\partial x} = \zeta_1.$$

Rearranging equation (A31) yields

$$\frac{\partial(E((\tilde{l}^1_{x\hat{\tau}_{xt}})^2))}{\partial x} = 2\left[\underbrace{((q_{lL} - q_{lL}q_{D|L}\omega)(-1 - q_{D|L}\alpha) - q_{lM})l^2}_{=\zeta_2} + x\underbrace{((q_{lL}q_{D|L}\alpha + q_{lL})(1 + q_{D|L}\alpha) + q_{lN})l^2}_{=\zeta_3}\right].$$

Using the newly defined terms ζ_2 and ζ_3, one can write

(A36)
$$\frac{\partial\left(E\left((\tilde{l}^1_{x\hat{\tau}_{xt}})^2\right)\right)}{\partial x} = 2(\zeta_2 + \zeta_3 x).$$

Plugging the equations (A34)–(A36) back into equation (A27) yields

(A37)
$$\frac{\partial U_{x\hat{\tau}_{xt}}}{\partial x} = -\pi(1-t) - 0.5\lambda 2(\zeta_2 + \zeta_3 x) + (\lambda(\zeta_0 + \zeta_1 x) - 1)\zeta_1 = 0.$$

Solving equation (A37) for x results in

(A38)
$$x^1_{\hat{\tau}} = \frac{(-\zeta_2 + \zeta_0\zeta_1)}{(\zeta_3 - \zeta_1\zeta_1)} + \frac{-\pi(1-t) - \zeta_1}{\lambda(\zeta_3 - \zeta_1\zeta_1)}.$$

Collect here the corresponding expressions for ζ_0, ζ_1, ζ_2, and ζ_3 (with some rearrangement):

(A39)
$$\begin{aligned}
\zeta_0 &= (q_l - q_{lL}q_{D|L}\omega)\,l,\\
\zeta_1 &= (-q_l - q_{lL}q_{D|L}\alpha)\,l,\\
\zeta_2 &= \left(-q_l + q_{lL}q_{D|L}(\omega - \alpha) + q_{lL}{q_{D|L}}^2\alpha\omega\right)l^2,\\
\zeta_3 &= \left(q_l + 2\alpha q_{lL}q_{D|L} + q_{lL}{q_{D|L}}^2\alpha^2\right)l^2.
\end{aligned}$$

Plugging in the expressions in equation (A38) and rearranging the terms yields the expression given in equation (7).

For convenience, re-express $\check{x}^1_{\hat{\tau}}$ as

(A40)
$$\check{x}^1_{\hat{\tau}} = \frac{\Delta_1}{\Delta_3} + \frac{\Delta_2}{\lambda\Delta_3},$$

where Δ_1, Δ_2, and Δ_3 represent the corresponding terms. Because the expressions in equations (A38) and (A40) must be identical, the following holds:

(A41)
$$\begin{aligned}
\Delta_1 &= (-\zeta_2 + \zeta_0\zeta_1) = \sigma^2_{\tilde{l}1} + (\alpha - \omega)l^2 q_{D|L}q_{lL}(1 - q_l) - \alpha\omega l^2 {q_{D|L}}^2 q_{lL}(1 - q_{lL}),\\
\Delta_3 &= (\zeta_3 - \zeta_1\zeta_1) = \sigma^2_{\tilde{l}1} + 2\alpha l^2 q_{D|L}q_{lL}(1 - q_l) + \alpha^2 l^2 {q_{D|L}}^2 q_{lL}(1 - q_{lL}),\\
\Delta_2 &= -\pi(1-t) - \zeta_1 = -\pi(1-t)(1 - q_{lL}q_{D|L}) + (q_l - q_{lL}q_{D|L})l.
\end{aligned}$$

Going back to the variance formula $\sigma^2_{\tilde{l}^1_{x\hat{\tau}_{xt}}} = E\left((\tilde{l}^1_{x\hat{\tau}_{xt}})^2\right) - \left(E(\tilde{l}^1_{x\hat{\tau}_{xt}})\right)^2$, one can substitute the expressions in equations (A28) and (A29) and re-express $\sigma^2_{\tilde{l}^0_{x\hat{\tau}_{xt}}}$ using the terms in equation (A41) as

(A42)
$$\sigma^2_{\tilde{l}^1_{x\hat{\tau}_{xt}}} = \sigma^2_{\tilde{l}^1_{\hat{\tau}}} - 2\Delta_1 x + x^2\Delta_3,$$

where $\check{x}^1_{\hat{\tau}}$ is replaced with x for convenience and $\sigma^2_{\tilde{l}^1_{\hat{\tau}}}$ is the variance of the farmer's loss when disaster assistance is the only option, from equation (A9) (Online Supplement A, Part 3). The remaining terms shows the additional risk reduction through insurance coverage.

We first collect some useful relations between ω and α. Recall the critical levels of coverage demand, x_* and $\bar{x}_*$, from Lemma 1 and Online Supplement C. Recall also the definitions of ω and α: $\omega = 1 - \frac{1}{r}\ln(\frac{kM}{\psi})$ and $\alpha = (1-t)\frac{\pi}{l} - 1$. (Throughout, $|\cdot|$ indicates the absolute value operator.) Now the following holds:

$$\text{(A43)} \quad \begin{gathered} \omega \geq -\alpha\bar{x}_* > -\alpha x_* \geq -\alpha \check{x}^1_{\hat{\tau}}, \\ \alpha^2 \geq -\alpha\omega \geq \omega^2, \\ |2\alpha| \geq |\alpha - \omega| \geq 2\omega, \\ \omega = -\alpha = (1-p_l), \text{ when } k = \underline{k}_{x=1}, \pi = p_l l, \text{ and } t = 0, \\ 1 \geq -\alpha > \omega = (1-p_l), \text{ when } k = \underline{k}_{x=1},\ \pi = p_l l, \text{ and } t > 0, \\ -\alpha = (1-p_l) > \omega, \text{ when } k > \underline{k}_{x=1}, \pi = p_l l, \text{ and } t = 0. \end{gathered}$$

Recall that $\sigma^2_{\tilde{l}^1_{\hat{\tau}}}$ is the variance of the farmer's loss when the disaster assistance is only option from equation (A9). Now use Δ_0 instead of $\sigma^2_{\tilde{l}^1_{\hat{\tau}}}$ to obtain

$$\text{(A44)} \quad \Delta_0 = \sigma^2_{\tilde{l}^1} + \Delta_0^-,$$

where $\Delta_0^- = -2\omega l^2 q_{D|L} q_{lL}(1-q_l) + \omega^2 l^2 {q_{D|L}}^2 q_{lL}(1-q_{lL})$ and Δ_0^- represents the risk reduction.

Similarly, one can re-express Δ_1 and Δ_3 in terms of their risk-reduction components:

$$\text{(A45)} \quad \Delta_1 = \sigma^2_{\tilde{l}^1} + \Delta_1^-,$$

where $\Delta_1^- = (\alpha - \omega) l^2 q_{D|L} q_{lL}(1-q_l) - \alpha\omega l^2 {q_{D|L}}^2 q_{lL}(1-q_{lL})$, and

$$\text{(A46)} \quad \Delta_3 = \sigma^2_{\tilde{l}^1} + \Delta_3^-,$$

where $\Delta_3^- = 2\alpha l^2 q_{D|L} q_{lL}(1-q_l) + \alpha^2 l^2 {q_{D|L}}^2 q_{lL}(1-q_{lL})$.

One can re-express Δ_1^- and Δ_3^- as $\Delta_1^- = q_{D|L} q_{lL} l^2(-\alpha\omega)\left(\frac{(\alpha-\omega)}{-\alpha\omega}(1-q_l) + q_{D|L}(1-q_{lL})\right)$ and $\Delta_3^- = q_{D|L} q_{lL} l^2 \alpha^2 \left(\frac{2\alpha}{\alpha^2}(1-q_l) + q_{D|L}(1-q_{lL})\right)$. Recall from Online Supplement A, Part 3, that $\frac{\partial \sigma^2_{\tilde{l}^1_{\hat{\tau}}}}{\partial k} > 0$ holds in the domain of interest, which in turn implies that $-(1-q_l) + (1-q_{lL}) q_{D|L}\omega$ is negative in equation (A11). Combining that with the relations given in equation (A43), one obtains $\Delta_1^- < 0$ and $\Delta_3^- < 0$ in equations (A45) and (A46), respectively. Hence, the preceding terms indeed represent respective risk-reduction effects.

Now suppose that insurance, while covering $-\alpha$ portion of the farmer's loss, mimics disaster aid in terms of timing of payments. The implicit coverage level under insurance in that case would be $z^1 = q_{lL} q_{D|L}(-\alpha)/q_l$. Recall from Online Supplement A, Part 3, that the implicit coverage level under disaster aid is $y^1 = q_{lL} q_{D|L}\omega/q_l$. Because $-\alpha \geq \omega$ holds from equation (A43), $z^1 \geq y^1$ follows. Furthermore, one can re-express Δ_0 in terms of the respective implicit coverage level:

$$\text{(A47)} \quad \Delta_0 = \sigma^2_{\tilde{l}^1}\left(\underbrace{1 - 2y^1 + (y^1)^2 \wp}_{=\odot}\right),$$

where $\wp$ is the shorthand notation for $\frac{q_l/q_{lL}}{(1-q_l)/(1-q_{lL})}$. One can verify that the preceding term is greater than 1, which in turn implies that the quadratic equation based on the expression indicated with $\odot$ (refer to it as $\odot$ for the remainder of this section) has no real roots with respect to y^1. Recall that

$0 < y^1 < 1$. For all values of $y^1 \leq 1/2$, $\odot$ is positive. Moreover, the expression is positive even if y^1 took a value of 1. It then must be positive for all values of y^1 between 1/2 and 1. Based on the foregoing, one obtains $\Delta_0 > 0$. Similarly, one can re-express Δ_3 in terms of the respective implicit coverage level:

(A48) $$\Delta_3 = \sigma^2_{\tilde{l}1}\left(1 - 2z^1 + \left(z^1\right)^2 \wp\right),$$

where z^1 and $\wp$ are as defined earlier. Based on a similar reasoning suggested on the sign of Δ_0, one can claim that $\Delta_3 > 0$.

Furthermore, notice that $y^1 = \frac{q_{lL}}{q_l} q_{D|L}\omega < \frac{1}{\wp} = \frac{q_{lL}}{q_l}(1 - q_l)\frac{1}{(1-q_{lL})}$ holds, as the maximum value ω can take is $(1 - p_l)$. In addition, $(1 - p_l) \leq (1 - q_l)$ and $\frac{1}{(1-q_{lL})}$ >1. Based on the first-order derivative, this suggests that $\odot$ in equation (A47) decreases—which in turn implies that Δ_0 decreases—while the implicit coverage level increases and remains lower than $\frac{1}{\wp}$. Now one can know that $z^1 \geq y^1$. First, consider the parameter set: $k = \underline{k}_{x=1}$, $\pi = p_l l$, and $t = 0$. In this case, $\omega = -\alpha = (1 - p_l)$ holds from equation (A43), which in turn implies that $z^1 = y^1$. From equations (A44)–(A46), it follows that

(A49) $$\Delta_0^- = \Delta_1^- = \Delta_3^-; \text{ hence, } \Delta_0 = \Delta_1 = \Delta_3,$$

when $k = \underline{k}_{x=1}$, $\pi = p_l l$, and $t = 0$. Then, the intercept term of $\check{x}^1_{\hat{\tau}}$ in equation (A40) is 1; that is, $\Delta_1 = \Delta_3$ in equation (A42).

Alternatively, consider the parameter subdomain: $k > \underline{k}_{x=1}$, $\pi = p_l l$, and $t = 0$. In this case, $\omega < -\alpha = (1 - p_l)$. Then, $\frac{1}{\wp} > z^1 > y^1$ holds. As discussed earlier, $\Delta_0 > \Delta_3$ will follow.

Also consider the parameter subdomain: $k > \underline{k}_{x=1}$, $\pi = p_l l$, and $t = 0$. In this case, $\omega = (1 - p_l) < -\alpha < 1$, which implies $z^1 > y^1$. Regarding z^1 versus $\frac{1}{\wp}$, now $z^1 = \frac{q_{lL}}{q_l} q_{D|L}(-\alpha) < \frac{1}{\wp} = \frac{q_{lL}}{q_l}\frac{(1-q_l)}{(1-q_{lL})}$ holds whenever $q_{D|L}$ or $-\alpha$ is not too high. The former would be satisfied if $q_{D|L} \leq \bar{q}_{D|L} = \frac{(1-q_l)}{(1-q_{lL})}$, where the $q_{D|L}$ is the upper bound considered in equation (A11) of Online Supplement A, Part 3. Otherwise, $-\alpha$ would remain modest for low to medium subsidy levels. Even under the possibility that $z^1 > \frac{1}{\wp}$, recall that $z^1 < 1$ holds, and z^1 can be far below 1. As such, the value of $\odot$ at z^1 can still remain lower than the value of $\odot$ at y^1. Based on the foregoing, it is apparent that $\Delta_0 \geq \Delta_3 > 0$ holds for at least a large portion of the domain concerning k and t; while $\pi = p_l l$, and for sure for the entirety of the domain of interest if the value of $q_{D|L}$ is not too high or if one is willing to impose the aforementioned upper bound on $q_{D|L}$.

Defining the following functions will prove to be useful:

(A50) $$\begin{aligned} H_1 &= \sigma^2_{\tilde{l}1} + (\alpha - \omega)l^2 q_{D|L} q_{lL}(1 - q_l) - \omega^2 l^2 {q_{D|L}}^2 q_{lL}(1 - q_{lL}), \\ H_3 &= \sigma^2_{\tilde{l}1} + (\alpha + \omega)l^2 q_{D|L} q_{lL}(1 - q_l) + \alpha^2 l^2 {q_{D|L}}^2 q_{lL}(1 - q_{lL}). \end{aligned}$$

Combining equations (A49) and (A50) with the result $\Delta_0 \geq \Delta_3 > 0$ from earlier and using the relationships obtained in equation (A43), one can deduce that $\Delta_0 \geq H_1 \geq \Delta_1 \geq H_3 \geq \Delta_3$. As a result, one can claim that

(A51) $$\Delta_0 \geq \Delta_1 \geq \Delta_3.$$

Finally, upon replacing the perceived probabilities (indicated with q) with the actual probabilities (indicated with p), one obtains the variance-related terms under the farmer's accurate perceptions (no overconfidence), as mentioned in footnote 17,

(A52) $$\begin{aligned} \Xi_0 &= \sigma^2_{\tilde{l}^0_{\hat{\tau}}} = \sigma^2_{\tilde{l}0} - 2p_{lL}p_{D|L}(1 - p_l)\omega l^2 + p_{lL}(1 - p_{lL})p_{D|L}p_{D|L}\omega^2 l^2, \\ \Xi_1 &= \sigma^2_{\tilde{l}0} + (\alpha - \omega)l^2 p_{D|L}p_{lL}(1 - p_l) - \alpha\omega l^2 {p_{D|L}}^2 p_{lL}(1 - p_{lL}), \\ \Xi_3 &= \sigma^2_{\tilde{l}0} + 2\alpha l^2 p_{D|L}p_{lL}(1 - p_l) + \alpha^2 l^2 {p_{D|L}}^2 p_{lL}(1 - p_{lL}). \end{aligned}$$

Recall that $\sigma^2_{\tilde{l}^0}$ is from equation (1)—the variance of the farmer's loss when neither disaster aid nor the insurance option is available—and $\sigma^2_{\tilde{l}^0_{\hat{\tau}}}$ is obtained in equation (A3) in Online Supplement A, Part 2. Finally, Ξ_0, Ξ_1, and Ξ_3 are the counterparts to Δ_0, Δ_1 and Δ_3, respectively. An analysis similar to the one shown here would also apply to the case when farmers are accurate in their perceptions (no overconfidence). Q.E.D. ■