Does Crop Insurance Inhibit Climate-Change Technology Adoption?

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Abstract

Changing temperatures and precipitation patterns from climate change could be a major risk to crop yields. Producers have technology options for mitigating this risk with one such technology termed Drainage Water Recycling (DWR). DWR involves diverting subsurface water to ponds where it is stored for later irrigation. Crop insurance could block DWR adoption by providing producers with another avenue to manage climate-change risk. Its hypothesized there exists a spillover effect from crop insurance, which inhibits climate-change technology adoption. Based on real options, the analysis considers two policy regimes: when crop insurance is in effect and not. In a Poisson jump process, it further considers the insurance effect of producer's returns jumping when facing a crop disaster. Results indicate crop insurance has a minimal effect on DWR adoption, and in most scenarios, the DWR adoption thresholds are too large for a producer to invest for climate-change mitigation. The benchmark DWR adoption scenario requires revenue of at least double the conventional revenue of $649 per acre before a producer would consider adopting.

Keywords: Asset replacement, Climate change, Crop insurance, Greenhouse gases, Technology adoption

Introduction

Historically, U.S. Midwest agricultural production has established a balance with annual mean precipitation and water demand (Lobell et al., 2014). An example is the mitigation of any potential spring excess precipitation with artificial drainage for timely fieldwork and aeration. With climate change, the increased volatility of precipitation and its effect on crop yield may inhibit this balance. Rainfall may not consistently occur when required, leading to enhanced periods of excess precipitation accompanying summer water deficits, which may negatively affect corn and soybean yields (Lobell et al., 2014). Researchers project such variable precipitation caused by climate change to continue (Karl, 2010).

Technology options for mitigating climate change exist. One such technology is drainage water recycling (DWR), which involves diverting subsurface drainage water into on-farm ponds for later irrigation. Federally subsidized crop insurance may play a role in the feasible adoption of DWR. The insurance can have a spillover (secondary or collateral) effect on mitigating yield and revenue losses from climate change. The insurance reduces producers' net-return volatility, which could interfere with the market solutions addressing precipitation-pattern changes such as DWR. The hypothesis is government subsidized crop insurance interferes with DWR adoption.

Investigating this hypothesis involves extending the theory of real options analysis (ROA) for considering the effect possible completing policies and technologies have on adoption. This is the first attempt to study the possible impact of government programs, crop insurance, on adoption of climate-change mitigation technologies, DWR. The theory develops revenue thresholds for Midwest corn production, which suggest investment in DWR with and without crop insurance. By comparing the two revenue thresholds, the analysis evaluates the extent crop insurance interferes with DWR adoption. Results indicate only when reduction in indemnity payments from adopting DWR is close to historical highs will crop insurance spillover and negatively influence DWR adoption.

Literature

Climate-change adaptation may not occur due to limited adoption incentives, public-good market failure, maladaptation, limited technologies, stochastic returns, and climate-change skepticism (Barnett and O'Neill, 2010; Glantz, 1996; McCarl et. al., 2016; Parry et. al., 2009; Rejesus et. al., 2013). In contrast, there are producers who have or plan to adopt climate-change practices. Mase et al. (2016) find in response to climate risks 64% of Midwestern corn producers are managing climate-change risks by implementing conservation practices, 59% purchasing additional crop insurance, and 43% utilizing new technology. It is this interface of climate-change technology adoption and crop insurance, which has not received attention.

Technology options for mitigating climate change vary from developing new crops and tillage practices to implementing irrigation (Smit and Skinner, 2002). Although these options exist, producers face many hurdles. Technology investment will generally not occur unless sunk costs are less than the expected present value of returns by a large hurdle rate. As an example, producers tend to wait until a random event, such as a drought, drives returns significantly above costs before investing in irrigation or conservation tillage (Carey and Zilberman, 2002; Schoengold et al., 2015).

The literature varies on the direction and magnitude crop insurance interferes with production technologies and factor inputs. Past results indicate crop insurance reduces conservation tillage, chemical inputs, and adoption of skip-row plantings (Schoengold et al., 2015; Smith and Goodwin, 1996; Woodard et al., 2012). In contrast, Horowitz and Lichtenberg (1993) find insured producers apply more nitrogen and spend more on pesticides with Babcock and

Hennessy (1996) finding mixed results depending of coverage. Without a clear consensus on the effect of crop insurance on technology adoption, a literature gap exists in determining the level of crop insurance and technology subsidies required for adoption. The question lacking an answer is the level of subsidies triggering adoption.

Related to this question is the work of Dalton et al. (2004) who find federal crop insurance programs are inefficient at reducing weather-related production risk in humid regions. The risk-management benefits from an irrigation system depend on the technology and production scale. Employing a biophysical simulation model, they compare crop insurance and non-irrigation relative to irrigation in an expected utility framework. A direct extension is considering the adoption of irrigation with and without crop insurance. This would address the hypothesis of crop insurance interfering with climate-chance technology adoption.

Generally implementing irrigation and DWR in particular is a major decision, which requires consideration of investment uncertainty, irreversibility, and timing flexibility. ROA incorporates the option value of waiting for future information, which considers uncertainty, irreversibility, and flexibility. A sample of literature in terms of agriculture, Price and Wetzstein (1999) explore irreversible investment decisions in perennial crops with yield and price as correlated stochastic processes and Loren and Tauer (2006) consider the entry/exit conditions of coffee plantations. In particular, for irrigation, Carey and Zilberman (2002) and Seo et al. (2007) employ ROA for determining the adoption trigger and Jeuland and Whittington (2014) investigate irrigation adoption under climate change. Based on previous literature, an investigation of crop insurance impact on climate-change technology adoption requires extending the theory to consider the correlation of climate-change yield effects with and without mitigating technology along with a disruptive program, crop insurance.

Crop Insurance

Within Indiana, the most common crop insurance policy purchased is Revenue Protection (RP), which currently accounts for 85% of insurance policies (RMA, 2018). RP ensures producers receive a certain level of revenue per acre instead of a payment solely based on yield or price (Plastina and Edwards, 2014).

In Indiana, the minimum (maximum) coverage level for RP insurance is 50% (85%) of revenue (RMA, 2018). Producers can elect to insure their acres by basic, optional, or enterprise unit coverage. Basic combines all of the crop units, whereas optional separates units of a single crop by type or practice. Enterprise allows for the combination of all acres of the same crop in the same county. A further segment is enterprise by practice where within a county separated fields by practice exist (irrigated vs non-irrigated).

Determining the possible influence of crop insurance on DWR adoption requires knowing the change in expected net insurance payout from adopting DWR. With adoption, producers would generally switch their RP insurance units from enterprise to enterprise by practice. This would allow the separation of irrigated and non-irrigated fields (Cole, 2018). If a producer switches to enterprise by practice, they are required to decrease the level of insurance on irrigated acres. This results in ambiguities on the magnitude and direction of the expected change in net crop insurance payout from adopting DWR. If producers switch from enterprise to enterprise by practice, their premiums will decrease given the imposed decline in coverage level. The magnitude depends on the initial coverage and the associated change following DWR adoption. With basic or optional units, a move to enterprise by practice would also realize a reduction in premiums from higher premium subsidies associated with enterprise units relative to basic or optional units. A move from basic or optional units to enterprise units would also affect revenue guarantees and thus expected indemnities. In contrast, the reduced yield risk associated with DWR will decrease expected indemnity with a lag in the requirement to build up a production history. In general, the direction of expected net insurance payout from adopting DWR is indeterminate and influenced by the net change in premiums and indemnity. If the decline in premium the producer pays is greater (less) than any possible gain in the expected indemnity, then the direction is negative (positive).

Stochastic Yield and Price

The stochastic nature of price, p, and yield, q, may be represented by geometric Brownian motion processes

$$dp = \alpha_p p dt + \sigma_p p dz_p,$$

$$dq = \alpha_q q dt + \sigma_q q dz_q,$$

where *dp* and *dq* represent the change in the per-bushel price and yield of corn, respectively, α is the rate of change or drift rate, σ denotes the standard deviation or volatility. The increment of a Wiener process is *dz*, with $E\left(dz_p^2\right) = E\left(dz_q^2\right) = dt$ and $E\left(dz_p dz_q\right) = \rho_R dt,$ where ρ_R denotes the correlation coefficient between p and q. Following Price and Wetzstein (1999), letting revenue be $R = pq$, the stochastic process of revenue is then

$$dR = \alpha_R R dt + \sigma_R R dz_R,$$

where $\alpha_R = \alpha_p + \alpha_q + \rho_R \sigma_p \sigma_q$ and $\sigma_R = (\sigma_p^2 + \sigma_q^2 + 2\rho_R \sigma_p \sigma_q)^{1/2}$.

Let the returns in period *t* with and without DWR be R_D and R_C, respectively. Allowing both price and yield to fluctuate randomly, two correlated geometric Brownian motion processes result

$$dR_C = \alpha_C R_C dt + \sigma_C R_C dz_C \,, \tag{1a}$$

$$dR_D = \alpha_D R_D dt + \sigma_D R_D dz_D \,, \tag{1b}$$

where α_C and α_D are associated with α_R, and σ_C and σ_D are associated with σ_R. The increment of a Wiener process is *dz* with the properties $E(dz_C^2) = E(dz_D^2) = dt$ and $E(dz_C dz_D) = \rho dt$, where ρ is the correlation coefficient between the uncertainties incorporated in the change of the two revenues.

The Role of Crop Insurance

DWR is not the only risk mitigating option available to the producer. Various government programs exist for a producer to avoid downside risk. One such predominant program is crop insurance. The availability of crop insurance results in producer's returns jumping when faced with a crop disaster. The effect is Poisson type policy jump on DWR adoption, investigated with the theory of investment under uncertainty. With DWR mitigating the adverse effects of weather on revenue, the expected net insurance payout, indemnity minus premium, may change with DWR adoption. Let $\theta > 0$ represent an expected decline ($\theta < 0$ an expected increase) with $\lambda_1 dt$ denoting if no current crop insurance indemnity the probability of receiving an indemnity in the next time interval, *dt*. Similarly, if receiving an indemnity currently, let $\lambda_0 dt$ represent the probability of not receiving an indemnity in the next time interval. Following closely Dixit and Pindyck (1994) along with Lin and Huang (2010, 2011), the theory assumes a producer is contemplating adopting DRW with sunk cost *I*.

Considering the range of returns, over the interval of low returns $(0, R_D^1)$, producers will not adopt DWR regardless if there is crop insurance or not. Over the interval (R_D^1, R_D^0), DWR will be adopted if there is no crop insurance, but producers will wait if there is insurance with the possibility of receiving a net insurance payout. Beyond R_D^0 the prospect of immediate revenues will be so large, the producer will adopt DWR regardless if there is crop insurance or not. As illustrated in Figure 1, interest is in determining the threshold returns R_D^1 and R_D^0, relative to R_C, where within this revenue interval no crop insurance is effective in stimulating DWR adoption.

Interval (R_D^0, ∞): Adopt DWR

Over the range *(R_D^0, ∞)*, the dominant strategy is to always adopt DWR regardless if there is crop insurance or not. The value of the investment opportunity is then

$$V^0(R_D - R_C) = \frac{R_D}{r-\propto_D} - \frac{R_C}{r-\alpha_C} - \frac{v}{r} - I, \tag{2a}$$

in the absence of crop insurance and

$$V^1(R_D - R_C) = \frac{R_D}{r-\propto_D} - \frac{R_C}{r-\alpha_C} - \frac{v+\theta}{r} - I, \tag{2b}$$

with crop insurance, where parameters *v* and *r* denote the DWR operating costs and the risk-free discount rate, respectively.

Interval (R_D^1, R_D^0): Disruptive Crop Insurance

In contrast, over the range *(R_D^1, R_D^0),* without crop insurance, DWR is adopted and with, it is not. Adoption without crop insurance is the same as (2a) and with, $V^1(R_D - R_C)$ differs from (2b). In the next time interval, *dt,* with crop insurance there will be a probability $\lambda_0 dt$ of no payment and DWR adopted with value $V^0[R_D - R_C + d(R_D - R_C)]$. DWR adoption will not occur with a payment, yielding a value of $V^1[R_D - R_C + d(R_D - R_C)]$. This yields

$$\begin{aligned} V^1(R_D - R_C) = e^{-rdt}\{&\lambda_0 dt EV^0[R_D - R_C + d(R_D - R_C)] \\ &+ (1 - \lambda_0 dt)EV^1[R_D - R_C + d(R_D - R_C)]\}, \end{aligned}$$

where *E* is the expectation operator. This is the probability of not receiving a payment times the value of DWR plus the probability of receiving a payment times the value of no DWR.

The Bellman equation yielding the optimal timing for DWR adoption with crop insurance (waiting to invest) is

$$E[dV^1(R_D - R_C)] = \{rV^1[R_D - R_C] - \lambda_0[V^0[R_D - R_C] - V^1[R_D - R_C]]\}dt\,, \tag{3}$$

where over the time interval *dt* the expected rate of capital appreciation, $dV^1[R_D - R_C]$, is equal to the total expected return, the right-hand side of (3). This total expected return consists of the discount rate *r* times the investment value with crop insurance mitigated by the expected capital gain from not having crop insurance, the last term in (3).

Expanding the left-hand-side of (3) by employing Ito's Lemma and substituting (1) results in

$$E[dV^1[R_D - R_C]] = \alpha_{RC} R_C V_C^1 \; + \; \alpha_{RD} R_D V_D^1$$
$$+ \tfrac{1}{2}(V_{CC}^1 \sigma_{RC}^2 R_C^2 + 2\rho V_{CD}^1 \sigma_{RC}\sigma_{RD} R_D R_C + V_{DD}^1 \sigma_{RD}^2 R_D^2)dt,$$

where $V_i^1 = \frac{\partial V^1}{\partial R_i}$ and $V_{ij}^1 = \frac{\partial^2 V^1}{\partial R_i R_j}$, i, *j* = *D*,*C*.

The Bellman (3) is then

$$\tfrac{1}{2}(V_{CC}^1 \sigma_{RC}^2 R_C^2 + 2\rho V_{CD}^1 \sigma_{RC}\sigma_{RD} R_D R_C + V_{DD}^1 \sigma_{RD}^2 R_D^2) + \alpha_{RC} R_C V_C^1 \; + \; \alpha_{RD} R_D V_D^1 - rV^1$$
$$+ \lambda_0[V^0 - V^1] = 0. \tag{4}$$

The last term captures the expected capital gain from no crop insurance. This is a partial differential equation with a free-boundary condition.

As noted by Dixit and Pindyck (1994), analytical solutions are rare with numerical solutions generally only tailored for a particular problem. For this problem, a solution is possible by exploiting its homogeneity nature, which reduces it to one dimension. If the returns for DWR adoption and non-adoption are double, then the value of the investment will also double. The optimal decision then depends the ratio $\omega = \frac{R_D}{R_C}$. This yields expression

$$V^i(R_D - R_C) = R_C f^i\left(\frac{R_D}{R_C}\right) = R_C f^i(\omega),\; i = 0,\, 1.$$

The partial differentiations are then

$$V_D^i = f_\omega^i(\omega),\; V_C^i = f(\omega) - \omega f_\omega^i(\omega),$$

$$V_{DD}^{i} = \frac{f_{\omega\omega}^{i}(\omega)}{R_C},\ V_{DC}^{i} = -\frac{\omega f_{\omega\omega}^{i}(\omega)}{R_C},$$

$$V_{CC}^{i} = \frac{\omega^2 f_{\omega\omega}^{i}(\omega)}{R_C},\ i = 0,\ 1. \tag{5}$$

Substituting (5) into (4) and rearranging

$$\frac{1}{2}(\sigma_{RC}^2 - 2\rho\sigma_{RC}\sigma_{RD} + \sigma_{RD}^2)\omega^2 f_{\omega\omega}^1(\omega) + (\delta_C - \delta_D)\omega f_{\omega}^1(\omega) - \delta_C f^1(\omega) + \lambda_0[f^0(\omega) - f^1(\omega)] = 0, \tag{6a}$$

where $\alpha_i = r - \delta_i$, and $f_{\omega}^1(\omega) = \frac{\partial f^1}{\partial\omega}$ and $f_{\omega\omega}^1(\omega) = \frac{\partial^2 f^1}{\partial\omega^2}$.

Solving (6a) yields

$$f^1(\omega) = A_1\omega^{\beta_1} + A_2\omega^{\beta_2} + \frac{\lambda_0\omega}{\delta_D(\delta_D+\lambda_0)} - \frac{\lambda_0(\frac{1}{\delta_C}+\frac{v}{rR_C}+\frac{I}{R_C})}{\delta_C+\lambda_0}, \tag{6b}$$

where A_1 and A_2 are constants and β_1 and β_2 are the positive and negative characteristic roots of the quadratic equation

$$\tfrac{1}{2}\sigma^2 \beta(\beta - 1) + (\delta_C - \delta_D)\beta - (\delta_C + \lambda_0) = 0,$$

where $\sigma^2 = \sigma_{RC}^2 - 2\rho\sigma_{RC}\sigma_{RD} + \sigma_{RD}^2$.

Interval $(0,R_D^1)$: Wait to Adopt DWR

In the final range $(0,R_D^1)$, the decision to adopt DWR is postponed regardless if there is crop insurance or not. Over this range, the differential equation for determining when to adopt DWR with crop insurance is (6a). Similarly, given no crop insurance, the differential equation for determining when to adopt DWR is

$$\frac{1}{2}(\sigma_{RC}^2 - 2\rho\sigma_{RC}\sigma_{RD} + \sigma_{RD}^2)\omega^2 f_{\omega\omega}^0(\omega) + (\delta_C - \delta_D)\omega f_{\omega}^0(\omega) - \delta_C f^0(\omega) + \lambda_1[f^1(\omega) - f^0(\omega)] = 0. \tag{7}$$

As demonstrated by Dixit and Pindyck (1994), (6a) and (7) yield solutions to the differential equations for the range $(0,R_D^1)$

$$f^{1}(\omega) = (\lambda_0\lambda_1 G\omega^{\beta_a} + \lambda_0 H\omega^{\beta_s})/(\lambda_0 + \lambda_1), \tag{8a}$$

$$f^{0}(\omega) = (\lambda_0\lambda_1 G\omega^{\beta_a} - \lambda_1 H\omega^{\beta_s})/(\lambda_0 + \lambda_1), \tag{8b}$$

where β_a and β_s are roots of quadratic equations with G and H parameters.

Solving the System of Equations: Value Matching and Smoothing Pasting Conditions

At the threshold R_D^1, there will be DWR adoption with no crop insurance, which leads to equality of (2.2a) and (2.8b) yielding the following value-matching and smooth-pasting conditions

$$(\lambda_0\lambda_1 G(\omega^1)^{\beta_a} - \lambda_1 H(\omega^1)^{\beta_s})/(\lambda_0 + \lambda_1) = \frac{\omega^1}{r-\alpha_{RD}} - \frac{1}{r-\alpha_{RC}} - \frac{v}{rR_C} - \frac{I}{R_C}, \text{ value matching,} \tag{9a}$$

$$(\lambda_0\lambda_1\beta_a G(\omega^1)^{\beta_a-1} - \lambda_1\beta_s H(\omega^1)^{\beta_s-1})/(\lambda_0 + \lambda_1) = 1/\delta_D, \text{ smooth pasting,} \tag{9b}$$

where $\omega^1 = R_D^1/R_C$.

For the R_D^0 threshold, the conditions are the equality of (6b) and (2b), yielding

$$A_1(\omega^0)^{\beta_1} + A_2(\omega^0)^{\beta_2} + \frac{\lambda_0\omega^0}{\delta_D(\delta_D+\lambda_0)} - \frac{\lambda_0(\frac{1}{\delta_C}+\frac{v}{rR_C}+\frac{I}{R_C})}{\delta_C+\lambda_0} = \frac{\omega^0}{r-\alpha_{RD}} - \frac{1}{r-\alpha_{RC}} - \frac{v-\theta}{rR_C} - \frac{I}{R_C}, \text{ value matching,} \tag{9c}$$

$$A_1\beta_1(\omega^0)^{\beta_1-1} + A_2\beta_2(\omega^0)^{\beta_2-1} + \frac{\lambda_0}{\delta_D(\delta_D+\lambda_0)} = 1/\delta_D, \text{ smooth pasting,} \tag{9d}$$

where $\omega^0 = R_D^0/R_C$.

Following Dixit and Pindyck (1994), the last conditions are the equality of (6b) and (8a), yielding

$$(\lambda_0\lambda_1 G(\omega^1)^{\beta_a} + \lambda_0 H(\omega^1)^{\beta_s})/(\lambda_0 + \lambda_1) = A_1(\omega^1)^{\beta_1} + A_2(\omega^1)^{\beta_2} + \frac{\lambda_0\omega^1}{\delta_D(\delta_D+\lambda_0)} - \frac{\lambda_0(\frac{1}{\delta_C}+\frac{v}{rR_C}+\frac{I}{R_C})}{\delta_C+\lambda_0}, \tag{9e}$$

$$(\lambda_0\lambda_1\beta_a G(\omega^1)^{\beta_a-1} + \lambda_0\beta_s H(\omega^1)^{\beta_s-1})/(\lambda_0 + \lambda_1) = A_1\beta_1(\omega^1)^{\beta_1-1} + A_2\beta_2(\omega^1)^{\beta_2-1} + \frac{\lambda_0}{\delta_D(\delta_D+\lambda_0)}. \tag{9f}$$

The six equations in (9) are solved numerically for the two triggers, R_D^0 and R_D^1, and the four parameters A_1, A_2, G, and H.

As a comparison, NPV analysis for when crop insurance is not effect is

$$\omega^{NPV0} = (r - \propto_D)\left(\frac{1}{r - \propto_C} + \frac{v}{rR_C} + \frac{I}{R_C}\right),$$

and when it is in effect is

$$\omega^{NPV1} = (r - \propto_D)\left(\frac{1}{r - \propto_C} + \frac{v + \theta}{rR_C} + \frac{I}{R_C}\right).$$

The threshold values represent the per acre level of revenue a producer requires to invest in DWR.

Yield and Price Data

The Variable Infiltration Capacity (VIC) model with the CropSyst crop simulation model simulate estimates for future (2041-2070) irrigated and non-irrigated west-central Indiana corn yield (Bowling et. al., 2018). The simulation assumes a high future greenhouse gas concentration with a Representative Concentration Pathway of 8.5, which corresponds to the pathway with the highest greenhouse gas emissions (Riahi et al., 2011). CropSyst also provides non-irrigated and irrigated yield data for the historic period (1984-2013). Indiana corn price data (1984-2013) are from the NASS Quick Stats website (NASS, 2018) adjusted by corn commodity PPI from the U.S. Bureau of Labor Statistics.

Unit Root Analysis

For determining whether or not the price and yield processes have unit roots (follow geometric Brownian motion), consider the augmented Dickey-Fuller (ADF) test employing an AR(1) process. Model selection employed the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). Results indicate yield and price are represented by an AR(1) process. The ADF test fails to reject the null hypothesis that the data series contain a unit root for both price and yield data at even the 40% significance level.

Cost Data

The baseline sunk and variable cost scenario assumes a west-central Indiana impounded pond system, requiring no excavation with a field size of 160 acres. The assumed irrigation type is diesel powered center pivot. The sunk cost includes the construction, land, pivot, and pumping plant. The variable cost includes the annual land cost, electricity, and labor. The total irrigated acreage of the field is 132 acres excluding the non-irrigated field corners, so per-acre costs are calculated based on the total irrigated acreage (Reinhart and Frankenberger, 2018). Table 1 lists the sunk and variable costs by category.

Crop Insurance Data

For analysis, a baseline value of $\theta = 0$ is set. For determining the range of θ, the RMA Summary of Business Reports by State/County/Crop/Coverage Level from 2011-2017 is employed. For Indiana, the data contain total premium, subsidy, and indemnity payment by coverage level for RP insurance. Dividing the data by the number of acres insured determines the associated mean per acre. Subtracting the per-acre premium from the indemnity yields the annual payout received per acre. The overall average across all the years is then determined for each coverage level, which yields the total average per-acre payout. This average ranges from $19.99 to $52.58 for a 50% and 70% coverage level, respectively. The change in the net insurance payout is assumed to be within a range similar to the absolute net payout, ±$30.

Estimation Procedure

Table 2 lists the benchmark parameter values and parameter ranges for the sensitivity analysis. Follwing Dixit and Pindyck (1994) and supported by the ADF test, price and yield follow geometric Brownian motion with their logarithms following a simple Brownian motion

$$d(lnx) = \left(\alpha - \frac{1}{2}\sigma^2\right) dt + \sigma dz.$$

where $d(lnx)$ follows a normal distribution with mean μdt and variance $\sigma^2 dt$ over a finite time interval t. Absolute changes in x, Δx, are lognormally distributed.

For the first difference of the logarithm of historical prices, non-irrigated and irrigated future yield, the drift, μ, and volatility, σ, are estimated by applying the maximum likelihood method to the simple Brownian motion

$$\hat{\mu} = \bar{\gamma} = \frac{1}{n}\sum\nolimits_{t=1}^{n} \gamma_t,$$

$$\hat{\sigma} = std\ (\gamma_t) = \sqrt{\tfrac{1}{n}\textstyle\sum_{t=1}^{n}(\gamma_t - \hat{\mu})^2}\,. \tag{10a}$$

where *n* is the number of observations and $\gamma_t = \Delta x_t \,/\, x_t$. The estimate for drift is

$$\hat{\alpha} = \hat{\mu} + \tfrac{1}{2}\hat{\sigma}^2. \tag{10b}$$

Equations (10) are employed to estimate price drift, α_p, and volatility, σ_p, conventional yield drift, α_C, and volatility, σ_C, DWR yield drift, α_D, and volatility, σ_D.

The conventional revenue drift, α_{RC}, and volatility, σ_{RC}, are

$$\alpha_{RC} = \alpha_p + \alpha_C + \rho_C \sigma_C \sigma_p,$$

$$\sigma_{RC} = \sqrt{{\sigma_p}^2 + {\sigma_C}^2 + 2\rho_C \sigma_p \sigma_C}\,.$$

and DWR revenue drift, α_{RD}, and volatility, σ_{RD}, are

$$\alpha_{RD} = \alpha_p + \alpha_D + \rho_D \sigma_D \sigma_p,$$

$$\sigma_{RD} = \sqrt{{\sigma_p}^2 + {\sigma_D}^2 + 2\rho_D\sigma_p\sigma_D}\ .$$

Parameters ρ_C and ρ_D are the correlation between price and historical conventional and irrigated yield, respectively.

Overall revenue volatility is

$$\sigma_R = \sigma_{RC}^2 - 2\rho_R\sigma_{RC}\sigma_{RD} + \sigma_{RD}^2,$$

where ρ_R denotes the correlation coefficient between DWR and conventional revenue.

Results and Discussion

Populating the models with the benchmark parameters yields revenue thresholds for DWR adoption with and without crop insurance. With change in expected net insurance payout from adopting DWR, $\theta = 0$, the revenue thresholds are equivalent. Table 3 lists the benchmark ROA and NPV under crop insurance distortion scenarios where $\theta = \pm\$30$. Employing NPV indicates investing much sooner than ROA. The difference between NPV and ROA has major implications for policy makers. If they focus on NPV results, then a much smaller policy nudge (incentive) is required to trigger DWR adoption. With zero net change in insurance payout, the revenue threshold considering real options is markedly higher, \$1358, than the NPV theshold, \$810. Considering the value of waiting to adopt plus the stochastic nature of adoption yields a hurdle rate of 168%. Revenue has to be 67% higher for adoption under ROA compared with NPV. The ability to wait has value given the cost of investment decreases by a larger discount factor than the revenue it generates. This value of waiting option is also associated with the stochastic nature of adoption. Revenue may fall in subsequent periods after adoption, which discourages adoption. There is a value to waiting, option value, which once the option is exercised it is lost. The results indicate this option value for DWR adoption is \$548 (1358 – 810).

Considering the effect of crop insurance does not have much of an impact on the adoption thresholds (Table 3). In the extreme, a net decrease in insurance payout from adoption of DWR of \$30 only increases the adoption triggers for ROA and NPV by 2.02% (1361/1334) and 1.48% (822/810), respectively. The elasticity of the net change in insurance payout with insurance at $\theta = 30$ is 0.220, highly inelastic. The low change in net insurance payout from DWR adoption does not result in much, if any, increase in the revenue thresholds. Crop insurance does not appear to influence the adoption of DWR. This maybe the result of crop insurance and DWR addressing different types of risk. DWR addresses yield loss from inadequate moisture by reducing crop-moisture stress between rainfall events. This yield enhancement positively effects yields. In contrast, crop insurance, as designed, covers catastrophic weather events including major droughts within a growing season. In the current time period, catastrophic weather events do not occur every year and a producer does not continually receive a large payout in crop insurance over an extend period of time. Crop insurance has little influence on the economics on efforts to enhance yields through relieving crop stress between periods of rainfall. There appears to be limited if any crowding out of DWR by crop insurance. In general, results indicate crop insurance as a program for addressing catastrophic weather events is not inhibiting adoption of technology for addressing negative agricultural weather effects from climate change.

Sensitivity Analysis

In terms of varying sunk and variable costs, they have similar positive linear effects on the revenue threshold. For the producer considering the DWR investment decision, all DWR sunk and variable cost scenarios are too large to consider investment in DWR. The sunk and variable cost elasticities, at the benchmark value, are 0.165 and 0.019, respectively, highly inelastic. The implication of these elasticities is any type of DWR investment and/or operating cost subsidy may not be very effective.

In contrast, as illustrated in Figures 2 and 3, a large respond in the revenue thresholds result from varying the drift rates. The benchmark value for the conventional revenue drift rate is calculated employing detrended yield data, so there is no assumed upward yield trend. An increase in yield from technical change is likely to drive any future change in the revenue drift. The thresholds increase (decrease) as the conventional (DWR) revenue drift rate increases. Similar results hold for varying the conventional and DWR revenue volatilities.

For further sensitively analysis, consider a Monte Carlo simulation generating 5000 random draws of the parameters, employing a uniform probability distribution over the parameter ranges listed in Table 2. Figure 4 illustrates the CDF for the ROA and NPV revenue thresholds with and without crop insurance. NPV is left-skewed relative to the ROA distributions. For the ROA Monte Carlo, less than ½% of revenue thresholds without and with crop insurance are below the conventional revenue \$649.00 per acre. This is in contrast to the NPV Monte Carlo with more than 10% of the revenue thresholds below the conventional revenue.

Probability of Indemnity Payment

For crop insurance as a DWR substitute with $\theta = 30$, the revenue threshold for DWR adoption increases (decreases) as the probability of receiving an indemnity (withdrawn) increases (Tables A1 and A2). The threshold changes across these probabilities represent a very small impact from payment uncertainty. Similar results occur for crop insurance complementing insurance at $\theta = -30$ (Tables A3 and A4). Policy uncertainty is not a big driver for DWR adoption.

DWR Subsidy

Midwest corn production results in nutrient runoff into surface and groundwater, external costs. Policymakers may consider subsidizing DWR in attempt to internalize these possible external costs. If the sunk cost of the DWR adoption is completely subsidized, $I = 0$, the NPV and ROA revenue thresholds are $676 per acre and $1133 per acre, respectively. The NPV revenue threshold is close to the conventional revenue of $649 per acre, which indicates producers may now consider adopting DWR. In contrast, the ROA revenue threshold is 75% higher than the conventional revenue, indicating producers are still likely not to currently consider adopting DWR even if sunk cost is completely subsidized. This is the result of additional variable cost greater than any expected yield gains from DWR. The DWR yield drift and volatility are very close to the conventional yield drift and volatility in the benchmark scenario. If the DWR yield volatility decreases and yield drift increases relative to conventional yield, DWR adoption would become more favorable. Without this yield enhancement, ROA suggests delaying the adoption decision. If climate change widens the drift and volatility between conventional and irrigated yields, then DWR may become feasible.

A possible feasible DWR adoption exists by setting a larger revenue drift for DWR, $\alpha_{RD} = 0.057$, relative to conventional, $\alpha_{RC} = 0$, and retaining zero DWR sunk cost. This yields the revenue thresholds of $735 and $639 with and without crop insurance, respectively. The result indicates adoption of DWR without and delay with crop insurance. If climate change causes conventional yield to decrease, DWR yield to increase, and if the sunk cost of DWR is completely subsidized, then adopting DWR now could become feasible.

Applying the same scenario with NPV criterion, the revenue thresholds are \$12.18 and \$11.61 per acre when crop insurance is and is not in effect. NPV suggests investing in DWR regardless of crop insurance.

Conclusion and Policy Implications

If crop insurance is a substitute for climate-change technology, then by definition it will inhibit adoption and the hypothesis is correct that government subsidized crop insurance interferes with climate-change technology such as DWR. The issue is then the magnitude or degree of interference. Results indicate this magnitude is small and not inhibiting DWR adoption. DWR and crop insurance are not perfect substitutes. They are managing different risk losses: shallow and deep losses. DWR manages shallow losses, such as short summer dry periods, which negatively effects yields. In contrast, crop insurance as designed manages deep loss, where the whole crop is lost or markedly reduced, such as a seasonal drought. Producers will generally not base their DWR adoption decisions on whether they have crop insurance.

DWR is a niche climate-adaption strategy. It is effective in short summer dry periods, but if climate change causes more frequent and prolonged droughts, then DWR will be ineffective. There is not enough pond capacity to main a prolonged irrigation schedule. If short dry periods become more frequent, then DWR possibly becomes a feasible climate-change adaption strategy.

Results indicate producers will not currently adopt DWR. Adoption DWR is infeasible as a consequence of high sunk and variable costs with only marginal reduction on climate-change risk. For improved feasibility, irrigated yields would have to be markedly higher and less volatile than conventional with lower adoption costs. A producer may consider instead climate-change adaption technologies including drought resistant seeds or precision technology. If a producer already has part of the DWR system in place, such as the pond or irrigation system, this could improve the feasibility of DWR adoption by lowering the large costs of DWR.

DWR has potential social welfare benefits. By capturing drained water from fields, DWR reduces nutrient runoff into water systems. Focusing solely on producers' DWR adoption, results do not consider any possible social welfare benefits of DWR adoption. Internalizing possible large DWR welfare benefits would positively influence DWR adoption. For any internalizing, results do not support a Pigouvian subsidy. A large decrease in sunk or variable costs resulted in minimal revenue-threshold declines.

The results do support the importance of considering option value of investment decisions. In general, NPV suggests considering adoption then ROA suggests waiting. For all the results, there is a large wedge between NPV and ROA.

In conclusion:

> Agriculture sustainability advocates need to be invested in the overall financial success of farmers and change course when conservation adoption does not help farmers remain viable (Monast et. al., 2018).

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Table 1. West-Central Indiana Impounded DWR 160 Acre Field Benchmark Cost Scenario

	Total Cost	$/acre
Sunk Cost		
Construction (NRCS, 2018)	$671,000	$5,083
Land (PAER, 2018)	96,000	727
Pivot (Kelley, 2018)	75,000	568
Pumping Plant (Dahl, 2018)	18,000	136
Total Sunk Cost	$860,000	$6,515
Variable Cost		
Diesel (EIA, 2018)	2,000	15
Labor (NASS, 2013)	3,000	23
Total Variable Cost	$5,000	$38

Table 2. Benchmark Values and Parameter Ranges for Real Options DWR

Description	Parameter	Benchmark	Range	
			Lower	Upper
Conventional Revenue (dollars/acre)	R_C	649.00		
Price Drift	α_p	0.026		
Price Volatility	σ_p	0.241		
Conventional Yield Drift	α_C	0.011		
Conventional Yield Volatility	σ_C	0.122		
Correlation between Price and Conventional Yield	ρ_C	−0.247		
DWR Yield Drift	α_D	0.011		
DWR Yield Volatility	σ_D	0.120		
Correlation between Price and DWR Yield	ρ_D	−0.264		
Conventional Revenue Drift	α_{RC}	0.030	0.000	0.040
Conventional Revenue Volatility	σ_{RC}	0.242	0.000	0.500
DWR Revenue Drift	α_{RD}	0.029	0.000	0.040
DWR Revenue Volatility	σ_{RD}	0.239	0.000	0.500
Correlation coefficient between the uncertainty incorporated in the change of the two revenues	ρ_R	0.900	0.000	0.990
Revenue Volatility	σ_R	0.012		
Discount Rate (percent)	r	5.00	4.00	10.00
Variable cost of adopting DWR (dollars/acre)	v	38.00	25.00	260.00
Sunk cost of adopting DWR (dollars/acre)	I	6515	3500	9300

Probability no indemnity in the next time interval	λ_0	0.010	0.010	0.400
Probability of an indemnity in the next time interval	λ_1	0.010	0.010	0.400
Change in expected net insurance payout from adopting DWR (dollars/acre)	θ	0.00	−30.00	30.00
Conventional Revenue (dollars/acre)	Rc	649		
The difference between the expected rate of return and the expected capital gain with no DWR.	δ_C	0.020		
The difference between the expected rate of return and the expected capital gain with DWR.	δ_D	0.021		

Table 3. Real Options Analysis and Net Present Value Benchmark Results for Different Levels of Change in Expected Net Crop Insurance Payout, θ[a]

	$\theta = \$30$	$\theta = \$15$	$\theta = \$0$	$\theta = -\$15$	$\theta = -\$30$
Real Options Analysis					
Revenue threshold trigger when crop insurance is not in effect, R_D^0	\$1334 (2.06)	\$1346 (2.08)	\$1358 (2.09)	\$1370 (2.11)	\$1382 (2.13)
Revenue threshold trigger when crop insurance is in effect (R_D^1)	\$1361 (2.10)	\$1360 (2.10)	\$1358 (2.09)	\$1357 (2.09)	\$1355 (2.09)
Net Present Value					
Revenue threshold trigger when crop insurance is not in effect (NPV_0)	\$810 (1.25)	\$810 (1.25)	\$810 (1.25)	\$810 (1.25)	\$810 (1.25)
Revenue threshold trigger when crop insurance is in effect (NPV_1)	\$822 (1.26)	\$816 (1.26)	\$810 (1.25)	\$804 (1.24)	\$797 (1.23)

[a] Revenue threshold ratio, ω, in parentheses with \$649.00 conventional revenue, R_C.

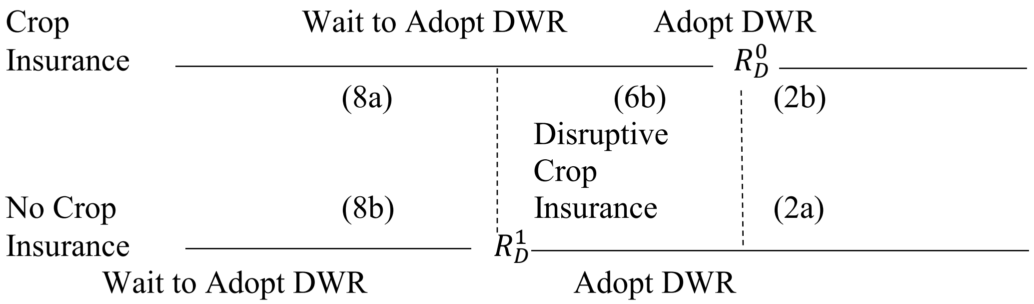

Figure 1. Revenue threshold for adoption of drainage water recycling, DWR

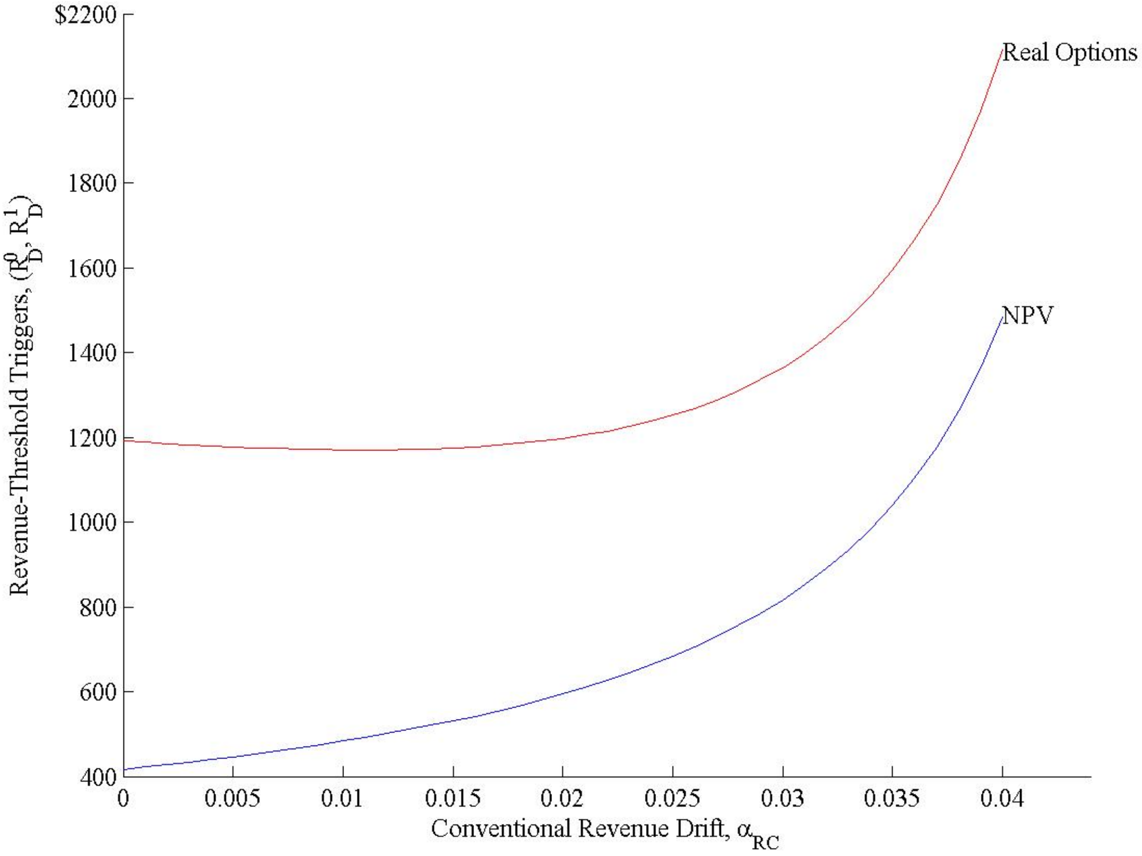

Figure 2. Response of revenue thresholds to conventional revenue drift

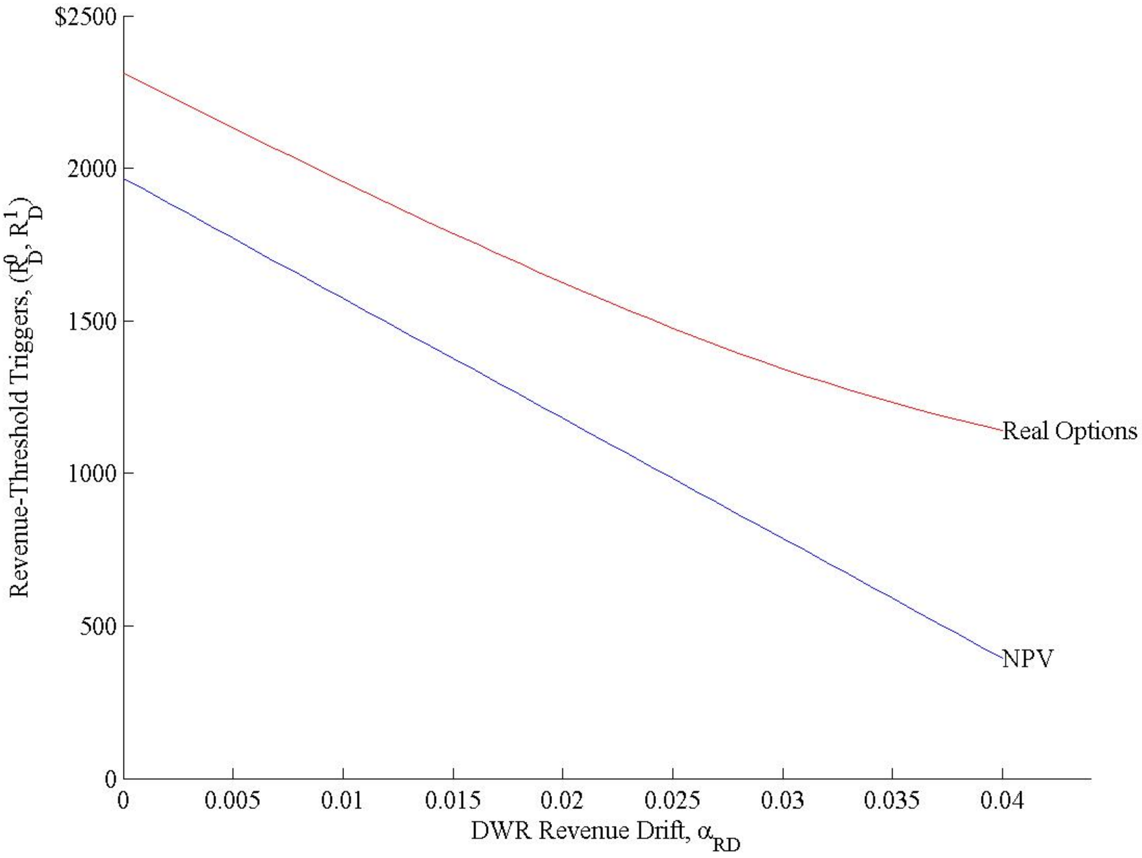

Figure 3. Response of revenue thresholds to DWR revenue drift

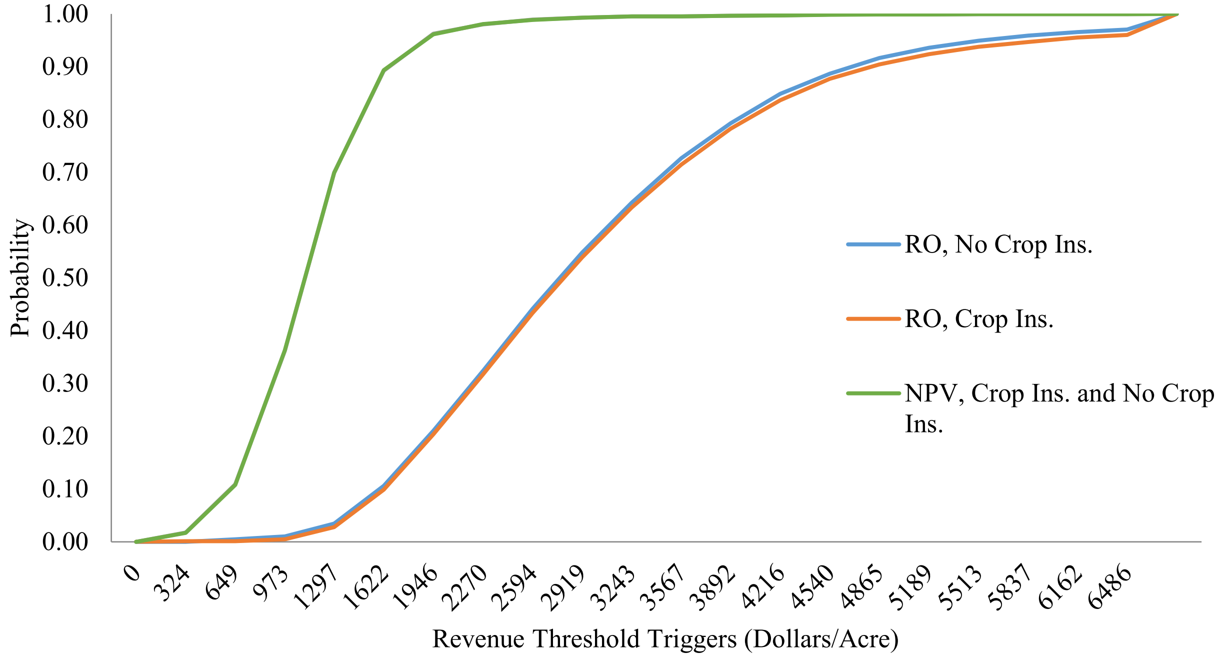

Figure 4. CDF of revenue thresholds

Table A1. Per-Acre Revenue Threshold when Crop Insurance is in not in Effect,R_D^0, and change in Expected Net Insurance Payment, θ is \$30 per acre

λ_1^a								
λ_0^b	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40
0.05	1,327	1,329	1,330	1,331	1,331	1,332	1,332	1,333
0.10	1,320	1,322	1,324	1,325	1,326	1,327	1,328	1,329
0.15	1,314	1,317	1,319	1,321	1,322	1,324	1,325	1,326
0.20	1,310	1,312	1,315	1,317	1,319	1,320	1,322	1,323
0.25	1,306	1,309	1,311	1,313	1,315	1,317	1,319	1,321
0.30	1,303	1,306	1,308	1,311	1,313	1,315	1,317	1,319
0.35	1,300	1,303	1,305	1,308	1,310	1,313	1,315	1,317
0.40	1,297	1,300	1,303	1,306	1,308	1,311	1,313	1,316

[a] $\lambda_1 dt$ denotes the probability of an indemnity in the next time interval if no indemnity occurs this time interval.

[b] $\lambda_0 dt$ denotes the probability of no indemnity in the next time interval if there is an indemnity in this time period.

Table A2. Per-Acre Revenue Threshold Trigger when Crop Insurance is in Effect,R_D^0, and change in Expected Net Insurance Payment, θ is \$30 per acre

λ_1^a								
λ_0^b	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40
0.05	1,370	1,380	1,389	1,398	1,407	1,416	1,427	1,439
0.10	1,369	1,379	1,388	1,397	1,406	1,416	1,427	1,440
0.15	1,368	1,378	1,387	1,396	1,405	1,415	1,427	1,441
0.20	1,368	1,377	1,386	1,395	1,404	1,415	1,427	1,442
0.25	1,367	1,376	1,385	1,394	1,404	1,415	1,427	1,444
0.30	1,367	1,376	1,385	1,394	1,404	1,415	1,428	1,446
0.35	1,367	1,376	1,385	1,394	1,404	1,415	1,429	1,449
0.40	1,367	1,375	1,384	1,393	1,404	1,415	1,430	1,453

[a] $\lambda_1 dt$ denotes the probability of an indemnity in the next time interval if no indemnity occurs this time interval.

[b] $\lambda_0 dt$ denotes the probability of no indemnity in the next time interval if there is an indemnity in this time period.

Table A3. Per-Acre Revenue Threshold when Crop Insurance is in not in Effect,R_D^0, and change in Expected Net Insurance Payment, θ is $-$\$30 per acre

λ_1^a								
λ_0^b	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40
0.05	1,391	1,390	1,389	1,388	1,388	1,388	1,387	1,387
0.10	1,401	1,399	1,398	1,397	1,396	1,396	1,395	1,395
0.15	1,409	1,408	1,406	1,405	1,405	1,404	1,403	1,403
0.20	1,418	1,416	1,415	1,414	1,413	1,412	1,411	1,411
0.25	1,426	1,424	1,423	1,422	1,421	1,420	1,419	1,419
0.30	1,433	1,432	1,431	1,430	1,429	1,428	1,427	1,426
0.35	1,441	1,440	1,439	1,438	1,437	1,436	1,435	1,434
0.40	1,449	1,448	1,447	1,446	1,445	1,444	1,443	1,443

[a] $\lambda_1 dt$ denotes the probability of an indemnity in the next time interval if no indemnity occurs this time interval.

[b] $\lambda_0 dt$ denotes the probability of no indemnity in the next time interval if there is an indemnity in this time period.

Table A4. Per-Acre Revenue Threshold Trigger when Crop Insurance is in Effect, R_D^0, and change in Expected Net Insurance Payment, θ is $-\$30$ per acre

λ_1^a								
λ_0^b	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40
0.05	1,348	1,340	1,335	1,330	1,326	1,322	1,319	1,316
0.10	1,349	1,343	1,337	1,332	1,328	1,325	1,322	1,319
0.15	1,350	1,344	1,339	1,334	1,331	1,327	1,324	1,321
0.20	1,351	1,345	1,340	1,336	1,332	1,329	1,326	1,323
0.25	1,352	1,346	1,342	1,338	1,334	1,331	1,328	1,325
0.30	1,352	1,347	1,343	1,339	1,336	1,333	1,330	1,327
0.35	1,353	1,348	1,344	1,340	1,337	1,334	1,331	1,329
0.40	1,353	1,349	1,345	1,342	1,338	1,336	1,333	1,331

[a] $\lambda_1 dt$ denotes the probability of an indemnity in the next time interval if no indemnity occurs this time interval.

[b] $\lambda_0 dt$ denotes the probability of no indemnity in the next time interval if there is an indemnity in this time period.