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Input Use Under Crop Insurance: The Role of Actual Production History

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Abstract: The impact of crop insurance on changes in inputs use has attracted much attention by economists. While there are a number of studies on this topic, they frame moral hazard in inputs use in a static model. However, when agricultural producers are forward-looking, they would make input allocation decisions realizing that their decisions would affect their future Actual Production History. This, in turn, affects the probability and size of future indemnity payments. Thus, moral hazard should be framed in a dynamic input use decision model. We first show theoretically that under certain feasible conditions, a static analysis always results in a lower optimal input use when compared to a dynamic one with endogenous Actual Production History. This is because static models fail to recognize the role of Actual Production History. Then, we run numerical simulations using nitrogen application rates as a case study. We find that static models indicate significant reduction in nitrogen use compared to the no-insurance scenario, whereas the dynamic models with a role for Actual Production History indicate almost no reduction in applied nitrogen. The dynamic analysis not only suggests an almost absence of moral hazard, but, for low coverage rate, it results in an optimal nitrogen rate higher than that under the no-insurance scenario. These findings illustrate the importance of recognizing the role of Actual Production History in mitigating moral hazard possibilities in crop insurance and the dynamic nature of moral hazard in crop insurance.

Keywords: actual production history, crop insurance, moral hazard, nitrogen, stochastic dynamic optimization

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Since its inception, the federal crop insurance program has become one of the most commonly adopted risk management tools for agricultural producers (Glauber, 2004, 2013). Under this program, agricultural producers purchase federal crop insurance to mitigate revenue risk.[1] In general, by protecting against risk, insurance has the potential to alter decisions, resulting in an increased exposure to risk; such changes in decisions are referred to as moral hazard.[2] In the context of the federal crop insurance program, moral hazard refers to changes in producers' decisions that result in more risk given the protection against revenue risk that the program provides.

While many authors have studied the allocation and welfare effects of moral hazard introduced by federal crop insurance (Atwood, Robison-Cox, and Shaik, 2006; Vercammen and van Kooten, 1994; Horowitz and Lichtenberg, 1993; Quiggin, Karagiannis, and Stanton, 1993; Babcock and Hennessy, 1996; Smith and Goodwin, 1996; Coble et al., 1997; Roberts, Key, and O'Donoghue, 2006; Schoengold, Ding, and Headlee, 2014), this article contributes to the body of knowledge by examining the changes in input use induced by crop insurance when the revenue guarantee is a function of historical yields-Actual Production History (APH). This innovation introduces a dynamic element to the decision-making process that farmers consider when determining input use. Specifically, in the short-run, since insurance reduces downside risk, producers may have an incentive to reduce an input that reduces yield and yield risk because crop insurance acts as a substitute. However, since APH influences the revenue guarantee, in the long-run, if current yields are reduced due to reduced inputs, future APH will decrease, causing lower insurance revenue guarantees. This decrease tempers the producers' inclination to reduce current yields. Therefore, an evaluation of the impacts of crop insurance on input use should be framed under a dynamic input use model that captures the impact of current input use on future earnings through APH. We show that when APH is a function of historical yields, this endogeneity affects the degree of the potential moral hazard and the direction of change in input use.

The effect of moral hazard in input use under crop insurance has been examined in a variety of contexts, using a variety of methods. Horowitz and Lichtenberg (1993) evaluated the relationship between crop insurance and input use via a cross-sectional farm-level survey. They found that insurance purchasers used significantly more nitrogen, pesticides, and insecticides per acre. Smith and Goodwin (1996) found from survey data that wheat producers who purchased insurance used fewer chemicals. Quiggin, Karagiannis, and Stanton (1993) used data from the 1988 Farm Costs and Returns Survey and found that insured producers tend to use fewer inputs. Roberts, Key, and O'Donoghue (2006), concerned with the identification strategies in Horowitz and Lichtenberg (1993) and Smith and Goodwin (1996), used administrative data to compare crop yields before and after insurance adoption. They found some moral hazard in Texas for wheat and soybeans but little moral hazard in Iowa and North Dakota. These past studies are all empirical examinations of moral hazard in input use and do not explicitly consider the role of APH on moral hazard. Furthermore, while Coble et al. (1997) considered the role of APH when examining moral hazard on indemnities, their focus was not on input use. This paper fills such a gap.

A few studies attempted to gain insights into moral hazard in input use using theoretical models and numerical analyses. Babcock and Hennessy (1996), via numerical simulation, predicted minor reductions in nitrogen rates at coverage rates up to 70%, and somewhat greater reductions in nitrogen rates at higher coverage rates. However, they used a static model where APH was set exogenously. Horowitz and Lichtenberg (1993) and Quiggin, Karagiannis, and Stanton (1993) as well as Chambers (1989) used a static framework. The only study that took into account the role of APH in a dynamic context is Vercammen and van Kooten (1994). They found that under yield protection, a steady state solution might contain "moral hazard cycles," where moral hazard is practiced in one year and excessive inputs are used in the following year to rebuild APH. However, the authors present a numerical illustrative analysis with no particular inputs in mind and point out that their study has little to say about moral hazard in practice. Furthermore, they only consider a yield protection plan rather than a revenue insurance plan, which dominates the market today with 89% of insured corn acres (USDA-RMA, 2018).

This article builds upon the Babcock and Hennessy (1996) model by extending their static model to a dynamic one that accounts for APH endogeneity in modeling the impact of crop insurance on input use. This article considers three types of crop insurance types-yield protection (YP), revenue protection with harvest price exclusion (RP-HPE), and revenue protection (RP)-and for each insurance type, we consider a 70%, 85%, and 90% coverage rate.[3] We first show theoretically that under certain feasible conditions and for all the crop insurance types considered, a static analysis always results in a lower optimal input use when compared to a dynamic model with endogenous APH. This difference manifests because static models fail to recognize the value of an input in building APH for future crop years. The input allocation resulting from a static approach is equivalent to the end-period allocation in a dynamic model, given that todays decisions are inconsequential in terms of future APH.

Then, for the three types of crop insurance types identified above, we run numerical simulations using a production function estimated in Babcock and Hennessy (1996) to compare how the degree of moral hazard changes when past input allocations affect APH. Our numerical results indicate that the amount of applied nitrogen (input) can substantially differ between the static and dynamic models. For example, when comparing insurance versus no-insurance scenarios for high coverage rates, and specific combinations of insurance and utility types, a static analysis suggests no applied nitrogen at all, whereas the dynamic solution indicates almost no reduction in applied nitrogen. In general, the static analysis suggests a reduced optimal amount of nitrogen rate relative to the no-insurance scenario. The dynamic model not only suggests almost an absence of moral hazard, but it indicates an optimal nitrogen rate that is higher than that under the no-insurance scenario for coverage rates of 70% and lower for all insurance and utility types. Our results indicate that the endogeneity of APH offsets the incentive for moral hazard in input use. These findings illustrate the importance of recognizing the impact of current input choice on future income as well as the need to frame the moral hazard due to crop insurance as a dynamic, repeated problem.

APH and Its Role in Crop Insurance

This section contains a brief description of the role of APH in the crop insurance program and introduces some useful concepts and definitions. The rate yield is the simple average of actual historical yields in the yield database, which represents a minimum of four and a maximum of ten years of historical yields. If fewer than four actual yields are provided, county transitional yields (T-yields) are used to stand in for the missing years. APH will be identical to the rate yield if there are no modifications via the use of yield endorsements (e.g., yield substitutions). For our analysis, we assume that APH and rate yields are equivalent and use them interchangeably in the remainder of the manuscript.

The Role of APH in Indemnity Payment

Holding everything else constant, as APH goes up, guaranteed yield (or revenue) also increases, which in turn increases the size and probability of indemnity payments. However, the effects of APH on the size and probability of indemnity payments differ by the type of crop insurance (YP,RP-HPE,RP).

Under YP, the indemnity payment is:

$$I\{APH \cdot \tau \geq y\} \cdot pp \cdot (APH \cdot \tau - y) \tag{1}$$

where pp represents the projected price (calculated per RMA rules), y is the realized yield, and τ is the coverage rate chosen by the producer. $I\{\cdot\}$ is the index function that takes a value of 1 if the statement in brackets is true, and 0 otherwise. If the realized yield (y) is less than the guaranteed yield ($APH \cdot \tau$), the result triggers an indemnity payment of $pp \cdot (APH \cdot \tau - y)$. An illustration of this indemnity activation appears in figure 1, which shows that the indemnity payment is triggered only in areas A and B, wherein the realized yield is lower than the guaranteed yield.

Under $RP-HPE$, the indemnity payment is:

$$I\{pp \cdot APH \cdot \tau \geq hp \cdot y\} \cdot (pp \cdot APH \cdot \tau - hp \cdot y) \tag{2}$$

where hp is the harvest price calculated per RMA rules.[4] Figure 1 portrays the difference between the YP and *RP-HPE* crop insurance types. In Area B, an indemnity payment is not triggered under *RP-HPE* because revenue generated from the higher harvest price offsets the lower realized yield. This results in revenue greater than the revenue guarantee of $pp \cdot APH \cdot \tau$. Under YP, the harvest price plays no role in determining whether an indemnity payment is triggered or not, and an indemnity payment is triggered in Area B because the realized yield is less than the yield guarantee. In Area C, an indemnity payment is triggered under *RP-HPE* because revenue from the low realized harvest price multiplied by the higher realized yield is less than the revenue guarantee ($pp \cdot APH \cdot \tau$). Therefore, RP-HPE's relative advantage over YP resides in the fact that producers are protected against low-price events. Inversely, YP can be more advantageous than *RP-HPE* when yields are low, and the harvest price is high.

Under *RP*, the greater value between the harvest price and the projected price is used to calculate the revenue guarantee. Consequently, the indemnity payment under *RP* is:

$$I\{max\{pp,hp\}\cdot APH\cdot\tau \geq hp\cdot y\}\cdot(max\{pp,hp\}\cdot APH\cdot\tau - hp\cdot y) \quad (3)$$

When the revenue calculated based on hp ($hp\cdot y$) falls short of the revenue guarantee ($max\{pp,hp\}\cdot APH\cdot\tau$), an indemnity payment of $max\{pp,hp\}\cdot APH\cdot\tau - hp\cdot y$ will be triggered. As illustrated in figure 1, *RP* triggers an indemnity in regions A, B, and C. When compared to YP, *RP* expands the possibility of an indemnity payment by adding Area C. In Area C, the revenue from a higher yield multiplied by a low harvest price is less than the guaranteed revenue, so the policy pays an indemnity.

The Role of APH in Premium Rate and Payment

The premium paid by a producer may be broken down into three parts for the purpose of understanding the influence of APH:

$$\text{Premium} = \text{Liability} \times \text{Premium Rate} \times (1 - \text{Subsidy}) \quad (4)$$

Liability is calculated by $pp\cdot APH\cdot\tau$ and is the same across the three crop insurance types analyzed in this article. As APH increases, the liability also increases. The subsidy rate depends on the coverage rate chosen by the producer as shown in table 1.

Unlike the liability, the premium rate differs by crop insurance type to reflect the expected indemnity payments. The premium rate calculation corresponds to numerous factors and is much more complex than that of the liability. Since the focus of this article is on the role of APH, the following way of writing the premium rate is sufficient:

$$premium\ \ rate = f(\frac{rate\ \ yield}{reference\ \ yield}, D) \quad (5)$$

where $reference\,yield$ represents the expected county yield, and D embodies all other factors influencing premium rates.[5] The ratio of $rate\ \ yield$ to $reference\ \ yield$ measures how much better the producer is relative to the average producer in the same county. As APH goes up, the ratio goes down, which in turn results in lower premium rates. Figure 2 presents an example of how premium rates change as APH changes by crop insurance type and coverage rate, calculated for rainfed corn production for Sioux County, Iowa in 2016.[6] This figure illustrates how APH influences the premium rate by insurance type.

An increase in APH simultaneously raises the liability but decreases the premium rate. Thus, in theory, whether the premium payment goes up as APH goes up depends on the relative magnitude of the changes in the liability and the premium rate associated with a change in APH. Figure 3 shows how APH affects the premium amount for each YP, *RP-HPE* and *RP* under various coverage rates. The figure shows that a higher APH leads to a higher premium payment.

Modeling Input Use under Crop Insurance: Static vs. Dynamic Models

In this section, we model the input-use decision under YP, *RP-HPE* and *RP* for both static and dynamic models. We then show that the use of static models is likely to result in misleading conclusions about input use under crop insurance. Further, we show that under likely conditions, static input-use modeling often underestimates the optimal input use.

The static modeling approach assumes that producers maximize their expected utility of the concurrent production season. Denoting the input of interest by x, the producer would solve the following problem under YP:

Yield Protection (YP_s):

$$\text{(6)} \qquad max_x \int\int\int \Big[U\big(p\cdot y + I[APH\cdot\tau > y]\cdot pp\cdot(APH\cdot\tau - y) - \lambda_{YP}(APH) - w\cdot x - C_{other}\big)\Big] f(y,p,hp|x)dy\cdot dp\cdot dhp$$

This is the problem Babcock and Hennessy (1996) considered, setting nitrogen as x. $U(\cdot)$ is the utility function; p represents the price at which the producer sells the crop; x represents the input use; λ_{YP} is the producer's paid premium; w is the input price; C_{other} represents all the other production costs. The first term $(p\cdot y)$ represents revenue from physical grain sales. The second term is the indemnity payment that is triggered when $APH\cdot\tau > y$. The producer makes a payment of $w\cdot x$ for the input and C_{other} for all the other costs. The expected value of the utility function is obtained by integrating over y, p, and hp for their joint distribution conditional on x, denoted as $f(y,p,hp|x)$. The choice of input (x) influences the joint distribution, which in turn affects the expected size and probability of indemnity payment. Note that hp has no role under YP. Indeed, the expectation can be taken over just y and p for their joint distribution, ignoring hp. However, it is still correct to take expectation over y, p, and hp because they will be identical. We introduce $f(y,p,hp|x)$ here because we need it for both *RP-HPE* and *RP*. Using a common joint distribution function notation across all the insurance types helps us save unnecessary text and mathematical expressions later. Further, for the sake of brevity, we use $\int_3$ for $\int\int\int$ integrals and $d\mathbf{z}$ for $dy\cdot dp\cdot dhp$ hereafter.

Profit maximization problems under *RP-HPE* and *RP* have basically the same structure as the problem under YP except that they differ in the condition under which an indemnity payment is triggered and the amount of indemnity payment.

Revenue Protection with Harvest Price Exclusion ($RP - HPE_s$):

(7) $$max_x \int_3 \Big[U\big(p \cdot y + I[pp \cdot APH \cdot \tau \geq hp \cdot y] \cdot (pp \cdot APH \cdot \tau - hp \cdot y) - \lambda_{RP-HPE}(APH) - w \cdot x - C_{other}\big)\Big] f(y, p, hp|x) d\mathbf{z}$$

Revenue Protection (RP_s):

(8)
$$max_x \int_3 \Big[U\big(p \cdot y + I[max\{pp, hp\} \cdot APH \cdot \tau \geq hp \cdot y] \cdot (max\{pp, hp\} \cdot APH \cdot \tau - hp \cdot y) - \lambda_{RP}(APH) - w \cdot x - C_{other}\big)\Big] f(y, p, hp|x) d\mathbf{z}$$

The revenue protection considered in Babcock and Hennessy (1996) corresponds to $RP-HPE$, not RP. RP dominates the market today–with 89% of insured corn acres (USDA-RMA, 2018).

In these static models, premium rates and the other costs (C_{other}) do not influence the input-use decision, as they are independent of the concurrent choice about input use. Consequently, static formulations of YP_s, RP_s, and $RP-HPE_s$ fail to take into account the influence of the input-use decision on future APH. The input-use decision is inherently dynamic because the choice of input use in the current period influences yield, which in turn influences APH for the next ten times the particular crop/practice is grown in that unit.

Now, we let $R_t^I(APH_t)$ denote the profit before input cost is subtracted in the static model under insurance type I. For example, under YP, $R_t^{YP}(APH_t) = p_t \cdot y_t + I[APH_t \cdot \tau > y_t] \cdot pp_t \cdot (APH_t \cdot \tau - y_t) - \lambda_{YP}(APH_t) - C_{other}$. Then, the dynamic optimization problem under insurance type I is written as follows:

$$(9) \qquad max_{\{x_1,\ldots,x_T\}} \sum_{t=1}^{T} \frac{\int_3 \left[U\left(R_t^I(APH_t) - w \cdot x_t\right)\right] f(y,p,hp|x_t) d\mathbf{z}}{(1+\gamma)^{t-1}} + SV(APH_T)$$

$$s.t. \quad APH_{t+1} = (\sum_{i=1}^{9} y_{t-i} + y_t)/10$$

where γ is the producer's subjective discount rate. APH updates based on the state equation $APH_{t+1} = (\sum_{i=1}^{9} y_{t-i} + y_t)/10$; APH in the next period is the simple average of yields over the past 10 years. By changing the amount of input use, the calculation changes the distribution of each year's yield, which in turn affects future APH. $SV(APH_T)$ is the terminal value of the land–specifically, the price at which the producer can sell the land after the final year of production season before retirement.[7] $SV(APH_T)$ is modeled as a function of APH–among other things–because APH may signal the productivity of the land, which allows us to model producers' incentive to maintain high APH so the land can be sold at a higher price in the last period.

This model lets $V_t^I(APH_t)$ denote the value function under insurance type I at time t. Then, for $t = \{1,\ldots,T-1\}$, the Bellman equation for the dynamic optimization model becomes:

$$(10) \qquad V_t^I(APH_t) = max_{x_t} \int_3 \left[U\left(R_t^I(APH_t) - w \cdot x_t\right)\right] f(y,p,hp|x_t) d\mathbf{z} \\ + (1+\gamma)^{-1} \cdot \int [V_{t+1}^I(APH_{t+1})] h(y|x_t) dy$$

Unlike the static models, input use (x) not only affects expected profit in the current year (t), but also APH in the next year ($t+1$), which in turn affects the effectiveness of crop insurance in reducing risk in future periods.

Comparing the first order conditions (FOC) for the static and dynamic cases further clarifies this point. First, in the static case, taking the derivative of the objective function with respect to x_t, the FOC at t for $t = \{1, \ldots, T-1\}$ is

$$\int_3 U(R^I(APH_t) - w \cdot x_t) \cdot f'(y, p, hp|x_t) d\mathbf{z} - w \cdot \int_3 \frac{\partial U(\pi)}{\partial \pi} \cdot f(y, p, hp|x_t) d\mathbf{z} = 0 \tag{11}$$

where $\pi = R^I(APH_t) - w \cdot x_t$. We let $\mu(x)$ denote the left-hand side of the above equation, which is the concurrent marginal expected utility with respect to x. As long as $\mu(x) > 0$ and $\mu(x) < 0$, the solution to the above first-order condition satisfies the second-order condition. In the dynamic case, the FOC is

$$\begin{aligned} &\int_3 U(R^I(APH_t) - w \cdot x_t) \cdot f'(y, p|x_t) d\mathbf{z} + \int V_{t+1}(APH_{t+1}) h'(y|x_t) dy \\ &- w \cdot \int_3 \frac{\partial U(\pi)}{\partial \pi} \cdot f(y, p|x_t) d\mathbf{z} = 0 \end{aligned} \tag{12}$$

In the static case, the marginal revenue of the input simply equates to the marginal cost of the input (w). In the dynamic case, w equals the marginal revenue of the input plus the cumulative marginal profit of the input that will be earned in the future. Because the indemnity and premium rates are both functions of APH, ignoring the impact of current input use on future APHs leads to an erroneous optimal input use. As a result, static models are likely to under-predict the optimal input use.

Theorem:

For any period in $t = 1, \ldots, T-1$, the static problem would always underestimate the optimal nitrogen rate when compared to the dynamic problem $^{\forall}I = \{YP, RP-HPE, RP\}$ at a given level of APH under the following conditions (see Appendix A in the on-line supplementary appendix for the proof):

1. Condition 1:

$$\begin{cases} \mu(x) > 0, \text{ if } 0 \leq x < x_s^* \\ \mu(x) = 0, \text{ if } x = x_s^* \\ \mu(x) < 0, \text{ if } x > x_s^* \end{cases} \tag{13}$$

2. Condition 2: For $x^a < x^b \leq \tilde{x}$

$$P[y > \alpha | x^a] < P[y > \alpha | x^b] \tag{14}$$

3. Condition 3: For $APH^a < APH^b$ and $x^*(APH^a)$ (the optimal input level that maximizes the concurrent expected utility when $APH = APH^a$),

$$\begin{aligned} &\int_3 \left[U\left(R^I(APH^a) - w \cdot x^*(APH^a)\right)\right] f(y,p,hp|x^*(APH^a))d\mathbf{z} \leq \\ &\int_3 \left[U\left(R^I(APH^b) - w \cdot x^*(APH^a)\right)\right] f(y,p,hp|x^*(APH^a))d\mathbf{z} \end{aligned} \tag{15}$$

4. Condition 4:

$$SV'(APH_T) \geq 0 \tag{16}$$

Condition 1 states that for an input level lower (or more) than x_s^* (the static optimal level), the marginal utility of the input is always positive (or negative, respectively). This condition means that the marginal utility of the input hits 0 only once, which ensures that the x_s^* indeed maximizes the concurrent utility globally. Condition 1 is less stringent than simply assuming the marginal utility of the input is monotonically declining. For example, the marginal utility can increase at first and then decline toward x_s^* as long as $\mu(x)$ stays positive for $x < x_s^*$.

Condition 2 states that the input is beneficial to crop yield up to the threshold $\tilde{x}$. Since the input is non-damaging, the distribution of yield conditional on x^b first-order stochastically dominates the distribution of yield conditional on x^a when $x^a < x^b$ as long as $x^b < \tilde{x}$. The marginal impact of additional input on the distribution is zero at the threshold, meaning that the input no longer enhances yield and the conditional yield distribution stays the same.

Condition 3 states that if one continues to use $x^*(APH_a)$ when APH increases to APH_b while all other values remain fixed, then the expected concurrent utility is going to be greater. In order to understand why Condition 3 is likely to be satisfied for many producers, we consider a risk-neutral producer as an illustration. Under the two levels of APH, the respective expected profits conditional on $x^*(APH^a)$ are:

$$\begin{aligned} (17) \quad APH^a: \; & E\left[p \cdot y + I[APH^a \cdot \tau > y] \cdot pp \cdot (APH^a \cdot \tau - y)\right] - (1-\sigma(\tau)) \cdot \lambda_{YP}(APH^a) \\ & - w \cdot x^*_{APH^a} - C_{other} \\ (18) \quad APH^b: \; & E\left[p \cdot y + I[APH^b \cdot \tau > y] \cdot pp \cdot (APH^b \cdot \tau - y)\right] - (1-\sigma(\tau)) \cdot \lambda_{YP}(APH^b) \\ & - w \cdot x^*_{APH^a} - C_{other} \end{aligned}$$

where $\sigma(\tau)$ is the subsidy rate, which is determined by the coverage rate (τ). Since $APH^a \cdot \tau < APH^b \cdot \tau$, $E\left[I[APH^a \cdot \tau > y]\right] < E\left[I[APH^a \cdot \tau > y]\right]$. That is, the producer is more likely to get an indemnity payment when $APH = APH^b$. Also, $APH^a \cdot \tau - y < APH^b \cdot \tau - y$: the size of the indemnity payment given y is greater when $APH = APH^b$. Thus, the expected indemnity payment is greater when $APH = APH^b$. However, the premium payment is greater because $(1-\sigma(\tau)) \cdot \lambda_{YP}(APH^a) < (1-\sigma(\tau)) \cdot \lambda_{YP}(APH^b)$. Now, when we suppose premium rates are calculated by RMA to be actuarially fair,

$$E\big[I[APH^a \cdot \tau > y] \cdot pp \cdot (APH^a \cdot \tau - y)\big] = \lambda_{YP}(APH^a) \tag{19}$$

$$E\big[I[APH^b \cdot \tau > y] \cdot pp \cdot (APH^b \cdot \tau - y)\big] = \lambda_{YP}(APH^b) \tag{20}$$

For the expected profit to stay the same after changing APH from APH^a to APH^b, the premium rate must increase by $\lambda_{YP}(APH^b) - \lambda_{YP}(APH^a)$. However, due to the subsidy, the actual increase in premium payment would be $(1 - \sigma(\tau))(\lambda_{YP}(APH^b) - \lambda_{YP}(APH^a))$, which is always less than $\lambda_{YP}(APH^b) - \lambda_{YP}(APH^a)$. For example, under the coverage rate of 0.75, the subsidy rate is 0.55. Therefore, if an exogenous increase in APH were to make a producer worse off, the premium rate must have been calculated so that the premium rate is more than twice the expected indemnity payment in the first place. This simple case illustrates why exogenous increase in APH is likely to enhance expected utility because of premium subsidy. While the above argument cannot be used directly for risk-averse producers, a similar argument still holds: subsidy on premium makes it likely that an exogenous increase in APH makes producers better off.

Finally, Condition 4 simply states that an increase in APH (historical yield) does not decrease the price at which the producer sells the land at the last period. Note that, by design, the static problem is not able to consider the terminal value of land. This situation means that the static model implicitly assumes $SV(APH_T) = 0$, and thus $SV'(APH_T) = 0$. It is important to keep in mind that the above theorem holds under the same assumption $SV'(APH_T) = 0$ (see Appendix A in the on-line supplementary appendix for the proof). When $SV'(APH_T) > 0$, the increase in input use under the dynamic model is even greater because an increase in APH implies greater terminal-period benefits.

Now, at $t = T$, the Bellman equation of the dynamic problem is:

(21) $$V_T^I(APH_T) = max_{x_T} \int_3 \left[U\left(R_T^I(APH_T) - w \cdot x_T\right)\right] f(y,p,hp|x_T) d\mathbf{z} + SV(APH_T)$$

Then the FOC is

(22)
$$\int_3 U(R^I(APH_T) - w \cdot x_T) \cdot f'(y,p|x_T) d\mathbf{z} + SV'(APH_T) - np \cdot \int_3 \frac{\partial U(\pi)}{\partial \pi} \cdot f(y,p|x_t) d\mathbf{z} = 0$$

Now, if the producer does not consider the impact of APH_T on the land value at the final period, $SV'(APH_T) = 0$, equation (22) becomes identical to the static FOC. This situation means that the optimal allocation obtained from the static approach is appropriate to measure moral hazard only for those who intend to quit farming next year and does not consider the impact of their yield history on their land value when they retire.

Numerical Examples: Nitrogen Use

In this section, we use the parameterization used in Babcock and Hennessy (1996) and contrast the optimal allocations and implied moral hazard in nitrogen use under crop insurance in the static versus dynamic problem.

Model Parameters

We follow Babcock and Hennessy (1996) for the parameterization of the problems. Let N denote the applied nitrogen rate (lb/acre). The distribution of corn yield conditional on nitrogen rate (denoted $h(y|N)$) is assumed to be the same as that estimated for Site 11 in Babcock and Hennessy (1996), which is used to obtain their main results.

$$h(y|N) = \frac{\Gamma[p(N)+q(N)]}{\Gamma[p(N)]\Gamma[q(N)]} \cdot \frac{(y-a)^{P(N)-1}(b-y)^{q(N)-1}}{b^{p(N)+q(N)-1}} \tag{23}$$

where $p(N) = 3.14 - 0.0921\sqrt{N} + 0.00603N$, $q(N) = 12.30 - 1.353\sqrt{N} + 0.00456N$, $a = 48$, and $b = 202$. Figure 4 shows how the mean and 5% and 95% quantiles of yield change as one changes the nitrogen rate. This figure shows that the marginal impact of nitrogen on yield is declining, consistent with agronomic theory. Figure 5 shows how the yield distribution is modeled to respond to nitrogen rate (lb/acre); this figure shows that the yield distribution is skewed towards the left at lower nitrogen rates, and then shifts to the right as the producer applies more nitrogen.

In order to make the optimal nitrogen rates comparable between the static and dynamic problems, the projected price stays constant, and the distribution of harvest price stays the same through time in the dynamic problem. We use the projected price and the distribution of harvest price used in Babcock and Hennessy (1996). The projected price is set at \$2.20/bu. The distribution of harvest price follows a log normal distribution with $E[hp] = pp$ and $Var(hp) = 0.45$. We use a copula method to generate correlated yield and harvest price, with the correlation coefficient of -0.3. Premium rates and payments are calculated using the actuarial parameters for the 2016 production season in Sioux County, Iowa. The impact of APH on the terminal value of land (selling price of the land in the end period) is set to 0 ($SV'(APH_T) = 0$). Since the static model is unable to capture the terminal value of land, it implicitly assumes $SV'(APH_T) = 0$. Thus, assuming $SV'(APH_T) = 0$ in the dynamic model allows us to attribute the difference in optimal nitrogen use between the static and dynamic models purely to the dynamics introduced by the use of APH, which is the objective of this article.

We consider three types of utility functions. Two of them are from Babcock and Hennessy (1996): a risk neutral (RN) utility function and a constant absolute risk aversion utility function with a risk parameter of 0.1 (CA). The third type is a constant relative risk aversion utility function with a risk parameter of 0.6 (CR).[8]

In order to solve the dynamic model, the true equation of motion ($\tau_{t+1} = (\sum_{i=1}^{9} y_{t-i} + y_t)/10$) is approximated by the following formula, which is used also in Vercammen and van Kooten (1994):

$$\tau_{t+1} = \frac{9\tau_t + y_t}{10} \tag{24}$$

This approximation reduces the time needed to solve the dynamic model with the true equation of motion. Optimal nitrogen rate choice in a given time period requires the knowledge of yields in the past nine years ($y_{t-9}, \ldots, y_{t-1}$). When one considers only 11 possible yield values (say, 100 bu/acre to 200 bu/acre, with an increment of 10 bu/acre) for each of the past nine years, one needs to find the optimal nitrogen rate for $11^9 = 2,357,947,691$ combinations of $y_{t-9}, \ldots, y_{t-1}$ realizations in each time period. This process means that even at the very coarse step of 10 bu/acre, it would not be feasible to complete simulations in a reasonable amount of time, at least with the state of the computational power modern machines possess. The approximate equation of motion dramatically decreases the number of optimization problems to solve. Even with a step of 0.1 bu/acre, only 1001 optimization problems are needed to be solved at each time period. Importantly, equation (24) approximates the true equation of motion reasonably well, though not perfectly (see Figure D.1 in the on-line supplementary appendix, which depicts an example of APH trajectories derived from the true and approximated equation of motion).

Numerical Simulation

This article uses numerical methods to solve the static and dynamic optimization models since analytical solutions are not obtainable due to the complexity of the models. For the dynamic models, backward induction determines the optimal nitrogen rate path (see Appendix A in the on-line supplementary appendix for more details). All the simulations were performed using R software (R Core Team, 2016), and all the codes are available in the on-line supplementary appendix. The Rcpp package (Eddelbuettel and François, 2011), in particular, was extensively used to enhance computational speed.

Results

We first report results from the static and dynamic models independently, with a particular focus on how APH affects optimal nitrogen rates. We then compare the static and dynamic results when the APH is at the expected APH level at the steady state.

Static Model

Under the no-insurance scenario, the optimal nitrogen rates (lb/acre) are 198.0, 196.3, and 197.5 for the risk averseness types of RN, CA, and CR, respectively. These numbers are generally very similar to those reported in tables 3 and 5 of Babcock and Hennessy (1996), though our estimates are roughly 3 lb/acre smaller than their estimates–these differences are likely due to the difference in numerical accuracy.[9] Figure 6 shows the optimal nitrogen rate conditional on APH under the three insurance types by risk averseness. The vertical dotted lines represent the APH value of 136.5, the level used in Babcock and Hennessy (1996). For all the cases we consider, the optimal nitrogen rate declines as APH increases. As we saw in figure 5, nitrogen shifts the skewness of the yield distribution to the right.

Since a higher APH means a greater ability for crop insurance to reduce downside yield (revenue) risk, producers have less incentive to apply more nitrogen to shift the production to the right; APH and nitrogen are complements. Interestingly, at higher coverage rates, there exist thresholds of APH beyond which zero nitrogen is the optimal strategy. For example, as shown in figure 6, at the coverage rate of 0.9, producers of CA utility type would apply no nitrogen if APH is higher than 132 under RP. Consistent with economic intuition, the APH threshold becomes lower as the coverage rate increases. While the APH thresholds are similar between YP and $RP-HPE$, they are much lower under RP as it possesses the greatest ability to insure revenue.

Dynamic Model

The solutions to the dynamic model are series of functions that map APH (APH_t) on nitrogen rate (N_t^*) at each time period. Here, we focus on the optimal nitrogen level at the steady state as this value is normally where producers make decisions. Specifically, we discuss the optimal nitrogen rates at $t = 20$.[10] Figure 7 shows the optimal nitrogen rate choice (N_t^*) conditional on (APH_t) at $t = 20$ by insurance type, coverage rate, and utility type. They are similar to the static cases in that the optimal nitrogen rate declines as APH increases. However, unlike the static cases, APH thresholds do not exist in any of the cases considered.

Static vs. Dynamic

Table 2 presents optimal nitrogen rates under no insurance and the static and dynamic optimal nitrogen rates by risk averseness, insurance type, and coverage rate when $APH = 136.5$. For the dynamic model, the expected optimal nitrogen rates at the steady state ($t = 20$) are used for comparison; the optimal nitrogen rates at $APH = 136.5$ under YP, and

RP-HPE that were obtained in this article are slightly smaller than those found in Babcock and Hennessy (1996).

Under the static cases, moral hazard is most severe under *RP*, which was not considered in Babcock and Hennessy (1996). Since *RP* provides the most flexibility in protecting revenue, unsurprisingly, the optimal nitrogen rates under *RP* are lower than under the other two insurance plans at any combination of a coverage rate and utility type. For example, under $\{\tau = 0.85, U = CR, I = RP\}$, the optimal nitrogen rate is 172.7 lb/acre, which is 24.8 lb/acre less (12% reduction) than under the no-insurance scenario. If we were to draw conclusions about moral hazard based on these results (with assumed APH of 136.5), we would conclude that moral hazard is rather severe under *RP*, ranging from -20% to -30% (except for the one case of 100% reduction under the utility function of *CA* and the coverage rate of 0.9, which is not currently offered); alternatively, the moral hazard is modest under YP and $RP-HPE$ ranging from -10% to -20% depending on risk preferences. As discussed earlier, these conclusions would be appropriate only for producers who intend to quit farming next year, when no consideration is given to the signaling through a strong yield history (APH) on the price of land.

Compared to the static case, optimal nitrogen levels in the dynamic cases are larger at any combination of insurance type, coverage rate, and risk averseness. Figure 8 compares the marginal value of nitrogen between the static and dynamic cases for $\{\tau = 0.85, U = RN, I = RP\}$. MR is the marginal expected revenue $\partial E\left[R^I(APH_t)\right]/\partial N_t$ and MVF_t is the cumulative expected marginal profit earned in the future periods $\partial E[V_{t+1}^I(0.9 \cdot APH_t + 0.1 \cdot y_t)]/\partial N_t$. The figure illustrates MVF_t is a big part of the marginal value of nitrogen. Consequently, ignoring MVF_t can result in substantial underestimation of optimal nitrogen rates.

In many cases, differences between the static and dynamic cases are substantial. In general, the divergence becomes larger as one moves from YP to $RP-HPE$, then to RP and also as the coverage rate goes up. At the extreme, for the case of $\{\tau = 0.9, U = CA, I = RP\}$, the dynamic case indicates only 3.3 lb/acre (1.7%) reduction in nitrogen rate, while the static case suggests 100% reduction. For many other cases, the static results over-estimate the degree of reduction in the nitrogen rate due to crop insurance. For example, for the case of $\{\tau = 0.85, U = CR, I = RP\}$, the static solution suggests about 13% reduction in nitrogen rate, while the dynamic suggests a 1% reduction.

Interestingly, under the coverage rate of 0.7, the optimal nitrogen rates are actually greater than under no insurance across all the insurance and utility types. This outcome may explain why Roberts, Key, and O'Donoghue (2006) observed statistically significant increases in soybeans and wheat yields in North Dakota. In general, the above finding illustrates the point that modeling the impact of insurance on optimal input allocation without allowing for the impact of yield on APH can result in erroneous conclusions about the direction of change in input use. This finding is important because it reveals that even if an input can be regarded as a complement to crop insurance in the static case, producers may use more inputs under crop insurance due to the way APH is used to calculate the indemnity payment and premium rate.

Table 2 also reveals how insensitive the optimal nitrogen rates are to coverage rate and the type of insurance. In the dynamic case the optimal nitrogen rate lies in the interval $[193.5, 200.1]$, rather than in the $[160.9, 194.2]$ (excluding the 90% coverage rate) interval of the static solution. In the dynamic approach the range of changes in nitrogen rate compared to the no-insurance case for different coverage levels, insurance and utility types is $[-1.7\%, +1.0\%]$. That is, moral hazard is almost non-existent and negligible for the particular case considered in this article. Vercammen and van Kooten (1994), using a dynamic model, suggest that using APH may exacerbate moral hazard. At least for the parameterizations used in this article, that situation does not appear to be true. Indeed, the use of APH can help alleviate moral hazard. Thus, our findings are in line with Lambert (1983) and Rogerson (1985) in that moral hazard can be lessened using the history of performances (yields) to modify the pay-off structure (indemnity and premium payment) for future insurance schemes. Our findings are also consistent with the empirical findings in Roberts, Key, and O'Donoghue (2006) that moral hazard is small.

Conclusion

The focus of this article is to examine the effect of actual production history on the moral hazard created by crop insurance. APH is a crucial parameter that determines the benefit of crop insurance by influencing the size and probability of the indemnity payment and the value of the premium payment. Theoretically we show that when producers are forward-looking, they use a greater amount of input when their current input decisions impact current yield and thus future APH. We illustrate this result using the parametrization in Babcock and Hennessy (1996), where we find higher optimal nitrogen rates when considering future opportunities– which is to say that we find a lower degree of moral hazard associated with crop insurance than in their study.

We also find that at low coverage rates, the optimal application is higher than without insurance, completely offsetting the incentive for moral hazard normally associated with insurance. Under the different circumstances we explore in the dynamic context, we find that the difference in optimal input use across these simulations are in the range of $[-1.7\%, +1\%]$, whereas we observe reductions of up to 100% in input use in simulations run using static models with high APH. This difference suggests that the existing policy design that uses APH based on historical yields to adjust indemnity payments and premium rates appears to minimize the moral hazard potentially created by crop insurance. Our results are consistent with Roberts, Key, and O'Donoghue (2006), who found little evidence of moral hazard as opposed to the conclusions in Vercammen and van Kooten (1994). Allocative and welfare impacts due to the moral hazard in the federal crop insurance program seem to be rather limited given the dynamic implications of APH.

While our results suggest APH plays a critical role in mitigating moral hazard, changes in the calculation of APH may change this result. Recently, the RMA released new products impacting the APH calculation: trend adjustment and yield exclusion, both with the potential to increase APH. Trend adjustment increases APH using the RMA-determined county trend value. Yield exclusion allows producers to exclude actual yields from their APH database when the current county average yield is below 50% of the ten-year county average. It would be of interest to study these products using simulated as well as econometric models, and to focus on the degree of moral hazard brought about by these alternative designs rather than just contrasting insured versus uninsured behavior, as most studies have done (Horowitz and Lichtenberg, 1993; Quiggin, Karagiannis, and Stanton, 1993; Smith and Goodwin, 1996; Roberts, Key, and O'Donoghue, 2006). Research on the allocative as well as the welfare implications of these products is left for future research.

Our theoretical findings that under the specific conditions considered, optimal input use when APH is exogenous is smaller to that when APH is endogenous applies generally. However, the degree of departure is conditional on the parametrization used in the simulations–specifically, the distribution and parameters from Babcock and Hennessy (1996). The reason for this choice was to illustrate how the degree of moral hazard due to crop insurance is affected by APH in a dynamic decision model. It would be important to investigate to what degree the difference in static versus dynamic input allocation depends on the parametric choice. These pathways offer future research options for those interested in the economic implications of the federal crop insurance program.

Footnotes

[1]The Risk Management Agency (RMA) administers the Federal Crop Insurance Corporation (FCIC), which carries out the federal crop insurance program.

[2]Arrow (1963) was the first to look into the economic significance of moral hazard. Arrow (1985) proposed the term "hidden action" as a substitute for the term moral hazard. A change in input use due to insurance that increases risk represents a "hidden action" by the insured, and is categorized as moral hazard.

[3]While a 90% coverage rate does not exist, we analyze this coverage rate following Babcock and Hennessy (1996) as an illustration.

[4]Note that p (the price producers receive for the grain) and hp (the price used to calculate the indemnity payment) are different. The difference between the two is called basis.

[5]D includes commodity type, commodity year, state, county, insurance unit, and practice, among other factors.

[6]Premium calculation is based on the on-line premium calculation tool by USDA-RMA (`https://ewebapp.rma.usda.gov/apps/costestimator/Estimates/QuickEstimate.aspx`). We took the formula from the tool and wrote an R program to calculate premium payment under various APH levels, coverage rates, and insurance types. The reference yield and other actuarial parameters used to calculate the premium rates and payments presented in figures 2 and 3 are for the 2016 rainfed corn production for Sioux County, Iowa. We picked Sioux County here because we use a production function estimated in Babcock and Henessy (1996) using data generated via field trial in Sioux County.

[7]The technical term for "terminal" value is salvage (or scrap) value in dynamic optimization.

[8]We do not present the results with constant absolute risk aversion with the risk parameter of 0.06 from Babcock and Hennessy (1996) because they are similar in nature to those with

CR.

[9]The advancements in computational power allowed us to run 50,000 iterations as opposed to 1,000 in Babcock and Hennessy (1996).

[10]Figure D.2 shows the path of expected nitrogen rates by insurance type when the coverage rate is 85% and the starting APH is 136.5. As one can see, the expected nitrogen rate soon reaches the steady state when the expected nitrogen rate is stabilized around 195 and 200. For other cases, a similar pattern manifests. Indeed, the optimal nitrogen rates are almost identical from $t = 5$ through $t = 30$. We picked the optimal nitrogen levels at $t = 20$ to serve the optimal nitrogen levels at the steady state.

Table 1: Subsidy Schedule

Coverage rate	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85
Subsidy rate	0.67	0.64	0.64	0.59	0.59	0.55	0.48	0.38

Note: This table presents subsidy rates for each coverage rates.

Table 2: Comparison of Static and Dynamic Optimal Nitrogen Rates by Coverage Rate, Risk Averseness, and Insurance Type

	No Insurance	(YP_s, YP_d)	$(RPHPE_s, RPHPE_d)$	(RP_s, RP_d)
Risk Neutral				
70%		$(194.4, 200.1)$	$(194.2, 200.0)$	$(191.8, 199.6)$
85%	198.0	$(183.5, 197.9)$	$(183.1, 197.6)$	$(175.7, 196.2)$
90%		$(177.7, 196.9)$	$(176.6, 196.7)$	$(166.7, 195.2)$
Constant Absolute Risk Aversion (0.0100)				
70%		$(188.2, 197.7)$	$(186.7, 197.4)$	$(182.9, 196.7)$
85%	196.3	$(171.9, 194.9)$	$(169.5, 194.8)$	$(160.9, 193.5)$
90%		$(164.9, 193.9)$	$(160.3, 194.3)$	$(0, 193)$
Constant Relative Risk Aversion (0.6)				
70%		$(193.0, 199.5)$	$(192.5, 199.4)$	$(189.8, 198.9)$
85%	197.5	$(181.0, 197.2)$	$(180.3, 196.9)$	$(172.7, 195.5)$
90%		$(174.9, 196.2)$	$(173.3, 196.2)$	$(163.0, 194.7)$

Note: This table presents the optimal nitrogen use for the static and dynamic models from our numerical simulations. Optimal nitrogen uses are reported for various combinations of insurance types, coverage rates, and utility types. YP refers to yield protection, *RP*-HPE refers to revenue protection with harvest price exclusion, and *RP* refers to revenue protection. Subscripts s (d) for crop insurance types indicate the model considered is static (dynamic).

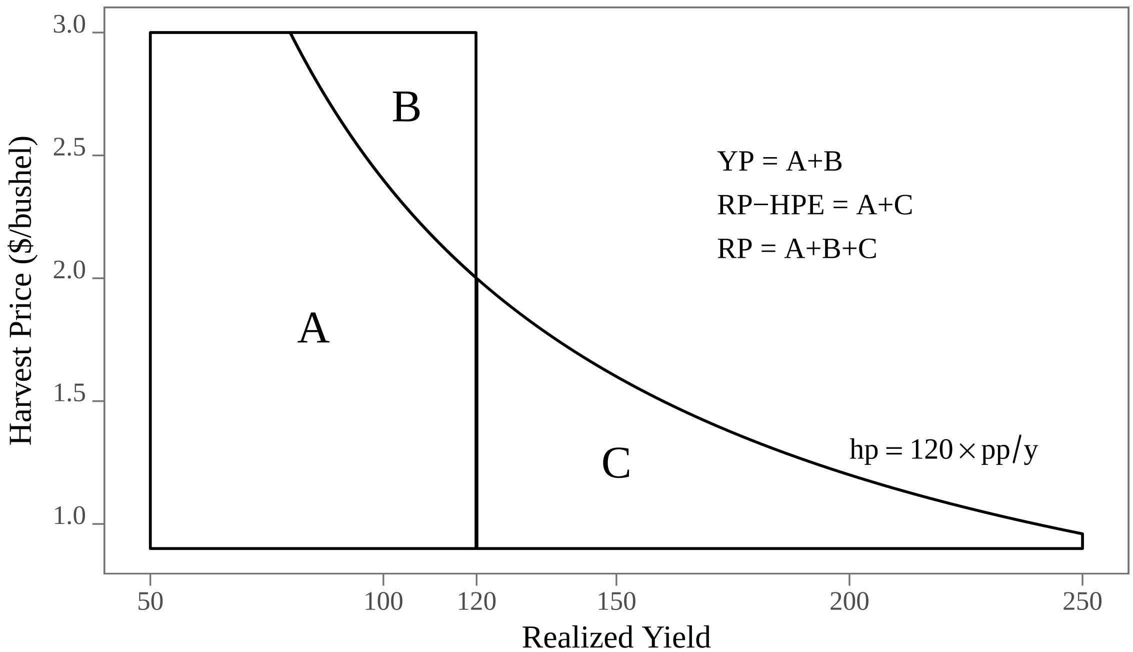

Figure 1: Regions where indemnity payments are triggered by insurance type

Note: This figure illustrates the parameter space of harvest price (hp) and realized yield (y) that would trigger indemnity payment at yield protection (YP), revenue protection with harvest price exclusion (*RP-HPE*), and revenue protection (*RP*) when the APH is 150, the projected price (pp) is \$2.20 bu/acre, and the coverage rate is 80%. Harvest price was limited from \$1 to \$4, as the range is sufficient to illustrate the differences among the insurance types. Under YP, if the realized yield is less than 120 $(150 * 0.8)$ (i.e., is left of the vertical line at 120), then indemnity triggered irrespective of the harvest price. Under *RP-HPE*, indemnity is triggered if $hp \cdot y \leq pp \cdot 120$ (i.e., below the convex line). The non-linear line that delineates the upper bound of region A and C is $hp = pp \cdot 120/y$. Finally, under *RP*, indemnity is triggered if $hp \cdot y \leq max\{hp, pp\} \cdot 120$, which covers all A, B, and C.

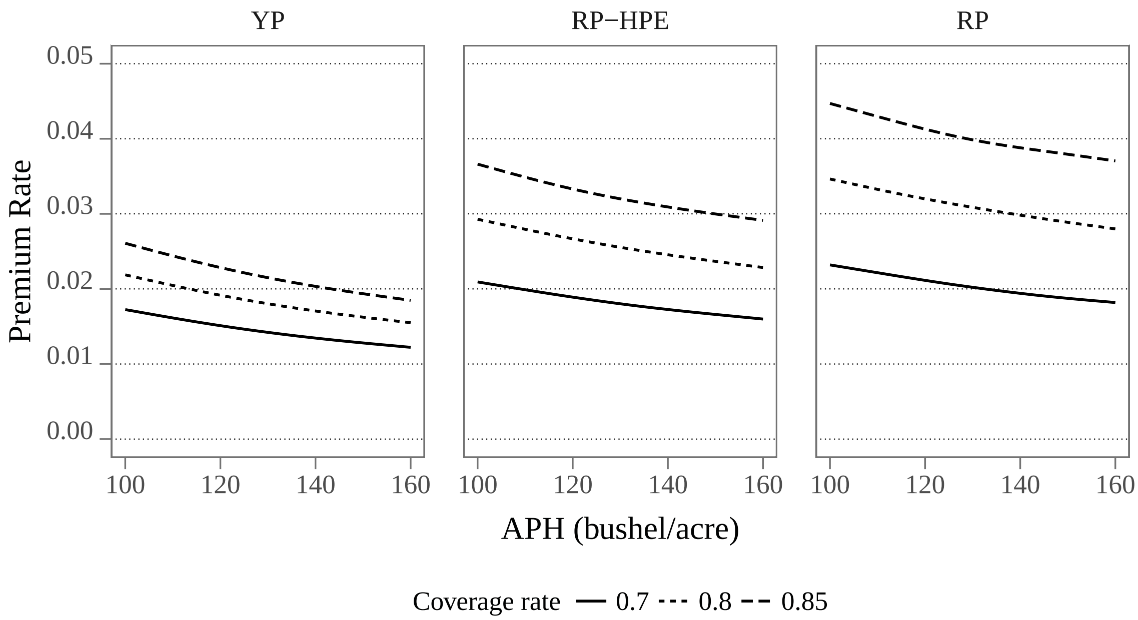

Figure 2: Subsidized premium rate against APH by coverage rate

Note: These panels show how subsidized premium rates change as APH goes up for coverage rates of 60%, 70%, 80%, and 85% under each of *YP*, *RP-HPE*, and *RP* insurance types. Reference yield and other actuarial parameters are for the 2016 production season in Sioux County, Iowa. Rate yield was set to be the same as APH.

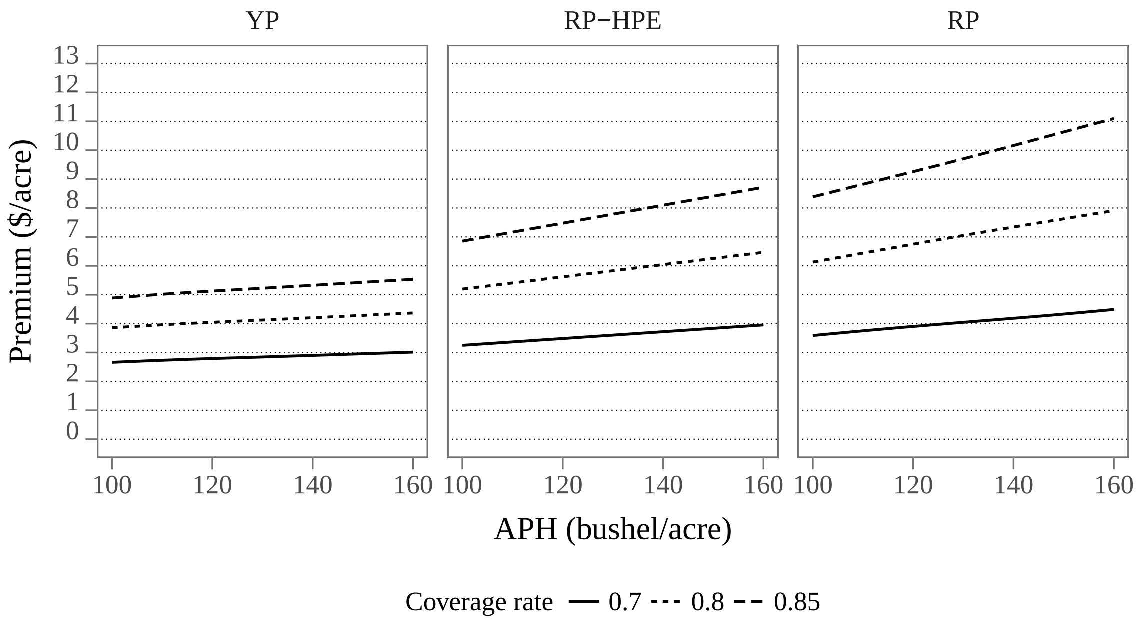

Figure 3: Subsidized premium ($/acre) against APH by coverage rate

Note: These panels show how subsidized premium payments change as APH goes up for coverage rates of 60%, 70%, 80%, and 85% under each of *YP*, *RP-HPE*, and *RP* insurance types. Reference yield and other actuarial parameters are for the 2016 production season in Sioux County, Iowa. Rate yield was set to be the same as APH.

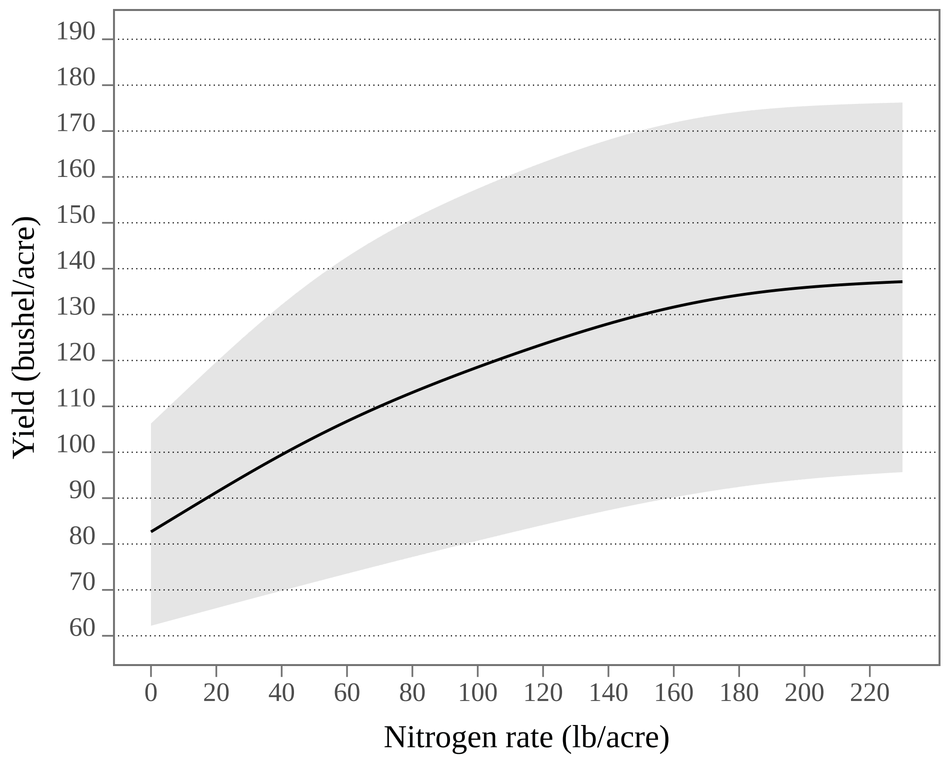

Figure 4: Modeled yield response to nitrogen

Note: This figure shows how yield (bu/acre) is modeled to respond to nitrogen rate (lb/acre) based on equation (23) in the numerical example. The black solid line represents the mean yield conditional on nitrogen rate. The lower and upper ends of the shaded region are the 10% and 90% quantiles of yield conditional on nitrogen rate.

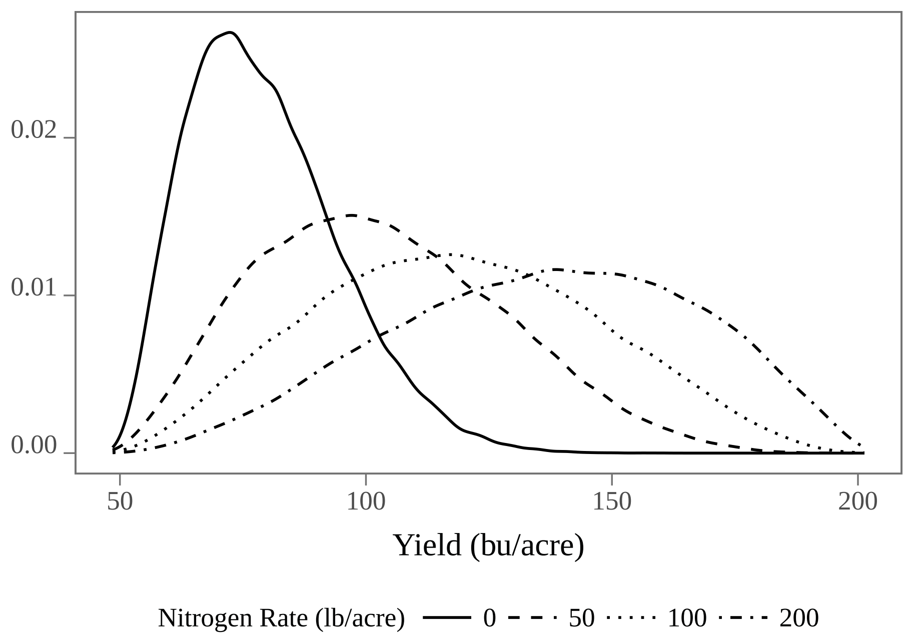

Figure 5: The distribution of modeled yield at select nitrogen rates

Note: This figure shows how the yield distribution is modeled to respond to nitrogen rate (lb/acre) based on equation (23) in the numerical example. At lower range of nitrogen rates, the yield distribution is skewed towards the left. As the nitrogen rate increases, the distribution shifts to the right.

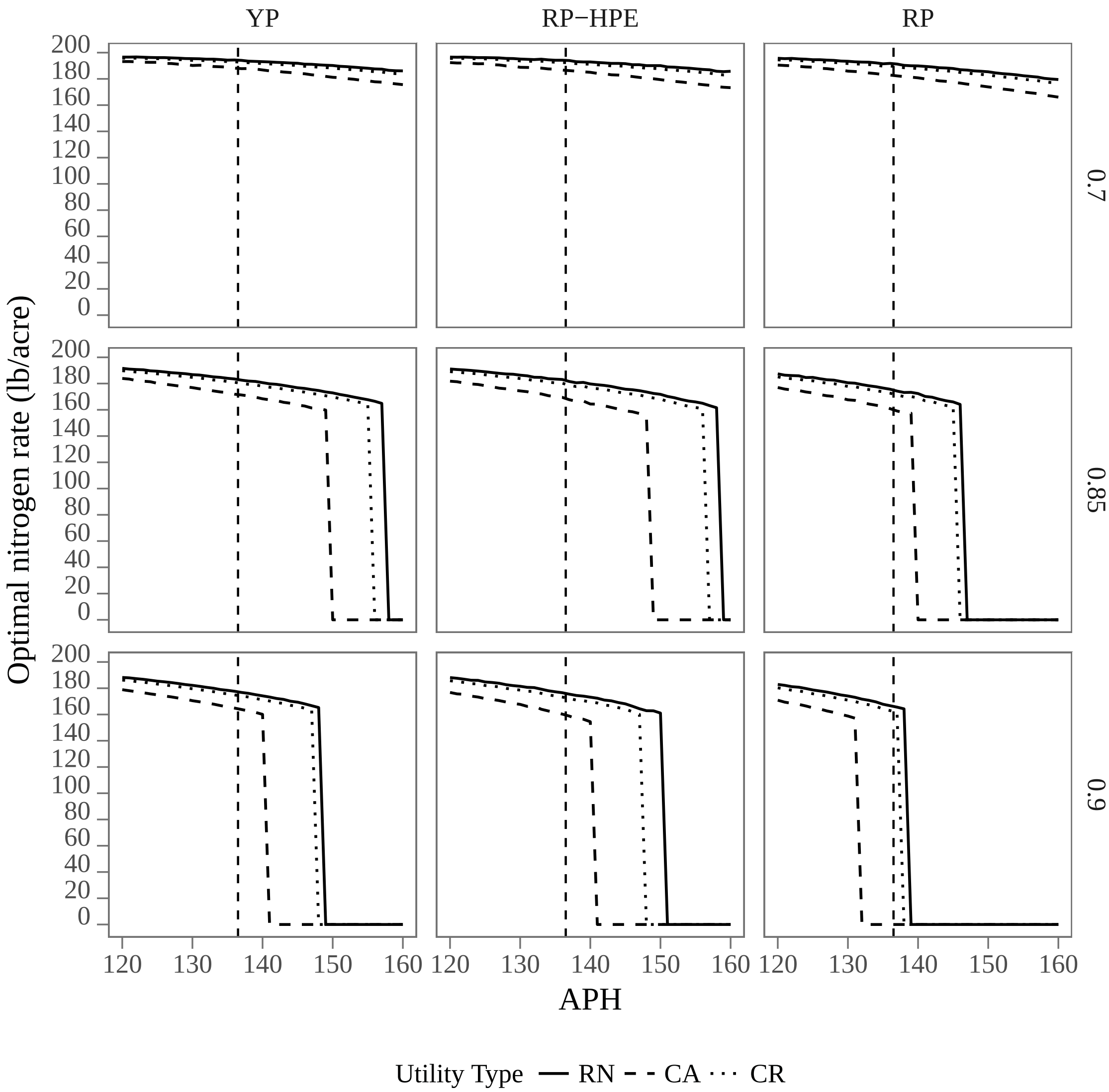

Figure 6: Optimal N choice conditional on APH for various combinations of coverage rates, insurance types, and utility types

Note: These panels show the optimal nitrogen rates (y-axis) of static models under various levels of APH (x-axis) by coverage rate (0.7, 0.85, and 0.9), insurance type (YP, *RP-HPE*, and *RP*), and utility type (*RN*, *CA*, and *CR*). Presented numbers are based on the numerical simulations. In general, the optimal nitrogen rate goes down as APH goes up for any combination of coverage rate, insurance type, and utility type. In some cases, optimal nitrogen rate fall sharply to zero when APH passes the threshold.

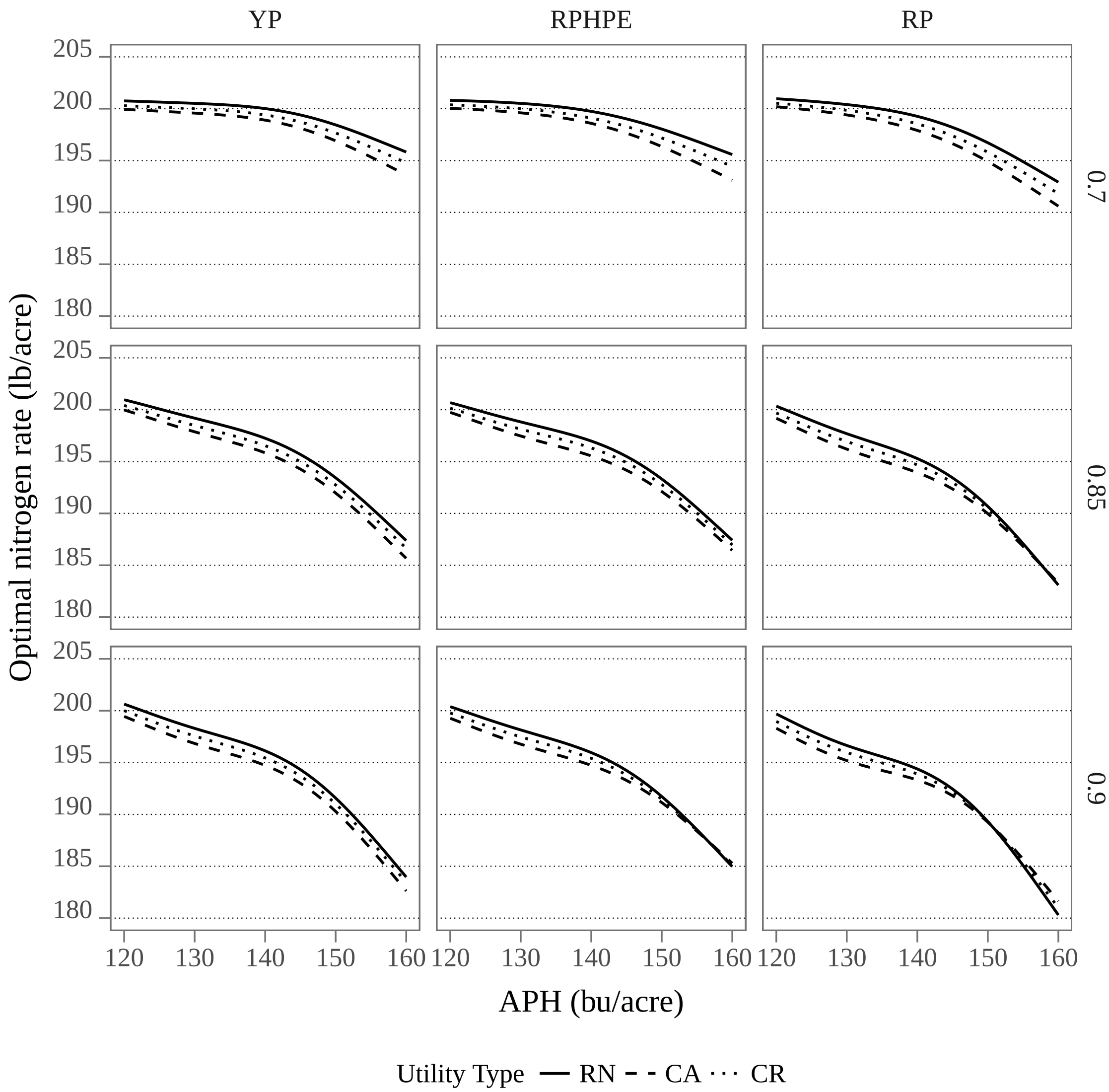

Figure 7: Optimal N choice conditional on APH at the steady state ($t = 20$) for various combinations of coverage rates, insurance types, and utility types

Note: This figure shows how the optimal nitrogen rates (y-axis) at the steady state differ based on APH (x–axis) by coverage rate (0.7, 0.85, and 0.9), insurance type (YP, $RP\text{-}HPE$, and *RP*), and utility type (*RN*, *CA*, and *CR*). Presented numbers are based on the numerical simulations. In all cases, optimal nitrogen rates at the steady state go down as APH goes up. Unlike the static case, APH thresholds do not exist.

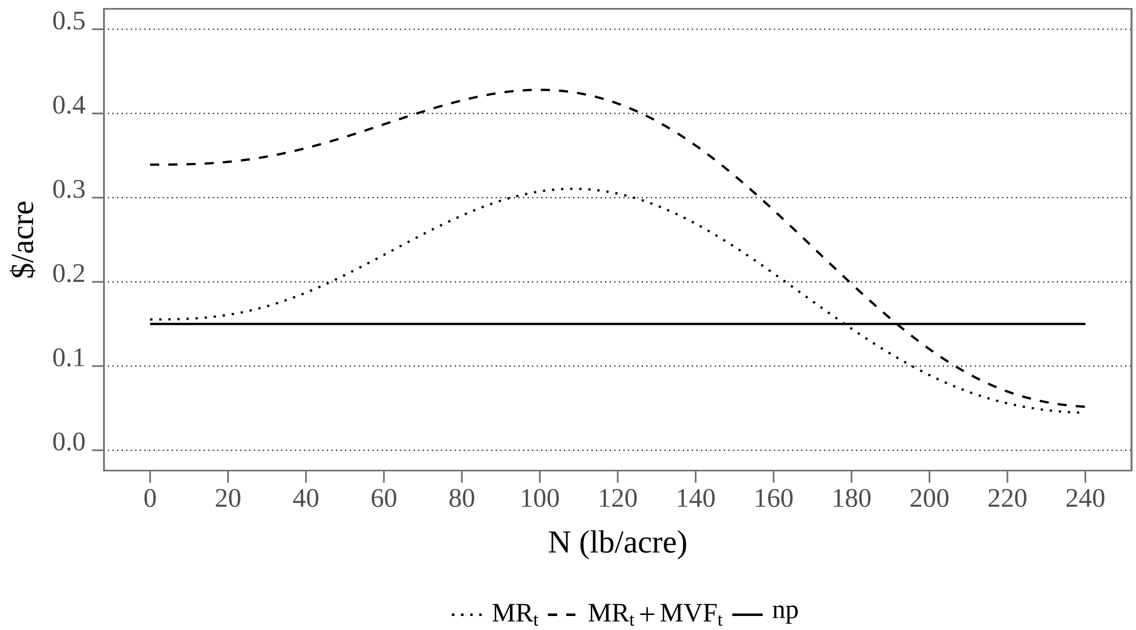

Figure 8: Comparison of marginal benefits of N between the static and dynamic cases

Note: This figure shows how the marginal expected value of nitrogen differ between the static and dynamic case for the coverage rate of 0.85 and utility type of *RN* (risk neutral) at $t = 20$. Presented values are based on the numerical simulations. In the static case, the marginal value of nitrogen is simply the marginal increase in revenue in the current period. In the dynamic case, the marginal value of nitrogen consists of marginal increases in revenue in the current period and marginal increases in the profit in the future periods. Nitrogen price is also presented in the figure. The optimal nitrogen rate is where the marginal value of nitrogen curves intersect with the the flat nitrogen price line. Here, the marginal value of nitrogen is always greater in the dynamic case compared to the static case. Hence, the larger optimal nitrogen rate.

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