The State Contingent Approach to Farmers' Valuation and Adoption of New Biotech Crops: Nitrogen-Fertilizer Saving and Drought Tolerance Traits

Paul E. Jaramillo[i]
University of Florida
polj26@ufl.edu

Pilar Useche
University of Florida
useche@ufl.edu

Bradford L. Barham
University of Wisconsin
barham@mailplus.wisc.edu

Jeremy D. Foltz
University of Wisconsin
jdfoltz@wisc.edu

Selected Paper prepared for presentation at the Agricultural & Applied Economics Association 2010 AAEA,CAES, & WAEA Joint Annual Meeting, Denver, Colorado, July 25-27, 2010

Contact Author:
Paul Jaramillo
Tel:(352)275-1545
Email: polj26@ufl.edu

---

[i] Senior authorship is shared by first two authors. Paul Jaramillo obtained his Ph.D. in Food and Resource Economics from University of Florida, 2009. Pilar Useche is assistant professor in the Department of Food and Resource Economics and Center for Latin American Studies at the University of Florida. Bradford Barham is professor and Jeremy Foltz is associate professor in the Department of Agricultural and Applied Economics at the University of Wisconsin, Madison.

The State Contingent Approach to Farmers' Valuation and Adoption of New Biotech Crops: Nitrogen-Fertilizer Saving and Drought Tolerance Traits

ABSTRACT

We used a state contingent approach to give a detailed analysis of the uncertainty surrounding seed trait adoption. Our framework emphasizes the role of timing and information in farmers' adoption decisions. The inherent embeddedness of seed traits results in timing restrictions and the inability of post-planting adjustments, this in turn results in farmers necessarily engaging in a game with nature. Two main types of traits we identify are supplementing traits and stabilizing traits – classification into each category is directly related on the mobility of the production factor the trait intends to substitute. Supplementing traits allow for acting after nature (i.e., ex post) while stabilizing traits are better modeled as acting before nature (i.e., ex ante). The type of trait results in different determinants of the farmers' WTP function.

Key Words: State Contingent, Genetically Modified, Biotech, Contingent Valuation, Nitrogen Absorption Efficiency, Drought Tolerance, Uncertainty, Seed Trait, Technological Adoption

INTRODUCTION

Farmers hold two main agronomic strategies to obtain high yields with higher consistency: (1) modifying the environment surrounding the plant, or (2) modifying the plant itself. Cultural and agronomic practices such as irrigation and fertilization fall in Strategy 1, whereas seed choice or choice of the traits embedded in the seed falls under Strategy 2. Similar yields may be obtained with either strategy, thus making them substitute inputs. However, the differences in time and information dynamics of each strategy may provide for no more than an imperfect substitution.

Which strategy is favored by farmers represents an empirical question and should be reflected in a differential willingness to pay of producers for Strategy 1 inputs (e.g., insecticide) as opposed to Strategy 2 traits that are embedded in seeds (e.g., insect resistance). For example, Qaim and DeJanvry (2003) found that farmers' willingness to pay (WTP) for a dollar savings in insecticide use (strategy 1) is often less than a dollar when these savings are embedded in the seed (strategy 2).

However, the conceptual framework of technology adoption studies is not suited to provide a compelling explanation for this imperfect substitutability. Beyond empirical aspects, the WTP gap reflects the uncertainty inherent to seed trait choices and, therefore, inherent to genetically modified (GM) crop adoption. This uncertainty has traditionally been oversimplified and sometimes even neglected in studies of GM crop adoption (e.g., Hubbel,Marra and Carlson 2000; Qaim and DeJanvry 2003; Useche et al. 2009).

In this work we present an analysis of GM crops that emphasizes the uncertainty in seed choice. We use a novel conceptual framework that examines the adoption process as a game with nature that occurs over time, an approach consistent with the State Contingent theory of Chambers and Quiggin (2000). A key implication of our model is that seed traits which interact with environmental factors that are relatively stable in nature, over time, are better described as state-general, while others, which interact with more variable environmental factors, are best described as state-specific. State-general inputs obtain similar yield advantages under a larger number of states of nature and are less risky than state-specific inputs (Rasmussen 2003).

Our approach also emphasizes the fact that cultural practices such as irrigation (which fall under Strategy 1) may be changed at will at any time during the growing season based on actual needs determined using day-to-day information retrieved from the field (i.e., ex post). While, on the other hand, a decision to adopt a seed with a drought tolerance embedded trait that substitutes for irrigation (Strategy 2) must be necessarily made before or at the beginning of the growing season (i.e., ex ante) based on limited information that is used by the farmer to develop long term expectations regarding the probability of a drought occurring in the future. The timing and information used by farmers to make decisions involving Strategy 1 are quite different from the timing and information allowed for decisions involving Strategy 2, implying Strategy 2 only imperfectly substitutes Strategy 1.

We apply our framework to two of the most important seed traits in the pipeline of biotech companies: nitrogen efficiency absorption (NAE) and drought-tolerance (DT) traits. The DT and NAE traits, as defined in our CV questionnaires, are more correctly classified as state-specific and state-general, respectively. Based on our conceptual model, we derive the determinants of the state-contingent WTP for each specific type of input. Then, we empirically estimate farmers' WTP for these traits and test the imperfect substitution hypothesis. We used a representative sample of corn farmers in Minnesota and Wisconsin.

The results support our hypothesis that seed traits, regardless of their type (GM or nonGM), are regarded by farmers as imperfect ex ante substitutes (i.e., less than dollar per dollar) for their relevant cultural practices. They also support the hypothesis that the WTP for traits that are designed to interact with variable environmental factors is state contingent.

In order to distinguish the uncertainty that is purely due to genetic modification, as opposed to the ex-anteness of the choice, we provide WTP estimates for both GM and non-GM seed traits. In total four hypothetical traits were presented to farmers for valuation: (iii) Drought Tolerance-GM, and (iv) Drought Tolerance-nonGM (i) Nitrogen Absorption Efficiency-GM, (ii) Nitrogen Absorption Efficiency-nonGM,. The estimated mean WTP's, in dollars per acre, were $18.63, $20.81, $17.35, and $19.78, respectively. In both DT and NAE traits, farmers are, in average, willing to pay more for the nonGM version compared to the GM version: $2.18 and $2.43, respectively.

Consistent with Aldana et al. (2010), our results dicate that the uncertainty associated with GM versions of the crop disappears as farmers acquire more experience with the GM technology. In particular, early GM adopters showed willing to pay between $16.88 and $11.94 per acre more than other adopters for the DT and NAE traits, respectively.

We argue that the state contingent approach provides a powerful tool for studying the dynamics of trait adoption and how farmers trade one strategy for the other depending on the subjective probabilities they assign to different states of nature. Thus, this framework is most adequate when studying how farmers engage in risk management when constructing their valuation for state-specific seed traits (i.e., trading one risky strategy for another).

CONCEPTUAL FRAMEWORK

From the perspective of a farmer whose goal is that of output maximization, nature results inefficient in providing optimal levels of production factors where and when they are necessary. Nature is unpredictable and inconsiderate to the farmer's goal of output maximization. Farmers continuously search for innovations that allow them to reduce uncertainty and better protect or stabilize their yields against nature's inefficient, untimely and potentially adverse supply of highly mobile production factors (e.g., rainfall/droughts, pest populations) or supplement deficiencies of those production factors that are more stable in the agro-ecosystem (e.g., nutrients in the soil).

The focus of this paper centers on a particular type of innovation, namely, on the adoption of new seed traits or what we call seed strategies. However, seed traits are only one of two distinct main agronomic strategies we identify as being available and used by farmers on the field to obtain high yields with higher consistency. These are:

Strategy 1: modifying the environment surrounding the plant.

Strategy 2: modifying the plant itself.

Cultural and agronomic practices such as irrigation and fertilization fall in Strategy 1, whereas seed choice or choice of the traits embedded in the seed falls under Strategy 2. For given market prices, these strategies obtain also higher and more consistent profits. In terms of profits and off the field – but still out of the market - we can identify a third strategy if we allow for market instruments such as insurance:

Strategy 3: output insurance.

Similar outputs may be obtained with either Strategy 1 or 2, thus making them substitute inputs. However, the differences in time and information dynamics of each strategy may provide for no more than an imperfect substitution. Similar reasoning is possible, in terms of profits, if we consider all three strategies.

Similar distinction of strategies in the hazard mitigation literature was presented early on by Ehrlich and Becker (1972) and developed further by Quiggin (1992, 2002) and Lewis and Nickerson (1989). Our own critical distinction between these strategies is their timing; in short, the possibility for timely adjustments in supplementation which exists in Strategy 1 but results impossible with Strategy 2 (for a detailed discussion see Jaramillo 2009, p. 144-52). To more clearly see this consider irrigation, pesticide applications, or any other cultural practice falling in Strategy 1. Any of these may be adjusted at will[1] at any time during the growing season based on actual needs determined using day-to-day information retrieved from the field. On the other hand, a decision to adopt a drought tolerance trait (Strategy 2) that substitutes for i.e., irrigation must be necessarily made at the beginning of the growing season. Once a seed without an insect resistance trait is sowed, there is no possibility of adjustment into a seed with the trait in the case where a severe pest infestation occurs during plant growth – and vice-versa. In this sense, when adopting seed traits that stabilize yield and protect against uncertain natural supplies of highly mobile factors, the farmer is forced to act before nature (i.e., ex ante).

Going back to Strategy 1, in theory, if one could – on real time basis – gather perfect information regarding the plants needs and deliver the exact necessary Strategy 1 inputs on the spot, one could obtain the same yield in every single growing exercise – thus completely eliminating production uncertainty. In fact, precision agriculture aims to do just this by using information-gathering and input-delivery methods and technologies to manage natural resource variability.[2] In contrast, when it comes to Strategy 2, the farmer's adoption decision must be based on limited information that is used by the farmer to develop long term expectations regarding the probability of i.e. a drought occurring in the future.

The take away message is that with Strategy 1, although potentially very costly, it is always possible to act after nature (i.e., ex post). With Strategy 2, acting before (i.e., ex ante) or after (i.e., ex post) nature depends largely on whether the trait supplements production factors which are relatively stable on the field or protects (stabilize) against highly mobile factors, respectively.

State Contingent Approach

In this study we focus on production uncertainty and separately consider another source of uncertainty – adoption uncertainty – which derives from the lack of information or knowledge of the productive agent with respect to factors affecting the profitability of an innovation. In general, the agricultural technology adoption literature has assumed a priori that new technologies are more productive than traditional technologies and that the profitability level of the former is determined by farm and farmer characteristics. These studies have oversimplified or even ignored the role of uncertainty.[3]

In particular, contingent valuation studies which have been valuable in estimating farmers' WTP for GM traits (e.g., Qaim and DeJanvry 2003, Hubbel, Marra, Carlson 2000) have used models based on utility comparisons which assume certainty from the farmer's perspective. These models are made stochastic under a Random Utility framework (RUM) that adds an error term e to a deterministic portion of utility on the premise of components certain to the farmer but unknown to the researcher. Even if we naively assume that the RUM error term in these models adequately captures uncertainty, this would result in implicitly assuming an output cubical technology. As shown by Chambers and Quiggin (2000), an output cubical technology is characterized by inputs that have the same impact on output independent of which state of nature occurs. This is not the ideal theoretical framework to use when studying seed traits which, in some cases, impact output only in certain states.

A better representation of adoption decisions regarding seed strategies is made possible in our study by using a state contingent approach (Chambers and Quiggin 2000, Quiggin and Chambers 2006). In our framework the basic needs underlying the purchase of different traits embedded in seeds are identified with profit opportunities that are, to different degrees, contingent upon the occurrence of various mutually exclusive states of nature. If an input impacts output only when a specific state of nature occurs it is termed a state-specific input; in contrast, inputs which affect output on more than one state of nature are termed state-general (Chambers and Quiggin 2000, Rasmussen 2003).[4]

A key insight in our analysis is that whether a given seed trait is considered state-specific or state-general depends largely on the *mobility* of the production factor it supplements. Traits which protect (stabilize) yield against the uncertainty related to production factors such as rainfall or pest infestations which are highly variable in time, will more adequately be classified as state-specific. In contrast, traits which supplement factors that are more stable in the field such as soil nutrients are more adequately classified as state-general.

In the case where profit opportunities are most sensitive to states, seed-trait strategies may allow farmers to redistribute output opportunities towards the less well-environmentally-endowed states. Adoption of traits that redistribute outputs towards less favorable states of nature amount to self-insuring (Ehrlich and Becker 1972, Quiggin 1992, Quiggin 2002); these substitute for market insurance. Seed-traits that supplement environmental allocations of individuals substitute for variable inputs and can be thought of as self-protection strategies.

To summarize, the profit outcome experienced by the farmer's adoption of the new technology is determined by an interaction between the propensity to suffer monetary losses (or obtain gains) due to crop damage (or improved growth)– predetermined by environmental factors--, the strategies that the farmer uses to mitigate losses or increase gains, and purely stochastic factors. For example, a higher likelihood of pest infestations translates into higher risk of loss, which may be mitigated by using insecticide, by adopting pest resistant technologies or by insuring against crop loss.

We argue that, in order to understand the adoption of seed traits and disentangle the factors determining the willingness to pay for them, it is paramount to analyze the timing of events that occur and the underlying causes of uncertainty.

MODEL

We focus on the case of one single output and a finite Ω set with $S+K$ possible states of nature. We represent the multiple exogenous factors affecting environmental quality by θ in Ω^k and the quality improving strategies available by $\mathbf{x}$ in $\Re^N$. The former are fixed *ex ante* and the latter are committed *ex ante* and fixed *ex post*. The state contingent profit outcome (or outcome profile) $\mathbf{y} \in \Re_+^{(S+K)xN}$ is determined *ex ante* but produced *ex post.* With finite S, the random variable $\mathbf{y}$ with monetary payoffs can be represented as $(y_1, y_2,..., y_s)$. Uncertainty enters the model through the stochastic states of nature represented in the probability space $\Omega = \{1,2,..,S\}$.[5] Strategies have an associated cost vector $\mathbf{p}_x$ which is assumed certain.[6]

Essentially, while θ represents non-stochastic states of nature –from the farmer's perspective, s represents stochastic ones. This distinction is directly linked to the timing of events. When nature plays before the farmer's decision period, the realized states of nature are known to the farmer. To the contrary, when nature plays after the farmer's decision is taken, affecting unrealized outcomes, the farmer relies on probability assessments on the likelihood π_s of each s in order to calculate his expected utility.

Thus, the model may be understood as a three period game with nature. In period 0 nature determines θ, in period 1, the decision maker commits to a strategy x (ex ante), which determines the vector of possible outcomes $\mathbf{y}$ she may observe in all possible states of nature. The exact outcome depends on which state of nature s occurs. In the last period, nature "reveals" the state of nature s after the decision maker has committed to x, what results in output y_s being produced in period 2 (i.e., ex post). In our study, θ may be associated with soil nutrients, which are relatively stable in the agro-ecosystem, while s can be conceived as stochastic – unfavorable or favorable – weather conditions resulting in crop damage or growth. Then, $\mathbf{x}$ are strategies that can be used to supplement or stabilize environmental conditions. The adoption of seeds with embedded environmental quality traits is identified as one of these multiple strategies on which farm outcome opportunities are contingent upon: (1) modifying the environment surrounding the plant (farmer can do it himself through input application); (2) modifying the plant itself (farmer adopts seed technologies); and (3) purchasing insurance in the market

The difference between supplementation and stabilizing strategies is that the former interact with θ, while the latter stabilize y_s. Thus, a key insight of this analysis is that while considering whether to adopt or not a seed trait, an individual's choice set will not be fixed. Specifically, it will depend on θ in the supplementation case. Furthermore and as shown next, this will result in different determinants of the WTP function for different trait types.

Utility Maximization and WTP for new traits

Given strategy x and profit vector y, the individual's *ex post* profit is

(1) $y(x;\theta,s,r) = r + g(x;\theta,s,r) - p(x)$,

where r is base wealth, g is state contingent gain or loss of revenue associated with the strategy x, and $p(x)$ is the cost associated with x.

It is important to note that when the strategy is a new technology, its cost will include not only the monetary cost to be paid for the seed, but also the cost associated with acquiring information to decrease the uncertainty about the performance of the technology under the specific farmer's conditions, $e(.)$. This term can be modeled as a negative function of the amount of time that a farmer has used similar technologies, the size of her farm, the degree of specializations and education. Aldana et al. (2010) provide a theoretical explanation of this specific component in the context of GM crop adoption.

We assume that farmers aim to maximize their utility V :

(2) $Max_x V(y^*(x;\theta,s,r)) \quad where \quad y^*(x;\theta,s,r) = r + g(x;\theta,s,r) - p(x)$

This defines the indirect utility function as a quasi-concave and monotone increasing in y, state-contingent preference function $V(\theta,s,r) = Max_x\ V(y^*(x;\theta,s,r))$, where x is the strategy used to change environmental conditions in an optimal way. In a continuous space $x(\theta,r) = \arg\max V(y^*(x;\theta,r))$, would be the amount of strategy x demanded. We focus on the discrete case where there are N strategies are $\mathbf{x} = \{x_1,...,x_N\}$. With a finite S and $\mathbf{x}$, the random variable $\mathbf{y}$ with monetary payoffs can be represented as

$\mathbf{y} = (y_{11,}, y_{12},..., y_{1S}, y_{21}, y_{22},..., y_{2S},..., y_{NS})$.

Because supplementation strategies interact with the natural factors θ , which are by definition stable over time, farmers are able to observe these factors [7] before making their strategy choice. This implies that the choice set of supplementation strategies is $x(r;\theta) = \{x \text{ in } \Re^N : x \text{ can produce } r \text{ given } \theta\}$. To the contrary, stabilizing strategies interact with s factors, which occur after the farmer has chosen his strategy. This implies that the choice set of stabilizing strategies is $x(r) = \{x \text{ in } \Re^N : x \text{ can produce } r\}$.[8] The former reflects that when the decision maker is making her choice she has already experienced θ.

With these definitions, the WTP for environmental supplementation using a strategy x_j is given by :

(3) $$WTP(\theta^{xj}, r) = \max\{p^* : V^*(\theta^{xj}, r + g - p^*) \geq V^*(\theta^{x0}, r)\},$$

where θ^{x0} is the level of environmental quality associated with current strategy x^0. And the WTP for environmental stabilization using a strategy x_j is :

(4) $$WTP(\mathbf{F}^{xj}, r) = \max\{p^* : V^*(\mathbf{F}^{xj}, r + g - p^*) \geq V^*(\mathbf{F}^{x0}, r)\},$$

where $\mathbf{F}^{x0} = (\pi_{s1}^{x0},..., \pi_{sN}^{x0})$ is the base distribution of outcomes associated with strategy x^0.

Thus, the utility of environmental supplementation seed-traits will compete with alternative supplementation strategies, and similarly will happen with stabilizing traits.

Applications of Conceptual Framework

In this section we apply the conceptual framework described above to two major traits that are in the pipeline of biotech companies, but have not yet been commercialized in corn. The first, a drought tolerance (DT) trait, corresponds to a stabilizing strategy that allocates profits from favorable states of nature to unfavorable states of nature. The second is a nitrogen absorption efficiency (NAE) trait, which supplements the nitrogen available on the farmer's soil.

For the DT trait we analyze a basic case where no insurance is available. For the NAE trait we show how it competes with fertilizer uses, depending on which θ level has been assigned to the farmer ex-ante. The possibility of acquiring insurance in the DT trait is allowed in a third case (Case 3) presented in the Appendix.[9]

Since states of nature unfold over time, we illustrate these examples using extended form game representations (See Figures 1,2,3), where the final nodes stand for possible states realized by time T=3. It is important to note that since the DT trait by definition only interacts with *s* states of nature, the first period of the game, where nature determines θ is irrelevant for the first two illustrations. We assume that there are two states of the world, a favorable one, s_0, that occurs with probability π_0 ,and an unfavorable one , s_1, that has probability $\pi_1 = (1- \pi_0)$. We represent the different ex-post monetary payoffs with $\mathbf{y} = (y_{11,}, y_{12}, ..., y_{1S}, y_{21}, y_{22}, ..., y_{2S}, ..., y_{NS})$, r=base income, p_x=cost of strategy x, g =-L=potential gain or loss relative to the base income.

Importantly, adoption uncertainty is captured by the term $e(.)$, which is a function of farmer's characteristics that relate to the amount of experience that she has had with seed-trait technologies: time using similar technologies, farm size, degree of specializations and education (Aldana et al. (2010) provide a theoretical explanation of this specific component in the context of GM crop adoption). Finally, the willingness to pay premium for a specific trait, relative to the price of the competing technology, is given by p^*.

Case 1: Drought tolerance trait with no insurance option

In this basic case the farmer faces a decision whether to adopt a drought tolerant trait embedded in the seed or simply use conventional seed. The corresponding payoffs are: $y_{10} = r - e(.) - p_T$, $y_{11} = r - e(.) - p_T$, $y_{21} = r - L - p_C$, $y_{20} = r - p_C$. The structure of this scenario is shown in Figure 1.

In order to adopt this type of trait, our model requires that:

$$\begin{aligned}
E[U(\text{Trait})] &\geq E[U(\text{Conventional})] \\
\pi_0 y_{10} + \pi_1 y_{11} &\geq \pi_0 y_{20} + \pi_1 y_{21} \\
r - e(.) - p_T &\geq (1-\pi_1)(r - p_C) + \pi_1(r - L - p_C) \\
\pi_1 \cdot L - e(.) &\geq p_T - p_C = p^*
\end{aligned}$$

Giving,

(5) $\pi_1 \cdot \alpha \cdot r - e(.) \geq p^*$

The latter shows that the maximum willingness to pay for a DT trait, in the absence of insurance, depends on three main variables: the likelihood of loss in the unfavorable state of nature, the probability of this loss, and the uncertainty related to the lack of knowledge about the technology of embedded traits in seeds.

Case 2: Nitrogen Fertilizer Saving Trait

In the case of a trait that increases nitrogen absorption, nature has taken the first move and has defined θ, here the level of nitrogen in the soil. Farmers observe the latter and self-select into groups with heterogeneous choice sets. In particular, if $\theta > \tilde{\theta}$, where $\tilde{\theta}$ is the nitrogen requirement for the specific crop grown, the farmer's choice set will exclude the seed-trait from the onset. In this case, the farmer would not need to apply any fertilizer to the soil, which would yield the trait useless. To the contrary, if $\theta \leq \tilde{\theta}$, the farmer will compare the trait-strategy with the variable-input supplementation strategy. The latter is then our population of potential adopters and the respective payoffs are: $y_{10} = r + g_{X1} - p_C - p_F$, $y_{11} = r + g_{x1} - L - p_c - p_F$, $y_{20} = r + g_{X2} - e(.) - p_T$, and $y_{21} = r + g_{x2} - L - e(.) - p_T$

Given $\theta \leq \tilde{\theta}$, $E[U(\text{Trait})] \geq E[U(\text{Conventional+Fertilizer})]$, if and only if,

(6) $(g_{x2} - g_{x1}) + p_F - e(.) \geq p^*$.

Notice that the outcomes here are conditional on θ ; specifically the cost of fertilizer are conditional on this factor. Additionally, since fertilizer can always be added to the plant *ex-post* and at a specific cost, it should always be possible to match the gain in yield obtained with the trait with gains from applying fertilizer, such that $(g_{x2} - g_{x1}) = 0$ at a cost of λp_F . In this case the tradeoff in the decision to adopt is between the normalized cost of fertilizer versus the price premium of the seed trait added to the cost of uncertainty (cost of information):

(6') $\boldsymbol{\lambda}\, p_F - e\,(.) \geq p^*.$

These results show two important points. First, that even though the absolute expected payoffs for the supplementation trait are contingent upon the likelihood of the unfavorable stochastic state of nature, the willingness to pay for the trait is not a function of this likelihood. And second, that because of the higher flexibility of application of fertilizer, there is not a one-for-one relationship between the cost of fertilizer and the cost of the trait. In particular,if this lack of flexibility is perceived by farmers as a disadvantage, then $\boldsymbol{\lambda} < 1$. If farmers do not care about it, $\boldsymbol{\lambda} = 1$. The latter provides a way of testing for the degree of substitutability between the *ex-ante* expenditure in the fertilizer saving trait vs. anytime expenditures in fertilizing inputs.

Results obtained in Equation 5 and Equation 6 guide our empirical implementation and estimation of WTP for the DT and NAE traits in the next section.

EMPIRICAL APPLICATION

We used a Contingent Valuation (CV) method to estimate farmers WTP for two of the most important GM traits in the R&D pipeline of seed companies.[10] Using a Double Bounded-Dichotomous Choice (DB-DC) elicitation format[11] [12], corn farmers in Minnesota and Wisconsin were asked about their WTP (in $ per acre) for having a Nitrogen Absorption Efficiency (NAE) trait added to their current most-used corn seeds (i.e., conventional). The NAE trait was characterized as obtaining the same yield as was being obtained with the current seed used but using 1/3 less nitrogen fertilizer. WTP was elicited for two different versions of the same trait. In the first version of the trait the farmer was told that the trait was to be added to the seed by conventional selective breeding methods (i.e., nonGM), in the second version the farmer was told that the trait was to be conferred to the plant via genetic modification (i.e., GM).

A second trait was also considered in a separate DB-DC question. In this second CV question farmers were asked about their WTP for having a Drought Tolerance (DT) trait added to their current most used corn seeds so that under severe drought conditions it would still obtain 75% of the normal yield (i.e., a loss of 25%). Two different versions of the trait (nonGM and GM) were also presented for this second trait. Table 1 shows the four different traits that were presented for farmer valuation. The CV questionnaire portion of the survey used to elicit WTP for both traits and both versions may be seen in Figure 3.

Data and Surveys

The data for this study was mainly provided by two separate interview-based surveys: (i) the 2006 Corn Poll (CP06) and (ii) the 2007 Corn Poll (CP07). Both surveys were administered to corn farmers in the states of Minnesota and Wisconsin by the University of Madison-Wisconsin – Program on Agricultural Technology Studies (PATS).

The CP06 (conducted in 2006) contained sections of questions asking 945 randomly selected corn farmers about their individual demographics, farm characteristics, purpose of corn production (i.e., grain, silage, sweet corn, or other), and previous experience with GM-corn varieties. The CP07 (conducted in 2007) was administered to 451 randomly selected farmers and was in essence a short CV survey designed to complement the CP06 and find out which corn seed technologies farmers are using and how they value certain traits. The CP07 also yielded data on production practices, insurance practices and, most importantly, it provided the CV responses per se.

The CV questionnaire had four different versions (A, B, C, and D) each presenting a different initial price scenario and also varying in the subsequently presented follow-up price scenarios – this is typical of CV surveys.[13] Table 2 shows the different versions and their respective price offers.

Additionally, data from the Drought Monitor Index archives (National Drought Mitigation Center 2006) was used to calculate the average area under severe drought (*mD2*) at the county level for Minnesota and Wisconsin in 2006. [14]

A list of all variables included in the models estimated and their respective descriptions is presented in Table 3.

Statistical Model

In the DB-DC format, individuals in the sample are randomly assigned an initial price scenario. Based on their answer to the initial price scenario, they are offered a higher price P_i^H or a lower price P_i^L in the follow-up question. In any given price scenario, a given individual will answer "yes" and adopt the technology only if his WTP (represented by p^* in our notation) is larger than some asked price P_i (i.e., $p_i^* = WTP_i \geq P_i$). Four possible answer sequences to the initial and follow-up questions are possible

$$d_i = \begin{cases} 1 & no, no \\ 2 & no, yes \\ 3 & yes, no \\ 4 & yes, yes \end{cases}$$

The likelihood of an individual giving a response sequence $d_i = yes, yes = 4$ is given by

$$\begin{aligned}\pi_i^{YY}(P_i, P_i^H) &= \Pr(P_i \leq WTP_i \text{ and } P_i^H \leq WTP_i) \\ &= \Pr(P_i \leq WTP_i \mid P_i^H \leq WTP_i) \cdot \Pr(P_i^H \leq WTP_i) \\ &= \Pr(P_i^H \leq WTP_i)\end{aligned}$$

where we have used $\Pr(P_i \leq WTP_i \mid P_i^H \leq WTP_i) \equiv 1$. The term π_i^{YY} represents the likelihood of adoption by individual i at some offered price $P_i \geq P_i^H$.

Equations 5 and 6 show deterministic relations between WTP = p^* and variables that explain p^* which were derived starting from individual farmer utility comparisons. While farmers may know their utility functions with certainty, some components entering such utility may be unobserved by the researcher. A stochastic term $\varepsilon \sim N(0, \sigma)$ is added to the left hand side of both Equations 5 and 6 in order to account for these unobservables.[15] Then, equations 5 and 6 can be solved for $\varepsilon < p^* - \mathbf{z}'\beta$ where

$\mathbf{z} = \{\pi_1 \cdot \alpha \cdot r \quad - e(.) \quad \}$ in Case 1

$\mathbf{z} = \{(g_{x2} - g_{x1}) \quad p_F \quad - e(.)\}$ in Case 2

where D^I is a dummy =1 if insured and =0 otherwise.

Then,

$$\pi_i^{YY}(P_i, P^H) = \Pr(P_i^H \leq WTP_i) \equiv \Pr(\varepsilon \leq \mathbf{z}_i'\beta - P_i^H) = 1 - \Phi\left(\frac{P_i^H - \mathbf{z}_i'\beta}{\sigma}\right)$$

Similar derivations obtain π_i^{YN}, π_i^{NY} and π_i^{NN} (see Hanemann, Loomis and Kanninen 1991) and the standard Double Bounded Dichotomous Choice likelihood function (for a detailed derivation see Jaramillo 2009, p.81). Maximum likelihood methods are used to obtain estimates of β and σ. The estimated β may be directly interpreted as the marginal effects of $\mathbf{z}$ (in dollars per additional unit of $\mathbf{z}$) on WTP.

Results: Drought Tolerant Seed Trait

Table 4 shows the estimation results for both the GM and nonGM DT traits for the case with available insurance. The likelihood ratio test on the global null hypothesis that all coefficients are equal to zero is strongly rejected at the 1% level in both the GM and nonGM models. A Pseudo R-square of 0.45 and 0.44 for the GM and nonGM traits, respectively, seems to indicate good explanatory power.

The first three columns present the coefficients of the explanatory variables for the WTP of a GM-DT trait. As suggested by our conceptual framework, we find a positive and significant effect of potential loss ($loss = yield * mD1 * \alpha$) on WTP for the GM DT trait. The higher the loss in the event of a drought the more dollars the farmers is willing to pay to prevent that loss. Each extra potentially lost bushel due to drought increases WTP by 51 cents. The relation is significant even after controlling for other factors.

Additionally, the WTP for this trait is highly sensitive to reductions in the cost of uncertainty. The latter goes a long way in explaining adoption. Significant variables that are negatively related to the cost of uncertainty are early adoption *(earlyadopt)* and farm specialization (*grain*), both of which have expected positive signs. We also confirm that a higher farm income (*f_income*) results in higher WTP for the GM DT trait. In contrast, farm size (*farmsize)* as measured in acres bears no effect on farmers' WTP for the trait. This could be evidence that the technology has no scale dependency per se which seems to make sense because a seed input is perfectly divisible. The positive relation between farm income and WTP suggests that "scale dependency" may be more related to cash flow constraints.

Early adopters (*earlyadopt*) are in average willing to pay more than non-early adopters for both the GM and nonGM traits; $16.88 per acre and $12.88 per acre, respectively. This shows that the effect of mitigating adoption uncertainty is higher for the GM that for the non GM trait. If the effect would have been significant only for the GM trait we could have attributed the effect to familiarity only. That an effect is observed for both traits seems to indicate that our measure and its influence are related to farmer's risk attitudes towards the trait-embeddedness technology in general.

Columns 4 and 5 show the results for the non GM trait. Although jointly significant (see LR statistic), the individual effects of the variables in our model for the nonGM trait weren't significant with the exception of *earlyad*. Our hypothesis is that this is due to the hypothetical nature of the exercise. While farmers are aware that a GM DT trait is currently in the final stages of the R&D pipeline, they may also be aware that drought tolerance requires multiple and complex methods of action and genes. As such, the credibility of an effective nonGM trait may have been low resulting in careless response to that particular CV question. Under this reasoning, it makes sense that early adopters as risk takers may have been the only to identify themselves as WTP more for such nonGM DT trait.

The mean WTP for each trait is calculated by applying the estimated model to the mean of the sample data. The standard error for this linear function of the estimated parameters was calculated using the Delta Method. Both of the estimated mean WTP's are strongly significant (at 1% level). We find that in average, farmers in the sample were willing to pay around $18.63 per acre for the GM DT trait and $20.81 per acre for the GM DT trait.

Results: Nitrogen Absorption Efficiency Trait

The estimation results for the two NAE trait versions (GM and nonGM) are presented in Table 5. The likelihood ratio test of the global null hypothesis that all coefficients are equal to zero is strongly rejected at the 1% level in both models. Pseudo R-square values of 0.53 and 0.61 for the GM and nonGM models, respectively, suggest good explanatory power.

Columns 2 and 3 present results for the GM trait and Columns 4 and 5 for the nonGM version of the trait. As suggested by our conceptual framework, higher fertilizer costs increase the farmers' willingness to pay, in this case, for both traits (GM and nonGM). Farmers are willing to pay approximately 7 cents more for the NAE traits for every extra dollar they spend in fertilize. This imperfect substitution (i.e., not dollar for dollar) suggests that even for traits that supplement relatively stable production factors such as the NAE, the embeddedness of trait inputs may still bear an "ex-anteness" effect. In this case, farmers may see an imperfect substitutability possibly related to an ability to adjust fertilizer use in the event of high fertilizer prices as opposed to the inability to do so with the embedded trait.

The results concerning *farmsize* and *income* in the NAE model tell a similar story to what we found for the DT trait. This reaffirms our notion that farmers are indeed aware that seeds – being perfectly divisible inputs – are not scale dependent, but higher income does facilitate adoption probably by providing the extra push for experimentation during initial adoption stages.

Farmers specializing in grain are willing to pay less for the trait in comparison to farmers producing for silage. Of course, with silage, the objective on the field is to produce biomass which requires a more intensive use of Nitrogen. A good field of corn silage can yield 20-25 tons of wet forage per acre. A 20-ton yield will remove approximately 150 pounds of nitrogen per acre. In comparison, a 100-bushel corn crop will only remove 100 pounds nitrogen (Bates 2009).

Again, the effects of mitigating adoption uncertainty are larger for the GM NAE trait compared to the nonGM NAE trait (see DT trait results). Early adopters are willing to pay \$11.94 and \$10.18 more than late and other type of adopters for the GM and nonGM NAE traits, respectively. We also find that farmers which specialize completely in nonGM corn showed willing to pay less than GM farmers (-$7.970).

Finally, we find that in average, farmers in the sample were willing to pay around $17.35 per acre for the GM NAE trait and $19.78 per acre for the GM NAE trait. Both of the estimated mean WTP's are strongly significant (at 1% level).

CONCLUSIONS

The state contingent framework proves to be a powerful tool for studying the uncertainty dynamics of trait adoption. Seed traits are only one of two distinct main agronomic strategies used by farmers on the field to obtain high yields with higher consistency – Strategy 1: modifying the environment surrounding the plant (i.e., cultural and agronomic practices) and Strategy 2: modifying the plant itself (i.e., seed traits). The critical distinction between these strategies is their timing; that is, the possibility for timely adjustments in supplementation which exists in Strategy 1 but results impossible with Strategy 2

One should be careful when performing economic analysis involving GM Traits. While sharing a GM designation, we have seen that different traits can in fact be taken by the farmer as quite different from one another when it comes to economic and adoption decisions. The distinction we emphasize is based on a state contingent analysis of the uncertainty associated with a specific trait. Such uncertainty is directly related to whether the trait is more state-specific or state-general which is in turn related to the mobility of the production factor the trait intends to substitute (supplement).The two main types we identify are supplementing traits and stabilizing traits. Acting after (i.e., ex post) or before (i.e., ex ante) nature depends largely on whether the trait supplements production factors which are relatively stable on the field or protects (stabilize) against highly mobile factors, respectively.

Under our framework, as for the GM traits currently in the market, the glyphosate tolerant, for example, is state-general while a Bt trait is a state-specific input. Fernandez-Cornejo and McBride (2002) state: “In broad terms, the dynamic diffusion models indicate that future growth of Bt crops will be slow or even become negative, depending mainly on the infestation levels of Bt target pests […] On the other hand, herbicide-tolerant crops will continue to grow, particularly for soybeans and cotton, unless there is a radical change in U.S. consumer sentiment.” Our conceptual framework may explain the rapid and increasingly smooth adoption of herbicide tolerance as a supplementing trait but a slow and erratic adoption of insect resistance as a protective trait.

Other Strategy 1 inputs include precision delivery technologies (i.e.precision agriculture) which will also – to a certain extent – compete with embedded trait strategies. For example, the farmer may try to deliver different and precise amounts of N-fertilizer to different parts of the field to supplement (small) N deficiencies, or simply adopt the NAE trait.

As we emphasize throughout our discussion, the role of information is crucial in the adoption of different strategies. Which strategy is adopted by the majority will bear an effect on the type of information that is gathered (Henessy and Saaks 2002). Among seed traits, a supplemental trait will promote the gathering of on-site real-time data while on the other hand a stabilizing trait will promote the use of historical data to produce forecasts.

Our results also indicate that programs such as the Biotech Endorsement which promote lowering insurance premium rates for biotech farmers are effective in avoiding double payment for risk reduction, since biotech farmers pay once when they purchase insurance and again when they insure themselves by purchasing certain types of seed traits. However, this study also suggests that if farmers had a choice as of whether the price premium they pay for risk reducing traits should go to R&D in GM vs. conventional breeding, they would prefer the latter.

Finally, by definition, stacked traits – having a wider spectrum of action – are more adequately classified as state-general. Future research avenues include modeling stacked traits under a state contingent framework similar in spirit to the one presented here.

REFERENCES

Alexander, C., J. Fernandez-Cornejo, and R. E. Goodhue. 2003. "Farmers' Adoption of Genetically Modified Varieties with Input Traits." Giannini Foundation Research Report 347, University of California, Davis.

Aldana, U. et al. 2010. Sequential Adoption of Package Technologies. The Dynamics of Stacked Trait Corn Adoption, Working Paper, Department of Agricultural and Applied Economics, University of Wisconsin.

Arrow, K., R. Solow, P. Portney, E. Leamer, R. Radner, and H. Shuman. 1993. "Report of the National Oceanic and Atmospheric Administration Panel on Contingent Valuation." *Federal Register* 58:4601–14.

Bates, G. 2009. "Corn Silage." Report SP434-D, Agricultural Extension Service, University of Tennessee. Available at www.utextension.utk.edu/publications/spfiles/sp434d.pdf, accessed January 2009.

Cameron, T.A. and M.D. James.1987a. "Estimating Willingness to Pay from Survey Data: An Alternative Pre-Test Market Evaluation Procedure." *Journal of Marketing Research* 24: 389–95.

Cameron, T.A. and M.D. James. 1987b. "Efficient Estimation Methods for 'Closed-Ended' Contingent Valuation Surveys." *Review of Economics and Statistics* 69:269–76.

Chambers, R.G. and J. Quiggin. 2000. *Uncertainty, Production, Choice and Agency: The State-Contingent Approach.* New York: Cambridge University Press.

Cooper, J. and W.M. Hanemann. 1995. "Referendum Contingent Valuation: How Many Bounds Are Enough?" Working paper, USDA Economic Research Service, Food and Consumer Economics Division.

Ehrlich, I. and G. Becker. (1972). “Market Insurance, Self-Insurance and Self-Protection,” *Journal of Political Economy* 80:623–648.

Hanemann, W.M., J.B. Loomis, and B.J. Kanninen. 1991. “Statistical Efficiency of Double-Bounded Dichotomous Choice Contingent Valuation.” *American Journal of Agricultural Economics* 73:1255–63.

Henessy, D. and A. E. Saaks. 2002. “On the Demand for a State-Contingent, Cost-Saving Seed Trait.” Iowa State University, Working Paper 02-WP 321.

Hubbell, B.J., M.C. Marra, and G.A. Carlson. 2000. “Estimating the Demand for a New Technology: Bt Cotton and Insecticide Policies.” *American Journal of Agricultural Economics* 82:118–32.

Jaramillo, P. (2009). “Farmers' Valuation and Adoption of New Genetically Modified Corn Seeds: Nitrogen-Fertilizer Saving and Drought Tolerance Traits.” Ph.D. Dissertation, Food and Resource Economics, University of Florida.

Lewis, T. and D. Nickerson. (1989). “Self-Insurance Against Natural Disasters,” *Journal of Environmental Economics and Management* 16,:209–223.

National Drought Mitigation Center, The Drought Monitor. 2006. “Drought Monitor Archives Database.” *Drought Monitor Website.* Available at http://drought.unl.edu/dm/archive.html, accessed May 2009.

Qaim, M. and A. DeJanvry. 2003. “Genetically Modified Crops, Corporate Pricing Strategies, and Farmers' Adoption: the Case of Bt Cotton in Argentina.” *American Journal of Agricultural Economics* 85:814–28.

Quiggin, J. (1992). “Risk, Self-Protection and Ex Ante Economic Value—Some Positive Results,” *Journal of Environmental Economics and Management* 23:40–53.

Quiggin, J. (2002). “Risk and Self-Protection: A State-Contingent View.” *The Journal of Risk and Uncertainty* 25(2):133–45.

Quiggin, J. and R.G. Chambers. 2006. “The State-Contingent Approach to Production Under Uncertainty.” *Australian Journal of Agricultural and Resource Economics* 50:153–69.

Rasmussen, S. 2003. “Criteria for Optimal Production Under Uncertainty: The State-Contingent Approach.” *Australian Journal of Agricultural and Resource Economics* 47:447–76.

Useche, P., B. Barham and J. Foltz. 2009. "Integrating Technology Traits and Producer Heterogeneity: A Mixed-Multinomial Model of Genetically Modified Corn Adoption." American Journal of Agricultural Economics 91:444–61.

Table 1. Traits Presented to Farmers for Valuation

	Trait	Version
1	Nitrogen Absorption Efficiency	nonGM
2	Nitrogen Absorption Efficiency	GM
3	Drought tolerance	nonGM
4	Drought tolerance	GM

Table 2. Contingent Valuation Survey Versions with Initial and Follow-up Offers

	Initial offer	Follow-up offer	
Version	P_i	P_i^L	P_i^H
A	$10	$5	$15
B	$15	$10	$20
C	$20	$15	$25
D	$25	$20	$30

Table 3. List of Variables

Farmer characteristics	
f_age	Age (in years)
f_educ	Education level (less than high school=1, high school diploma=2, some college=3, completed 2-year degree college=4, completed 4-year degree college=5, and some graduate school or graduate degree=6)
f_income	Gross income received from all farming activities in 2005 (Under $20,000 =1, from $20,000 to $39,999=2, from $40,000 to $59,999=3, from $60,000 to $79,999=4, from $80,000 to $99,999=5, from $100,000 to $119-999=6, from $120,000 to $139,999=7, from $140,000 to $159,999=8, $160,000 or more=9)
earlyadopt	Past adoption practices with respect to GM corn seeds (habit formation) (=1 if farmer adopted Bt-crw varieties in their first year in the market)
nonGM100p	Current use of GM crops (=1 if farm production is 100 percent nonGM varieties, =0 otherwise)
Farm characteristics	
farmsize	Total farm size reported in 2005 (in acres)
yield	Corn yield reported for most used seed code in 2006 (bushels per acre)
fertcost	Fertilizer costs reported for most used seed code in 2006 ($ per acre)
grain	Purpose of corn production (=1 if corn produced for grain, =0 if produced for other purposes (i.e., silage, sweet corn, other)
mD2	Probability of drought (average percentage area under severe drought in farm's county in 2006)

Table 4. Estimation Results for Drought Tolerant Trait

	Drought GM		Drought nonGM	
Variable	Estimate	p-value	Estimate	p-value
Constant	8.865	(0.248)	30.870**	(0.000)
f_age	0.010	(0.931)	-0.193	(0.113)
f_educ	-0.731	(0.420)	-0.840	(0.370)
f_income	1.128**	(0.043)	0.830	(0.156)
Grain	7.965**	(0.017)	0.292	(0.928)
Earlyadopt	16.886**	(0.003)	12.884**	(0.024)
Loss	0.511*	(0.085)	0.342	(0.530)
Farmsize	-0.003	(0.388)	-0.004	(0.160)
Sigma	12.200**	(0.000)	13.263**	(0.000)
N	137		149	
Log-likelihood	-168.041		-190.471	
Mean WTP [i]	18.631**	(15.343)	20.807	(16.496)
C.I. 95 L	16.251		18.335	
C.I. 95 U	21.011		23.279	
Pseudo R^2	0.45		0.44	
LR Statistic	89.408**	(0.000)	100.660**	(0.000)

[i] For Mean WTP the t-statistic is reported in parenthesis. Standard error for mean WTP was calculated using the Delta Method. Note: ** indicates significance level of 0.05, and * indicates significance level of 0.1. LR statistic is for likelihood ratio test with $H_o : \beta_1 = \beta_2 = ... = 0$, sigma is left unconstrained.

Table 5. Estimation Results for Nitrogen Absorption Efficiency Trait

	Fertilizer GM		Fertilizer nonGM	
Variable	Estimate	p-value	Estimate	p-value
Constant	7.055	(0.226)	14.408**	(0.003)
f_age	0.094	(0.262)	0.023	(0.751)
f_educ	0.598	(0.344)	0.602	(0.280)
f_income	0.957**	(0.017)	0.731**	(0.040)
Grain	-2.700	(0.263)	-5.520**	(0.007)
Earlyadopt	11.946**	(0.008)	10.180**	(0.012)
Fertcost	0.065**	(0.021)	0.076**	(0.002)
Farmsize	-0.001	(0.489)	-0.002	(0.336)
nonGM100p	-7.970**	(0.001)	-0.097	(0.960)
Sigma	9.556**	(0.000)	8.982**	(0.000)
N	155		175	
Log-likelihood	-195.749		-228.782	
Mean WTP [i]	17.350**	(19.669)	19.784**	(25.664)
C.I. 95 L	15.621		18.273	
C.I. 95 U	19.079		21.295	
Pseudo R^2	0.53		0.61	
LR Statistic	126.132**	(0.000)	188.799**	(0.000)

[i] For Mean WTP the t-statistic is reported in parenthesis. Standard error for mean WTP was calculated using the Delta Method. Note: ** indicates significance level of 0.05, and * indicates significance level of 0.1. LR statistic is for likelihood ratio test with $H_o : \beta_1 = \beta_2 = ... = 0$, sigma is left unconstrained.

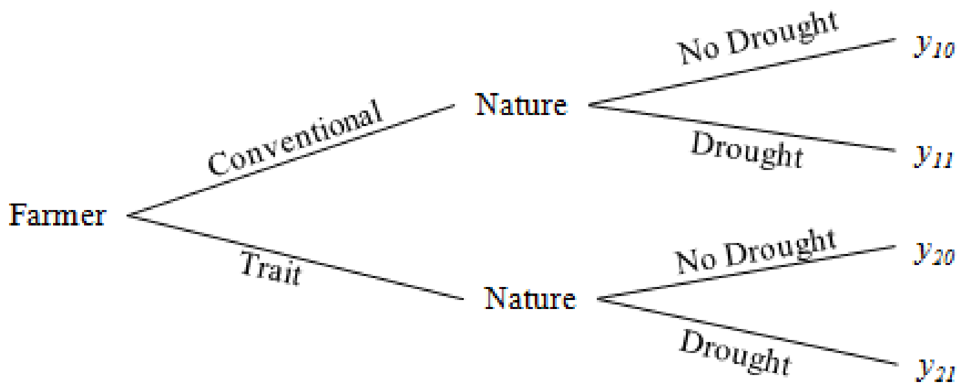

Figure 1. Game Tree for Drought Tolerance Trait with No Insurance Option

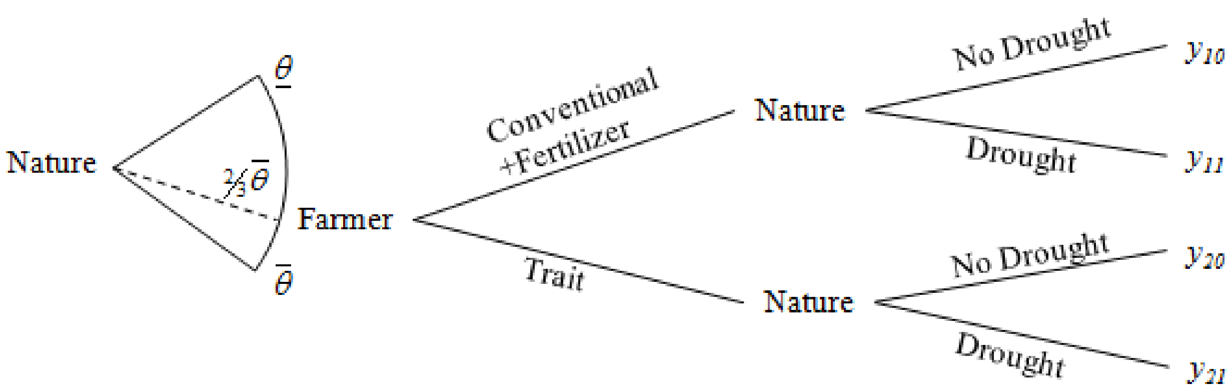

Figure 2. Game Tree for Fertilizer Saving Trait

7) Consider a new corn seed technology that comes along that maintains your same yield but reduces your nitrogen fertilizer requirements by one-third (33%).

Would you pay $10 extra per acre for this seed…	… **if it did <u>not</u> involve genetic modification?**		… **if it did <u>did</u> involve genetic modification?**	
	☐ Yes ⟹	If **yes,** would you buy it if it cost $15 extra per acre? ☐ **YES** ☐ **NO**	☐ Yes ⟹	If **yes,** would you buy it if it cost $15 extra per acre? ☐ **YES** ☐ **NO**
	(check one)		(check one)	
	☐ No ⟹	If **no,** would you buy it if it cost $5 extra per acre? ☐ **YES** ☐ **NO**	☐ No ⟹	If **no,** would you buy it if it cost $5 extra per acre? ☐ **YES** ☐ **NO**

8) Now consider a new corn seed technology that is drought tolerant so that under severe drought conditions it would still yield 75% of your normal yield.

Would you pay $10 extra per acre for this seed…	… **if it did <u>not</u> involve genetic modification?**		… **if it did <u>did</u> involve genetic modification?**	
	☐ Yes ⟹	If **yes,** would you buy it if it cost $15 extra per acre? ☐ **YES** ☐ **NO**	☐ Yes ⟹	If **yes,** would you buy it if it cost $15 extra per acre? ☐ **YES** ☐ **NO**
	(check one)		(check one)	
	☐ No ⟹	If **no,** would you buy it if it cost $5 extra per acre? ☐ **YES** ☐ **NO**	☐ No ⟹	If **no,** would you buy it if it cost $5 extra per acre? ☐ **YES** ☐ **NO**

Figure 3. Contingent Valuation (CV) Questionnaire Section of the 2007 Corn Poll

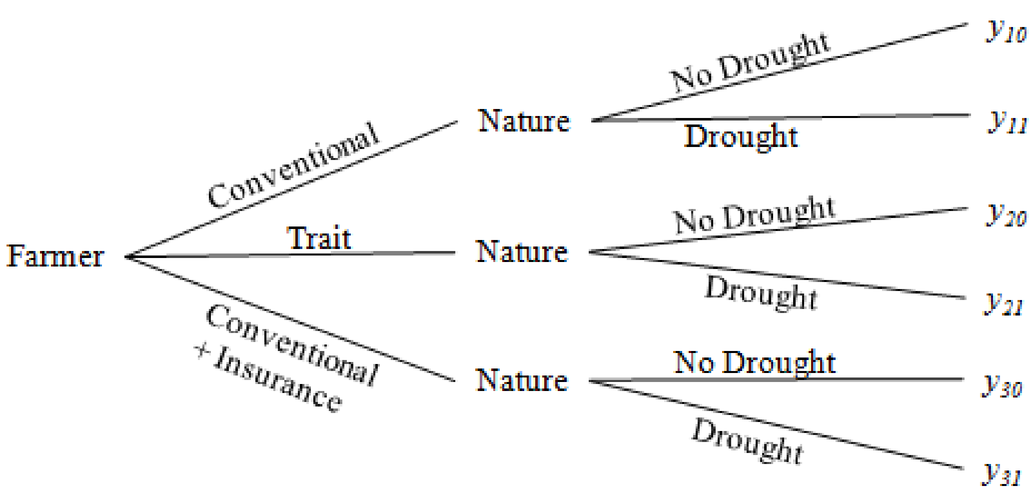

Figure 4. Game Tree for Drought Tolerance Trait with Insurance Option

APPENDIX

Case 3: Drought tolerance trait with insurance option

When insurance is available (i.e., strategy x_3) the tree is extended (see Figure 4) and the new considered payoffs are: $y_{30} = r - (p_c + p_I) = r - p_W$ and $y_{31} = r - L + I - (p_C + p_I)$ where I represents indemnity payments received by the farmer and p_I is the price of insurance. Assume $P_T > P_C$ and $P_W > P_C$ and y_{10}, y_{11}, y_{20} and y_{21} are the same as in Case 1.

$$\begin{aligned} E[U(\text{Trait})] &\geq E[U(\text{Insurance})] \\ r - e(.) - p_T &\geq (1-\pi_1)(r - p_C - p_I) + \pi_1(r - L + I - p_C - p_I) \end{aligned}$$

Assuming $L = I$:

$$\begin{aligned} r - e(.) - p_T &\geq r - p_C - p_I \\ p_I - e(.) &\geq p_T - p_C = p^* \end{aligned}$$

And from Case 1, $E[U(\text{Trait})] \geq E[U(\text{Conventional})]$ amounts to:

$$\pi_1 \cdot \alpha \cdot r - e(.) \geq p^*$$

Thus, the relevant competing strategy to seed traits is determined by the size of the contingent loss, relative to the cost of insurance:

$$\pi_1 \cdot \alpha \cdot r - e(.) \geq p^* \leq p_I - e(.)$$

$$\pi_1 \cdot Loss \geq p^* \leq p_I$$

One implication of this model for our empirical analysis is that, rather than explaining WTP as being determined by insurance cost size and probability of loss for all individuals, we have heterogeneous individuals, which in this basic case could be divided in two groups: the ones that determine their WTP by comparing the trait premium to their potential loss versus the ones that compare it with the price of insurance.

If Indemnity < Loss, the difference between them, (L-I) will enter as a contingent term (multiplied by the probability of drought) as a determinant of WTP, increasing the likelihood of adopting the trait. The only difference in the conclusion above is that the competing strategy depends on relative size of indemnity to price of insurance.

$$\begin{aligned} E[U(\text{Trait})] &\geq E[U(\text{Insurance})] \\ r - e(.) - p_T &\geq (1-\pi_1)(r - p_C - p_I) + \pi_1(r - L + I - p_C - p_I) \end{aligned}$$

Assuming $L \geq I$:

$$\begin{aligned} r - e(.) - p_T &\geq r - p_C - p_I - \pi_1(L - I) \\ p_I + \pi_1(L-I) - e(.) &\geq p_T - p_C = p^* \end{aligned}$$

Thus, the relevant competing strategy to seed traits is determined by the size of the contingent loss, relative to the cost of insurance plus the probable loss due to incomplete coverage:

$$\pi_1 \cdot Loss \geq p^* \leq p_I + \pi_1(L - I).$$

[1] Assuming away any resource availability constraints and costs limitations associated with delivering the resource to the field.

[2] See Precision Agriculture Journal aims and scope available at http://www.springer.com/life+sci/agriculture/journal/11119?detailsPage=aimsAndScopes.

[3] Alexander, Cornejo and Goodhue (2003) summarize the prevailing paradigm: "The decision to adopt a new technology depends on its expected profitability. The expected profitability of an innovation depends on the suitability of the innovation, given its characteristics, for a specific farmer and farm, given their characteristics."

[4] The state contingent approach is sufficiently general to allow for both types of inputs; in fact, the output cubical technology discussed above can be shown to be a special case of the state contingent model.

[5] We denote an individual state by s in S and assume, for simplicity, that the set of states is finite and that each state has a well defined objective probability $\pi s > 0$ that it occurs.

[6] The focus of our study is to disentangle the effects of environmental factors on seed-trait adoption and therefore we isolate this aspect in the analysis, assuming away any profitability variation caused by price instability.

[7] We assume here that farmers have access to information about their soil characteristics. This may not be an adequate assumption for developing country settings.

[8] Other studies present as the individual's choice set $H(y_0; \theta)=\{\mathbf{y} \text{ in } R^s: \mathbf{y}$ is feasible given θ and $x\}$. Here, we focus on the types of inputs, rather than on the quantities of expenditure on them. Thus, we directly map x into y, and define the individual's choice set in terms of x.

[9] At the moment only preliminary results are available for this case at request from authors.

[10] Contingent Valuation is a stated preference (SP) approach that has been extensively used to obtain estimates of WTP of nonmarket goods in the environmental economics literature. Cameron and James (1987a) suggested that the CV method can be equally useful in pretesting new market goods. The CV method obtains WTP estimates of goods in nonmarket situations.

[11] Dichotomous choice elicitation formats that require a “yes” or “no” answer from a respondent which is offered a hypothetical price to secure a good are endorsed in the *Federal Register* by the NOAA Panel on Contingent Valuation (Arrow et al. 1953) over open ended formats that simply ask respondents “How much would you pay?” Dichotomous choice formats are argued to better resemble a market situation to which respondents are more familiar.

[12] The DB-DC approach is usually preferred over the SB-DC method since it provides much larger statistical efficiency for same sample sizes (Hanemann, Loomis, and Kaninnen 1991). The gains obtained from adding a third (or further) question to the DB-DC method are insufficiently large to justify the added mathematical complications (Cooper and Hanemann 1995).

[13] The 451 randomly selected farmers who participated in the CP07 were randomly assigned one of each of the different versions of the survey. This randomization is made to avoid possible bias in the estimation. Also, the produced variation in P_i is what allows us to identify β instead of only being able to identify β / σ (Cameron and James 1987b).

[14] The Drought Monitor Index identifies four (D1, D2, D3 and D4) different types of drought areas by intensity. D1, D2, D3 and D4 indicate moderate, severe, extreme and exceptional drought, respectively. The four drought categories are based on six key indicators and numerous supplementary indicators. The Drought Monitor reports the county’s percentage area under each drought category. The Drought Monitor Index is produced by a partnership consisting of the U.S. Department of Agriculture (Joint Agricultural Weather Facility and National Water and Climate

Center), the National Weather Service's Climate Prediction Center, National Climatic Data Center, and the National Drought Mitigation Center at the University of Nebraska Lincoln. Advice and information from many other sources is incorporated in the index, including virtually every government agency dealing with drought.

[15] Since the difference and sum of two zero mean normal variables is also normal with mean zero, adding the stochastic term at the end of the derivation bears no effect on the result compared to adding a zero mean normal distributed term at the beginning to the basic definition of the utility function.