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ABSTRACT

We develop a real options framework to model producer participation in a subsidy program as a human capital investment to learn how the stochastic subsidy affects returns and how to adapt production activities to new program incentives, formally linking the framework to a multinomial logit specification for empirical applications. Analysis of farmer intentions for participation in the ACRE program created by the 2008 Farm Bill finds that reluctance to participate was driven largely by risk aversion and perceptions about income risk from yield and price variability, consistent with the theory that uncertainty creates an option value discouraging human capital investments.

Keywords: Agricultural Policy; Commodity Programs; Farm Bill; Multinomial Logit; Real Options Theory, Subsidy

JEL Codes: Q12; Q18

A Real Options Framework for Analyzing Program Participation as Human Capital Investments: The Case of the Average Crop Revenue Election (ACRE) Program

The Food, Conservation and Energy Act of 2008 (2008 Farm Bill) introduced a major change in the commodity title. Eligible producers now face an annual choice between participating in the traditional set of commodity programs (i.e., direct and counter-cyclical payments and loan deficiency payments) versus participating in the newly created average crop revenue election (ACRE) program (Zulauf et al. 2008). To become eligible for revenue-based ACRE payments, producers lose eligibility for price-based counter-cyclical payments, give up 20% of their direct payments and accept a 30% reduction in the loan rates used to determine marketing assistance loans and loan deficiency payments (USDA-FSA 2008, 2009a, 2009b; Zulauf et al. 2008). Furthermore, the choice to participate in the ACRE program is irrevocable through the life of the 2008 Farm Bill (i.e., at least through 2012). Thus, a farmer choosing ACRE cannot later opt back into the traditional program if market conditions change, but producers deciding to remain in the traditional program can in later years opt into ACRE.

ACRE is unique, as no previous U.S. commodity support program has relied on revenue (particularly state revenue) as the main determinant of payments, though revenue-based crop insurance has been available since the mid-1990s. As a result, many economists examined ACRE to determine the types of farmers who would likely benefit from it and therefore sign up. Most of these studies found that for many farmers growing crops such as corn, soybeans, and wheat, expected ACRE payments (largely driven by yield and price expectations) would likely exceed the 20% reduction in direct payments, the loss of counter-cyclical payments, and the reduction in for loan deficiency payments due to 30% lower loan rates. As a result, many land-grant economists encouraged farmers to examine ACRE and to seriously consider participating (e.g., Hilker et al. 2009, Edwards 2009; Schnitkey and Paulson 2009; Mitchell 2009; Marra 2008). Using national data, Woolverton and Young (2009, p. i) suggested that "… for 2009-12, producers of corn, soybeans, wheat, and rice are likely to benefit more from the ACRE program than from the price-based, income-support programs." Babcock and Hart (2008, p. 10) echoed this sentiment in their analysis and point out that "… a large proportion of U.S. farmers will find ACRE much more attractive than current commodity programs."

Some analyses also found that ACRE provides better risk protection. Cooper's (2009) simulation analysis for representative farms in Illinois, Kansas, and North Dakota found that ACRE reduced down-side revenue risk for corn, soybeans, and wheat in 2009 more than traditional programs, while Chen et al.'s (2010) simulation analysis found strong preferences for ACRE in all scenarios analyzed for a representative Indiana farm. Schnitkey (2010) concluded that, from a purely economic perspective, it is difficult *not* to take ACRE over the traditional programs since ACRE has higher expected returns and provides better risk protection.

Based on this work, many expected that a large number of eligible producers would sign up for ACRE in 2009. Consequently, extension economists and grower associations provided educational programs and publications prior to the 2009 sign-up deadline (August 14, 2009) to familiarize farmers with the program and its tradeoffs and advantages (Hilker et al. 2009; Mitchell 2009; Marra 2008; Schnitkey and Paulson 2009; USDA-FSA 2009b; NCGA 2009). However, initial ACRE enrollment data indicated that only about 8% of farms with eligible base acreage signed up for ACRE in 2009, representing roughly 13% of eligible base acreage (USDA-FSA 2009a; Woolverton and Young 2009). This lower than expected ACRE enrollment led many farm policy observers to ask why participation was not higher, for example:

> *Final signup for Average Crop Revenue Election (ACRE) frustrated land grant economists who spent months trying to explain the farm program's optional risk management program to producers. One complained he couldn't convince his own father to enroll. In the end, every land grant economist I know signed up for ACRE on their own farms, compared to less than 5 percent enrollment on eligible farms nationwide. What went wrong?* (Zarley Taylor 2009).

Woolverton and Young (2009) postulate that producer risk preferences, learning and negotiation costs, decision irreversibility, and the option to enroll in later years led to lower than expected enrollment, but they provide no empirical evidence. However, in a recent poll, the most commonly cited reason farmers did not sign up for ACRE was that they did not understand the program themselves or it was too difficult to explain to landlords (Zarley Taylor 2010).

This paper identifies factors significantly influencing farmer intentions regarding ACRE participation in 2009. We use a unique producer survey conducted in spring 2009 that specifically asked producers in four states about their intentions for the ACRE decision to be made later that year. This paper is the first to use farm-level survey data to empirically examine factors influencing participation in the new ACRE program. Previous investigations used simulation approaches with representative farm data and/or aggregate (national) data to explore factors driving the ACRE sign-up decision (Olson and DalSanto 2008; Cooper 2009; Chen et al. 2010; Woolverton and Young 2009).

We develop a real-options framework to conceptualize the analysis of factors affecting ACRE participation and to help explain the observed low ACRE enrollment in 2009. The choice between participating in ACRE versus remaining in the traditional programs has several attributes that suggest a real options approach. First, the decision is *irreversible* − once ACRE is elected, a producer is locked into the program for the life of the 2008 Farm Bill. Net returns with ACRE are also *uncertain* – future farm yields, state yields, and national prices for program crops affect returns to ACRE versus traditional commodity programs. Furthermore, the decision requires *dynamic tradeoffs* – the choice impacts subsidy payments and farm profits over multiple years, at least 2009 to 2012 and possibly longer. Producers also have the *option to defer* their decision, potentially creating an option value for waiting to see how ACRE performs and to learn more about the program. Finally, the decision requires a human capital investment.

Real options theory was developed to analyze investment decisions (Dixit and Pindyck 1994), and so agricultural applications have focused on investments in technology or production systems (e.g., Purvis et al. 1995; Price and Wetzstein 1999; Saphores 2000; Carey and Zilberman 2002; Isik and Khanna 2003; Baerenklau and Knapp 2007; Seo et al. 2008; Kuminoff and Wossink 2010). Jacobs (2007) extended real options theory to human capital investments, showing that the irreversibility of knowledge acquisition and the uncertainty of its benefits create an option value for individuals waiting to make investments in education. We follow this line of work, treating the acquisition of knowledge regarding ACRE and its managerial implications as a human capital investment by farmers.

ACRE represents a significant change from previous commodity programs and as a result, farmers commonly cite complexity as a problem (Woolverton and Young 2009;

Edwards 2010; Zarley Taylor 2010). Farmers must learn how the new ACRE program works and determine if it will be beneficial for their operation, requiring a substantial investment of time and effort. Furthermore, commodity support programs, even if decoupled, have crop allocation and input use effects (e.g., Gardner et al. 2010; Femenia et al. 2010; Bhaskar and Beghin 2009, 2010; Goodwin and Mishra 2006; Serra et al. 2006; Hennessy 1998; McIntosh et al. 2007), implying that farmers switching to ACRE would need to develop and apply managerial expertise to adapt their farming operations to the new program, including potentially adjusting crop allocations, technology choices and input use. Such effects are likely more important for ACRE, since it is not completely decoupled – ACRE payments also depend on the crops actually planted, not just the crops planted years ago to establish a farm's base acres (Mitchell 2009).

Real options models and arguments have been used to motivate the application of logit-based discrete choice models to analyze investment decisions. Verbal arguments based on real options theory (Ruer and Tong 2005; Brouthers et al. 2008; Wennberg et al. 2008) and formal mathematical real options models (Kouvelis et al. 2001; Downing and Wallace 2001) have been used to develop testable hypotheses. Empirical analysis then uses logit-based discrete choice models to test these hypotheses, but these specifications do not formally link the conceptual real options model to the empirical formulation. Hence, we develop a formal real options model of the ACRE decision and use it to specify a multinomial logit analysis of survey data. To our knowledge, no studies have formally linked a real options model and multinomial logit analysis, nor used such a framework to examine individual program participation decisions.

ACRE Program Background and Payment Calculation

The defining characteristic of the ACRE program is that, unlike traditional commodity programs, payments to farmers are triggered by revenue shortfalls rather than price shortfalls. Several proposals for a revenue-based commodity program were developed prior to the 2008 Farm Bill debate. All were similar in that they replaced a price-triggered program with a revenue-triggered program, but differed in the level of aggregation for calculating the revenue trigger − at the national, state, county or farm level. The National Corn Growers Association proposed replacement of counter cyclical payments with county-average revenue coverage, while the American Farm Bureau Federation proposed state-average revenue coverage, and the Bush administration and American Farmland Trust both proposed programs triggered on U.S. average revenue. None of these proposals enjoyed unanimous support and regional differences existed – for example, southern legislators generally favored maintaining pre-existing commodity programs. Ultimately, the final legislation was a political compromise that uses national prices, state yields and requires that a farm loss occur, but gives producers the option to remain in the traditional commodity programs or opt into the new ACRE program.

Producers elect ACRE for an officially designated USDA-Farm Service Agency (FSA) farm serial number, with many producers farming more than one FSA-designated farm. Because the choice to participate in the ACRE program applies to all eligible crops grown on a given FSA farm, producers must consider ACRE versus the traditional programs for all program crops by farm serial number, with eligible crops including barley, corn, cotton, oats, peanuts, sorghum, soybeans, and wheat.

ACRE payments for a crop are triggered when a revenue loss occurs at both the state level and at the individual farm level (i.e., both state and farm actual revenue are below their respective ACRE guarantees). When both triggers are met, ACRE payments are made for that crop based on the difference between the state ACRE guarantee and actual state revenue.

The state ACRE guarantee (*SG*) for a crop is 90% of the benchmark state yield (*BSY*) multiplied by the ACRE guarantee price (*AGP*): $SG = 0.9 \times BSY \times AGP$. The *BSY* is the average of the state's yield per planted acre (the sum of harvested acres and FSA-designated failed acres) for the five most recent crop years after removing the highest and lowest yields from the calculation (the "Olympic average"). The *AGP* is the simple average of the USDA national marketing year average price of the crop for the two most recent crop years. State actual revenue (*SAR*) equals the actual state yield per planted acre (*ASY*) multiplied by the higher of the national marketing year average price or 70% of the loan rate.

The farm ACRE guarantee (*FG*) is the benchmark farm yield (*BFY*) multiplied by the ACRE guarantee price (*AGP*), plus federal crop insurance premiums paid per acre by the producer. The *BFY* is the "Olympic" average of the five most recent years of farm yields. Farm actual revenue (*FAR*) is computed the same way as state actual revenue (*SAR*) except that actual farm yield (*AFY*) is used instead of actual state yield (*ASY*).

ACRE payments to producer *i* growing eligible crop *j* in year *t* are calculated as:

$$(1) \qquad ACRE_{ijt} = d_{ijt} \times \left(\max\left[0, \min\left\{ \left(0.25 \times SG_{jt} \right), \left(SG_{jt} - ASR_{tj} \right) \right\} \right] \right) \times \frac{BFY_{ijt}}{BSY_{jt}} \times A_{ijt} \times 0.833,$$

where d_{ijt} is an indicator variable equal to one when actual farm revenue is less than the farm ACRE guarantee ($FAR_{ijt} < FG_{ijt}$) and zero otherwise, and A_{ijt} is acres planted to crop *j* in year *t* by producer *i*. Note that the final multiplier in equation (1) is 0.833, which applies for 2009-2011, but 0.85 applies for 2012. Also, the benchmark state yield, state ACRE guarantee, state actual revenue (*BSY*, *SG*, *SAR*) will vary by state for each crop.

Various limitations apply to ACRE payments. The state ACRE revenue guarantee (*SG*) cannot increase or decrease by more than 10% from its value the previous year. Also, if the total number of acres planted to eligible program crops exceeds the farm's total base acreage (a common occurrence), the producer must annually designate which planted acres are enrolled in ACRE. Separate state ACRE guarantees (*SG*) are created for irrigated and non-irrigated land if state planted acres for a crop are at least 25% irrigated and 25% non-irrigated. Payment limitations apply to ACRE just as for other support payments, so total annual ACRE payments are limited to $65,000 per person or legal entity. See USDA-FSA (2009b) for additional details.

Conceptual Framework

Let R_T denote a farmer's net returns from crop production at time T if the farmer continues in the current commodity support programs. These returns may include income from multiple crops (both program and non-program crops), plus any direct payments, counter-cyclical payments, and loan deficiency payments the farmer receives. Due to uncertainty in realized crop prices and yields, these returns are random. Similarly, let S_T denote a farmer's net returns from crop production at time T if the farmer switches to the ACRE program, which are net of any cost changes as a result of switching, including costs for human capital investment. Again, these returns may include income from multiple program and non-program crops, plus ACRE payments and (reduced) direct payments and loan deficiency payments the farm receives. Due to uncertainty in realized crop prices and yields, these returns are also random.

Following common assumptions (Isik and Yang 2004; Kuminoff and Wossink 2010; Carey and Zilberman 2002), let R and S evolve following a geometric Brownian motion process:

(2) $$dR = \alpha_R R dt + \sigma_R R dz_R \quad \text{and} \quad dS = \alpha_S S dt + \sigma_S S dz_S,$$

where the α's and σ's are the respective drift and volatility parameters, and the dz's are the respective increments in the Weiner processes with mean zero and variance one. Because both R and S depend on common variables and are likely correlated, $E[dz_R dz_S] = \gamma dt$, where γ captures the covariance between changes in R and S.

We first determine the time T when it is optimal for a farmer to switch from the current program to the new ACRE program using an expected net present value (NPV) criterion. This criterion assumes a risk neutral farmer and ignores the irreversibility of the ACRE decision and the value of the option to delay the ACRE decision. For a farmer in the current program at time T with returns evolving according to equation (2), the expected NPV of returns is

(3) $$V(R_T) = E_R\left[\int_T^{\infty} R_T e^{-\rho t} dt\right] = \frac{R_T}{\rho - \alpha_R},$$

where ρ is the risk-adjusted discount rate. To derive equation (3), the expectation operator implies integration over the random variable R, so switch the order of integration to first integrate over R and then t, (i.e., move the expectation operator inside the integral over time t). Also, note that at time T, the expected value of returns at future time t is $E[R_T] = R_T e^{\alpha_R t}$, since returns R follow a geometric Brownian motion process (Dixit and

Pindyck 1994). Following the same logic, for a farmer in the ACRE program at time T with returns evolving according to equation (2), the expected NPV of returns is

$$W(S_T) = \mathrm{E}_S\left[\int_T^\infty S_T e^{-\rho t} dt\right] = \frac{S_T}{\rho - \alpha_S}. \tag{4}$$

Using an expected NPV criterion, it is optimal for a farmer to switch to the ACRE program at time T when the expected NPV of returns with ACRE equals or exceeds the expected NPV of returns with the current programs: $W(S_T) \geq V(R_T)$, or, using results from equations (3) and (4), it is optimal to switch at time T when

$$S_T \geq \frac{\rho - \alpha_S}{\rho - \alpha_R} R_T. \tag{5}$$

Returns for the current time period T appear for both programs in equation (5) because expected returns from time period T onward depend on the current realization of returns, i.e., $\mathrm{E}[R_T] = R_T e^{\alpha_R t}$ and $\mathrm{E}[S_T] = S_T e^{\alpha_S t}$. Current returns for each program provide an indication of future returns because the expected NPVs $V(R_T)$ and $W(S_T)$ are both increasing in R_T and S_T respectively (assuming $\rho - \alpha_R$ and $\rho - \alpha_S$ are positive), so that higher returns in the current time period imply higher expected returns for the future.

Equation (5) indicates that farmers should switch to the ACRE program when returns with the ACRE program equal or exceed returns for the current program after adjusting by the factor $(\rho - \alpha_S)/(\rho - \alpha_R)$. When the expected growth rates for returns R and S are equal ($\alpha_R = \alpha_S$), then the factor equals 1 and the expected NPV criterion simplifies to $S_T \geq R_T$, or switch when current returns with ACRE equal or exceed returns with the traditional program. When $\alpha_S > \alpha_R$, then $(\rho - \alpha_S)/(\rho - \alpha_R) < 1$ and the criterion implies that current returns with ACRE can be less than returns with the traditional program, but it is still optimal to switch to ACRE because of the higher expected growth rate of returns with ACRE. The reverse holds if $\alpha_S < \alpha_R$ – it is optimal to switch to ACRE only if current returns with ACRE exceed returns with the traditional program by enough to compensate for the lower expected growth rate of returns with ACRE.

Next we use a real options approach to incorporate the irreversibility of the decision and the option farmers have to delay their decision. In this case, the farmer chooses the year *T* to enroll in ACRE that maximizes the expected NPV of returns, treating the forgone returns for the current commodity program as a cost:

$$F(R,S) = \max_{T} \mathrm{E}_{R,S}\left[W(S_T) - V(R_T)\right], \tag{6}$$

subject to equation (2) for the stochastic processes for *R* and *S*. See the appendix for the solution to this optimization problem using dynamic programming. The solution is the typical real options result that it is optimal to switch to ACRE at time *T* when

$$S_T \geq \left(\frac{\beta}{\beta - 1}\right)\left(\frac{\rho - \alpha_S}{\rho - \alpha_R}\right) R_T, \tag{7}$$

where $\beta > 1$ is the positive root of the fundamental quadratic equation (equation (A10) in the appendix) and is a function of the parameters α_R, α_S, σ_R, σ_S, γ, and ρ.

Note that the factor $\beta/(\beta - 1)$ exceeds one since $\beta > 1$ and as a result, the threshold for switching to ACRE with a real options criterion is higher than with an expected NPV criterion (compare equations (5) and (7)). This factor $\beta/(\beta - 1)$ is called the hurdle or hurdle rate (Carey and Zilberman 2002; Baerenklau and Knapp 2007; Kuminoff and Wossink 2010) as it determines how much higher the real option threshold is versus the expect NPV criterion. Once the analysis accounts for the uncertainty involved, the irreversibility of the ACRE decision, and having the option of waiting to enroll in ACRE in a later year, the threshold value for S_T at which it is optimal to switch to ACRE is higher, a common finding with a real options approach (Carey and Zilberman 2002; Isik and Yang 2004; Baerenklau and Knapp 2007; Kuminoff and Wossink 2010). The real options framework provides a theoretical framework explaining why famers may be less likely to switch to ACRE, attributing this reluctance to concerns about the uncertainty in the program, irreversibility of the ACRE decision, and the value gained from waiting to make the ACRE participation decision at a later date. The expected NPV criterion ignores the irreversibility and the value of the option to delay the decision.

Empirical Model

To empirically implement the real options approach to the ACRE decision problem, equation (7) can be used to define an unobserved, farmer-specific index U_i^* that characterizes each farmer's net benefit from switching to ACRE in 2009:

$$U_i^* = S_i - \left(\frac{\beta_i}{\beta_i - 1}\right)\left(\frac{\rho_i - \alpha_{Si}}{\rho_i - \alpha_{Ri}}\right) R_i , \qquad (8)$$

where S_i and R_i are farmer *i*'s assessments or perceptions of returns with ACRE and with the traditional commodity programs, respectively. The other parameters also have subscripts *i* because each farmer may have a different risk-adjusted discount rate (ρ_i) and perceptions of the growth rates and volatilities for returns with the traditional program and with ACRE and their correlation (α_{Ri}, α_{Si}, σ_{Ri}, σ_{Si}, and γ_i), implying a different hurdle rate $[\beta_i/(\beta_i - 1)]$, as β_i depends on the same parameters. Thus, the right-hand side of equation (8) implies that the perceived benefit from switching to ACRE is a function of farmer i's perceptions of S_i, R_i, α_{Ri}, α_{Si}, σ_{Ri}, σ_{Si}, γ_i, and ρ_i.

Equation (8) provides a theoretical foundation for an index function characterizing the benefit farmer i derives from the ACRE program. However, a producer has more than one choice option available for ACRE. Specifically, a producer can choose (a) to switch to ACRE in 2009, (b) to wait and evaluate the ACRE program and possibly switch to ACRE in a later year, or (c) not to switch to ACRE during the life of the farm bill. Let k index a farmer's choice among these $K = 3$ options and let Y_i indicate farmer i's observed choice, so that $Y_i = 0$ denotes staying in the traditional commodity program through the life of the current farm bill, $Y_i = 1$ denotes waiting and possibly switching in a later year, and $Y_i = 2$ denotes switching to ACRE in 2009.

Note that these choices are not necessarily ordered. Farmers who report waiting and possibly switching in a later year ($Y_i = 1$) do not necessarily have an S_i less than their critical S_i to trigger switching ($Y_i = 2$) and greater than an S_i to report never switching to ACRE during the life of the farm bill ($Y_i = 0$). Rather, farmers who report waiting and possibly switching in a later year ($Y_i = 1$) have perceptions of the parameters S_i, R_i, α_{Ri}, α_{Si}, σ_{Ri}, σ_{Si}, γ_i, and ρ_i such that they believe it may be possible that realized and expected returns in the future may make switching optimal, or they believe that their perceptions of these parameters may change after acquiring more information so as to make switching optimal. Similarly, farmers who report never switching ($Y_i = 2$) have perceptions of these parameters such that realized and expected returns in the future are unlikely to make switching optimal and they do not believe that these perceptions will change sufficiently, or they have ideological or other personal reasons for not switching. Such possibilities are not ordered on a single variable or parameter such as S_i, but rather depend on the full set of parameters and how they interact to determine the farmer's assessment of the benefit from each choice: switching, waiting and possibly switching later, or never switching. Hence we specify a random utility model based on equation (8).

The benefit farmer i derives from the k^{th} choice is

$$(9) \qquad U_{ik}^{*} = \boldsymbol{\theta}_k' \mathbf{x}_i + \varepsilon_{ik},$$

where $\mathbf{x}_i$ is a vector of observable farmer-specific variables that determine or influence perceptions of the parameters S_i, R_i, α_{Ri}, α_{Si}, σ_{Ri}, σ_{Si}, γ_i, and ρ_i; $\boldsymbol{\theta}_k$ is the choice-specific parameter vector to be estimated and ε_{ik} is an error term. Conceptually, as a random utility model, $\boldsymbol{\theta}_k' \mathbf{x}_i$ linearly approximates the right hand side of equation (8) at $\mathbf{x}_i$. If a farmer chooses option k, U_{ik}^{*} is the maximum benefit derived from among all choices:

$$(10) \qquad \Pr\left[Y_i = k\right] = \Pr[U_{ik}^{*} > U_{im}^{*}] \ \ \forall \ k \neq m.$$

Because U_{ik}^{*} is unobserved, estimation based on equation (10) uses the observed choice Y_i as an indication of which choice k provided the greater perceived benefit to producer i. Hence, as a random utility model, estimation identifies factors significantly influencing the probability of making a particular choice k and not the actual benefit farmers derived from that choice.

For empirical tractability, let the ε_{ik} be independently and identically distributed with a type I extreme value (Gumbel) distribution, giving a multinomial logit model:

$$(11) \qquad \Pr\left[Y_i = k\right] = \frac{e^{\boldsymbol{\theta}_k' \mathbf{x}_i}}{\sum_{k=0}^{K-1} e^{\boldsymbol{\theta}_k' \mathbf{x}_i}}.$$

Here, the independent variables are farmer-specific, with no alternative- or choice-specific variables implying a conditional logit specification. Because response probabilities must sum to one, a normalization to identify the multinomial logit model is to define a base category for which the parameters equal zero (Greene 2003, p. 721). Here, staying in the traditional program (k = 0) is the base category, so that $\boldsymbol{\theta}_0$ is a vector of zeros and the resulting response probabilities become:

(12) $$p_{ik} = \Pr\left[Y_i = k\right] = \frac{e^{\boldsymbol{\theta}_k' \mathbf{x}_i}}{1 + \sum_{k=1}^{K-1} e^{\boldsymbol{\theta}_k' \mathbf{x}_i}},$$

for k = 1, ..., K – 1. The log-likelihood function for this model can then be expressed as:

(13) $$\ln L = \sum_{i=1}^{n} \sum_{k=0}^{K-1} D_{ik} \ln p_{ik}(\mathbf{x}_i, \boldsymbol{\theta}_k),$$

where D_{ik} = 1 if alternative k is chosen by individual i, and 0 otherwise. Note that for each i, one and only one of the D_{ik}'s equals 1. Given the chosen base category, estimated parameter vectors $\boldsymbol{\theta}_1$ and $\boldsymbol{\theta}_2$ for the decision to wait (k = 1) and to switch to ACRE (k = 2) are interpreted relative to the decision to stay in the traditional program through the life of the farm bill (k = 0).

Survey Design and Data Description

Data for this study were obtained from a survey of randomly sampled commercial-sized crop producers in Mississippi, North Carolina, Texas and Wisconsin. The USDA-National Agricultural Statistics Service (USDA-NASS) was contracted to conduct a mail survey using the population of farms in its database. The survey was restricted to producers who had produced at least one of the following crops: corn, cotton, grain sorghum, soybeans, rice, or wheat. Also farms were stratified into five categories based on gross sales, with each stratum representing approximately 20% of the population. The survey excluded the lowest stratum in order to focus on commercial farms. Six thousand questionnaires were mailed (1,200 in Mississippi, 1,500 in North Carolina, 1,650 in both Texas and Wisconsin) during March of 2009. Post card reminders were mailed one week following the initial mailing and a second questionnaire was sent to non-respondents approximately one month after the initial mailing.

Note that our survey predated the final ACRE sign-up deadline by a few months, so farmers reported their anticipated ACRE decision for the one FSA farm (i.e., farm serial number) they were asked to consider. Given the flow of information in the agricultural media and outreach efforts occurring during this period, it is likely that some respondents reevaluated their ACRE choice as the sign-up deadline approached. However, a great deal of attention had been given to the ACRE choice at the time of the survey and we believe these data are an accurate snapshot of producer thinking during a period of intense interest in the ACRE program. For example, the national FSA factsheets on the ACRE program came out on March 19, 2009 (USDA-FSA, 2009b). At the time the survey was initially mailed, USDA had announced sign-up would end on June 1, 2009, but that deadline was later extended to August 14, 2009.

A total of 1,380 surveys were returned with usable information (a 23% usable response rate). To assess whether respondents were representative of the population of interest, we compared respondent demographics to published 2007 Census of Agriculture summaries (USDA-NASS 2007). The average respondent age was 58.7 versus the Census average of 57.1. Also, respondent farms contained more total acres than the Census average, but were within half of a standard deviation in all four states, which is as expected since the survey sample omitted smaller crop farms. Finally, the national average debt-to-asset ratio for agricultural producers was 12.8% in 2009 (USDA-ERS

2010), while the respondent average ratio was 13.8%. Based on these measures, the USDA-NASS survey sample population was representative of the full population.

Table 1 reports summary statistics for the data used in the analysis. The dependent variable is farmer intentions about 2009 ACRE participation (*ACRE Decision*). At the time of the survey, only 2.8% of producers answered that they intended to switch to ACRE in 2009. A much larger 31.3% stated that they might switch to ACRE in later years, while 65.9% reported that they intended to stay in the current program for the life of the Farm Bill. Actual 2009 ACRE sign-up in Mississippi, North Carolina, Texas, and Wisconsin was 2.2%, with Wisconsin sign-up the highest among these four states at 7% of base acres (USDA-FSA 2009a).

Based on previous studies and the real options framework presented above, several farmer-specific independent variables from the survey ($\mathbf{x}_i$) were used in estimation to identify factors driving the ACRE participation decision. An indicator variable for producer perceptions about expected ACRE payments (*ACRE Pays More*) was included since it represents the expected NPV comparison between returns with ACRE versus the traditional commodity programs. This variable also embodies farmers' subjective evaluations of the many factors determining expected returns, including expected yields and prices and their correlation, the discount rate, and the growth rates and volatilities of returns. An indicator variable for the perceived additional risk protection provided by ACRE (*ACRE Risk Protection*) was included based on the argument that perceived risk management benefits influenced the ACRE decision. This variable also captures perceptions regarding the volatilities (riskiness) of returns with ACRE and traditional programs. Based on our survey data, only 3% of producers perceived that the ACRE program would pay more and only 8% believed ACRE would afford greater risk protection than traditional commodity support programs.

Estimation also included an indicator variable for the farmer's self-described willingness to accept risk (*Risk Averse*) and another for expectations regarding risks from farm programs (*Farm Program Risk*), since previous studies found that risk preferences play a role in evaluating the benefits and costs of ACRE participation (Cooper 2009; Woolverton and Young 2009). Furthermore, these variables also embody farmer perceptions for the volatilities of returns and an appropriate risk adjusted rate of return. About half of survey respondents described themselves as much less willing to accept risk compared to other farmers, while 31% expected significant income risk from farm program changes over the next five years.

Demographic variables were used to capture effects from inherent attitudes toward farm programs or exposure to different information sources. These included an indicator variable for membership in farm organizations such as the National Farmers Organization, the Farmers Union or the Grange (*Farmer Organization*), total cropland acres (*Farm Size*), and indicator variables for the primary crop (*Corn*, *Cotton*, *Soybeans*) and state (*North Carolina*, *Texas*, *Wisconsin*). Only 3% of respondents reported membership in the identified farm organizations. Average farm size in the sample was 724 acres. Texas and Wisconsin producers each reflect about 30% of respondents with North Carolina and Mississippi both providing approximately 20% of respondents. When asked to identify a primary crop, corn was identified by 29% of respondents, soybeans by 19%, and cotton by 7%.

Finally, estimation included indicator variables that reflected producer assessments as to how much yield and price variability would affect their income risk over the next five years (*Yield Variability Risk*, *Price Variability Risk*). These variables embody perceptions regarding the volatilities of returns with ACRE and the traditional programs and their correlation and also characterize the uncertainty embodied in the hurdle rate. Respondents used a five-category Lickert scale to describe their perceived potential for each source of variability to affect their income risk (5 = high potential and 1 = low potential), which we re-coded so that a 4 or 5 meant that the factor was perceived as a major source of income risk. Among all respondents, 64% described crop yield variability as a major source of income risk in the next five years, while 78% described crop price variability as a major source of income risk in the next five years.

Results

Table 2 reports parameter estimates for the multinomial logit regression and, as a robustness check, also reports multinomial probit parameter estimates. Similar parameter estimates and p-values for both the multinomial logit and multinomial probit imply essentially the same inferences for both models. Furthermore, since the multinomial probit does not need the independence of irrelevant alternatives (IIA) assumption for its results to be valid, the similar parameter estimates for the two models suggests that the IIA holds and that the multinomial logit results are valid (Greene 2003, p. 727). In addition, a Hausman test of no significant difference between the parameter estimates for the two models had a chi-square statistic less than 0.01, strongly indicating that the null hypothesis could not be rejected.

Another test of the validity of the multinomial logit model, and consequently of whether the IIA assumption holds, compares parameter estimates from the multinomial logit model with all choice alternatives to multinomial logit models with one of the alternatives removed (Greene 2003, p. 274). No significant difference between common parameter estimates in the models supports the IIA assumption and the validity of the multinomial logit results. In our case, the alternative models degenerate into simple logit models where the binary outcomes are (1) stay or wait, and (2) stay or switch. Results for these logit models are not reported, but the magnitude and significance of the parameter estimates were similar to those in Table 2. Also, Hausman tests comparing both alternatives to results in Table 2 had chi-square statistics of 0.07 and 0.01, implying no significant difference in the parameters at any meaningful level of significance and further supporting the multinomial logit results.

Multinomial Logit Results: Significant Variables and Direction of Effects

Parameter estimates for the multinomial logit model presented in Table 2 represent the effect of each variable on the log-odds ratio between the two alternatives (wait or switch) and the base outcome (stay). Focusing first on the switch outcome (Panel B), *ACRE Pays More*, *ACRE Risk Protection*, *Farmer Organization*, and *Cotton* are statistically significant at the 5% level (also at the 1% level). The direction of each variable's effect on the likelihood of switching to ACRE is the same as the sign of its estimated coefficient. Hence, if a producer believes that ACRE pays more than current commodity support programs, the log-odds ratio between switching to ACRE in 2009 and staying in the traditional program increases by 2.24, i.e., the producer is more likely to switch to ACRE in 2009 than stay with the traditional program (the base case). Similarly, the significance of *ACRE Risk Protection* implies that producers who perceive that ACRE provides more risk protection are more likely to switch to ACRE in 2009. In contrast, negative and significant estimates for *Farmer Organization* and *Cotton* indicate that producers who are members of these organizations or produce cotton are less likely to switch to ACRE in 2009.

Focusing next on the wait outcome (Panel A in Table 2), only *Risk Averse* and *Cotton* are statistically significant at the 5% level, while *Wisconsin* and *Price Variability Risk* are significant at the 10% level. The negative estimate for *Risk Averse* suggests that producers describing themselves as more risk averse are less likely to wait and possibly switch later, and hence more likely stay in the traditional support program for the life of this Farm Bill. Results suggest that producers planting cotton also exhibit the same tendency. In contrast, Wisconsin producers and producers who perceive that price variability will be a major source of income risk in the future show an increased likelihood of waiting and possibly switching later.

Multinomial Logit Results: Average Marginal Effects

The magnitudes of the multinomial logit parameter estimates in Table 2 are difficult to interpret directly as marginal effects. To illustrate the marginal effects of the variables on the probability of a given outcome, Table 3 reports the average of the marginal effects calculated for each observation in the sample. Similar to the parameter estimates, *ACRE Pays More*, *ACRE Risk Protection*, *Farmer Organization*, *Cotton* and *Texas* have significant marginal effects (at the 5% level) on the decision to switch to ACRE in 2009. The probability of switching to ACRE in 2009 is on average 0.08 higher for producers who believe that ACRE tends to pay more and 0.09 higher for those believing that ACRE provides more risk protection than the traditional programs. Farmers who are members of the identified farm organizations on average have a 0.03 lower probability of switching to ACRE in 2009. Farming in Texas (relative to the omitted Mississippi category) and growing cotton (relative to the omitted sorghum/rice/wheat category) also reduce the probability of switching to ACRE in 2009 by 0.03 on average.

Risk Averse, *Farm Organization*, *Cotton*, *Yield Variability Risk*, *Price Variability Risk*, and *Wisconsin* have significant marginal effects at the 5% level on the decision to wait and possibly sign up for ACRE later, with *Texas* significant at the 10% level. On average, the probability of waiting and possibly switching to ACRE later is reduced by 0.08 for producers describing themselves as more risk averse and by 0.09 for members of the identified farm organizations. Interestingly, producers who perceive yield variability as a major source of income risk have on average a 0.05 lower probability of waiting and possibly switching later, but those who perceive price variability as a major source of income risk have on average a 0.06 higher probability of waiting and possibly switching to ACRE. Relative to sorghum/rice/wheat growers, the probability of cotton growers choosing to wait and possibly switch later is lower by 0.12 on average. Relative to Mississippi growers, Texas and Wisconsin growers have a 0.08 and a 0.09 higher probability, respectively, of waiting and possibly switching to ACRE later.

Variables with significant marginal effects for the choice to stay with the traditional commodity programs for the life of the Farm Bill are the same variables that are significant for one or both of the other two outcomes, and the magnitude of these marginal effects completely offset the marginal effects of the other two outcomes. These results occur because of the “adding up” property of probabilities – the probabilities over all three outcomes must sum to one.

As an additional robustness check, binary logit and probit models that combined the wait and switch decisions (the dependent variable equaled 1 if the outcome was wait or switch and 0 otherwise) were also estimated. Results are not reported, but most of the variables significant in the multinomial logit estimation are also significant in the binary logit/probit estimations and have the same signs: *ACRE Pays More*, *ACRE Risk Protection*, *Risk Averse*, *Farmer Organization*, and *Cotton*. The only exceptions are *Yield Variability Risk* and *Price Variability Risk*, which are not significant in the binary logit/probit estimations. Apparently combining the wait and switch outcomes added sufficient variability in responses to mask the significant effect of these variables on the wait outcome, as the magnitude of the marginal effects for the binary logit/probit estimations are the same as for the wait outcome in the multinomial logit estimation.

Discussion and Conclusion

We developed a real options/multinomial logit framework to conceptualize and analyze farmer participation decisions in ACRE, the new commodity support program created by the 2008 Farm Bill. Based on analyses indicating higher expected net returns under ACRE, producer sign-up for ACRE was less than anticipated by many land grant economists, producer groups and agencies. A real options framework seems a compelling way to conceptualize farmer program participation decisions, as ACRE has made the human capital aspects of commodity program participation more apparent. Not only does ACRE participation involve substantial uncertainty, but it also requires a substantial human capital investment by producers. Producers must learn the details of the ACRE program, determine its appropriateness for their operations, and then determine how to adjust their management (e.g., acreage allocations, input choices, marketing) to best take advantage of the program. The explicit linkage we develop between the real options model and the multinomial logit specification provides a more formal basis for empirical analysis than has been the case for previous empirical work. Isik and Yang (2004) have come closest to developing such a framework, as they used a real options model of conservation reserve program (CRP) sign-up. However, they did not conceptualize CRP sign-up as a human capital investment and their empirical analysis used aggregate, not individual, data to estimate county CRP participation rates using county-level information as regressors in a logit analysis.

A real options/multinomial logit framework would also seem to be a fruitful alternative for explaining and empirically analyzing apparently non-optimal farmer behavior in situations when human capital investments and uncertainty are important aspects. Two cases that come to mind are the observed low farmer utilization of marketing strategies using futures and options to hedge price risk and the need for substantial premium subsidies to encourage farmers to purchase crop insurance (Davis et al. 2005; Goodwin and Schroeder 1994; Hall et al. 2003; Mishra and El-Osta 2002; Patrick et al. 2007; Sherrick et al. 2004; Velandia et al. 2009).

Our empirical results suggest that the decision to switch to ACRE in 2009 was primarily driven by producer perceptions of whether or not ACRE would pay more than existing programs and whether or not it would provide more risk protection. On the other hand, the decision to stay with existing programs in 2009 and to consider switching to ACRE later was likely driven more by producer risk aversion and perceptions about the effect of yield and price variability on income risk in the coming years. Membership in organizations such as National Farmers Union, National Farmers Organization, and the Grange was consistently and strongly associated with staying with existing programs in

2009. Consistent state and crop effects were also apparent. Texas and Wisconsin producers were more likely to choose to wait and possibly switch to ACRE later and cotton growers consistently and strongly preferred to stay with existing programs in 2009, likely due to the large 'cost' of giving up the relatively larger direct payments for cotton and price expectations that made counter-cyclical payments more likely.

Farmers who believed that ACRE would pay more or provide more risk protection acted quickly and tended to switch in 2009, as they perceived the expected benefits from switching to ACRE in 2009 to be much greater than the expected benefits from the traditional programs, even after accounting for the uncertainty and irreversibility as embodied in the hurdle rate. On the other hand, more risk averse producers tended to report that they would stay in the traditional commodity programs for the life of the Farm Bill. However, slightly less risk averse farmers, who were at the margin of believing whether or not ACRE pays more and provides more risk protection, tended toward a wait-and-see attitude with the option of switching later. This behavior is in line with the real options theory of waiting when there is uncertainty in the benefit stream from a proposed irreversible change in a government support policy.

These results lead us to conjecture about what many economists and policy analysts failed to foresee about ACRE participation – programmatic intangibles arising from uncertainty and administrative complexity. The fact that many producers did not follow recommendations – to sign up for ACRE because expected returns would exceed returns from traditional programs – runs contrary to the often accepted notion that producers are simply rent seeking in farm program participation. We believe this paper takes a first step toward understanding why. Anecdotes of not being able to obtain clear programmatic answers from the USDA Farm Service Agency (FSA) at the time of our survey suggest that producers may have perceived a significant value to deferring the decision until greater program clarity and more experience were obtained. Clearly, the value of waiting in a real options context is increased when more uncertainty exists and the choice requires a larger human capital investment due to program complexity.

Over time, a variety of forces have pushed farm policy toward a more complex revenue-based commodity program, rather than separate price and yield risk management programs as have dominated for many years. Given the tight budget situation leading up to the 2008 Farm Bill debates, rent-seekers may have played "budget scoring games" by proposing a complex ACRE program that they knew would likely pass muster with the Congressional Budget Office. In the end, we believe our results suggest that the next Farm Bill debate needs to consider whether farm program complexity has reached a point that those intended to benefit from the policy cannot effectively evaluate and utilize the farm program options presented. Perhaps more effort should be devoted to examining simpler revenue-based commodity support programs (Babcock 2010).

Finally, as economists, we may need to be more cognizant of farm program uncertainty and include it in our policy assessments. Perceiving farm policy as simply an exercise in rent-seeking, those asking for the ACRE program may have pushed to create a program that would pay in high-price scenarios, but in the end created something nearly impossible for USDA to implement and producers to fully comprehend. However, viewing these programs as tools to provide risk protection, economists perhaps need to step back and recognize that producers face not only price and yield risk, but increasingly another risk – farm program uncertainty.

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Table 1. Variable Description and Summary Statistics

Variable	Description	Mean	Standard Deviation
A. Dependent Variable			
ACRE Decision	= 0 if stay in current program for the life of the farm bill (65.9%) = 1 if stay in current program in 2009 but possibly switch later (31.3%) = 2 if switch to ACRE in 2009 (2.8%)	0.37	0.54
B. Independent Variables			
ACRE Pays More	= 1 if believe average annual payments for ACRE are more than for the current program	0.03	0.17
ACRE Risk Protection	= 1 if believe ACRE program provides more risk protection than current programs	0.08	0.28
Farm Program Risk	= 1 if believe changes in farm programs will be a major source of income risk in the next five years	0.31	0.17
Farm Size	Total acres of cropland in farming operation	724	1004
Risk Averse	= 1 if much less willing to take risk relative to other farmers	0.49	0.50
Farmer Organization	= 1 if member of National Farmers Union, National Farmers Organization, or The Grange	0.03	0.17
Mississippi	= 1 if farm in Mississippi	0.20	0.40
North Carolina	= 1 if farm in North Carolina	0.19	0.39
Texas	= 1 if farm in Texas	0.32	0.47
Wisconsin	= 1 if farm in Wisconsin	0.28	0.45
Corn	= 1 if primary crop is corn	0.29	0.45
Cotton	= 1 if primary crop is cotton	0.07	0.25
Soybeans	= 1 if primary crop is soybeans	0.19	0.39
Sorghum, Rice, or Wheat	= 1 if primary crop is sorghum, rice or wheat	0.12	0.32
Yield Variability Risk	= 1 if believe crop yield variability will be a major source of income risk in the next five years	0.64	0.48
Price Variability Risk	=1 if believe crop price variability will be a major source of income risk in the next five years	0.78	0.42

Table 2. Multinomial Logit and Probit Parameter Estimates

Variable	Multinomial Logit		Multinomial Probit	
	Coefficient	p-value	Coefficient	p-value
A. Outcome = Wait ($Y_i = 1$)*				
ACRE Pays More	0.21	0.56	0.20	0.51
ACRE Risk Protection	0.34	0.13	0.31	0.11
Farm Program Risk	0.11	0.49	0.09	0.49
Farm Size	<-0.001	0.55	<-0.001	0.54
Risk Averse	-0.38	0.04	-0.32	0.04
Farmer Organization	-0.52	0.16	-0.46	0.14
North Carolina	0.15	0.56	0.12	0.56
Texas	0.33	0.27	0.29	0.25
Wisconsin	0.43	0.09	0.36	0.09
Corn	0.21	0.44	0.20	0.40
Cotton	-0.67	0.04	-0.55	0.04
Soybeans	0.15	0.64	0.15	0.58
Yield Variability Risk	-0.24	0.16	-0.21	0.15
Price Variability Risk	0.31	0.09	0.27	0.08
Intercept	-1.14	<0.01	-1.01	<0.01
B. Outcome = Switch ($Y_i = 2$)*				
ACRE Pays More	2.24	<0.01	1.58	<0.01
ACRE Risk Protection	2.67	<0.01	1.72	<0.01
Farm Program Risk	-0.33	0.52	-0.14	0.65
Farm Size	<0.001	0.78	<0.001	0.87
Risk Averse	0.53	0.36	0.32	0.30
Farmer Organization	-33.65	<0.01	-7.21	<0.01
North Carolina	0.47	0.59	0.36	0.44
Texas	-0.87	0.43	-0.55	0.36
Wisconsin	0.14	0.88	0.12	0.83
Corn	0.99	0.37	0.64	0.29
Cotton	-30.14	<0.01	-4.44	<0.01
Soybeans	1.46	0.18	0.87	0.16
Yield Variability Risk	-0.06	0.92	-0.02	0.95
Price Variability Risk	0.61	0.30	0.35	0.31
Intercept	-5.97	<0.01	-3.91	<0.01
Log-Likelihood	-596.24		-595.32	
Pseudo R-squared	0.08		---	

Note: n = 881; base outcome is stay with the current program through life of the farm bill (Y_i = 0); omitted state variable is Mississippi and omitted primary crops are sorghum, rice, and wheat.

Table 3. Multinomial Logit Marginal Effects

	Outcome = Stay (Y_i = 0)		Outcome = Wait (Y_i = 1)		Outcome = Switch (Y_i = 2)	
Variable	Marginal Effect[*]	p-value	Marginal Effect[a]	p-value	Marginal Effect[*]	p-value
ACRE Pays More	-0.09	0.06	0.01	0.85	0.08	<0.01
ACRE Risk Protection	-0.13	<0.01	0.04	0.24	0.09	<0.01
Farm Program Risk	-0.02	0.42	0.02	0.25	-0.01	0.20
Farm Size	<0.01	0.42	<-0.01	0.33	<0.01	0.56
Risk Averse	0.07	<0.01	-0.08	<0.01	0.01	0.15
Farmer Organization	0.12	<0.01	-0.09	0.04	-0.03	<0.01
North Carolina	-0.04	0.32	0.03	0.45	0.01	0.53
Texas	-0.06	0.17	0.08	0.08	-0.02	0.05
Wisconsin	-0.09	0.02	0.09	0.02	-0.001	0.95
Corn	-0.06	0.17	0.04	0.36	0.02	0.34
Cotton	0.14	<0.01	-0.12	<0.01	-0.03	<0.01
Soybeans	-0.05	0.27	0.02	0.71	0.03	0.18
Yield Variability Risk	0.05	0.03	-0.05	0.03	0.001	0.92
Price Variability Risk	-0.07	<0.01	0.06	0.02	0.01	0.27

[a]Note: reported values are the average of producer-specific marginal effects, not marginal effects evaluated at regressor means.

Appendix: Derivation of Equation (7).

The Bellman equation for the dynamic optimization problem specified by equation (7) is:

(A1) $$\rho F(R,S)dt = \mathrm{E}[dF(R,S)].$$

Using Ito's lemma to expand $dF(\cdot)$ gives

(A2) $$dF(R,S) = F_R dR + F_S dS + \tfrac{1}{2}F_{RR}(dR)^2 + \tfrac{1}{2}F_{SS}(dS)^2 + F_{RS}dRdS,$$

since $F_t = 0$. Based on (A2) and equation (2) for dR and dS,

(A3) $$\mathrm{E}[dF(R,S)] = \left(\alpha_R RF_R + \alpha_S SF_S + \tfrac{1}{2}\sigma_R^2 RF_{RR} + \tfrac{1}{2}\sigma_S^2 SF_{SS} + \gamma\sigma_R\sigma_S RSF_{RS}\right)dt,$$

since $dz_R = dz_S = 0$ for both R and S. Substitute (A3) into (A1), dividing by dt, and rearrange:

(A4) $$\tfrac{1}{2}\left(\sigma_R^2 R^2 F_{RR} + 2\gamma\sigma_R\sigma_S RSF_{RS} + \sigma_S^2 S^2 F_{SS}\right) + \alpha_R RF_R + \alpha_S SF_S - \rho F(R,S) = 0.$$

For this partial differential equation, value matching and two smooth pasting conditions are

(A5) $$F(R,S) = \frac{S}{\rho-\alpha_S} - \frac{R}{\rho-\alpha_R}$$

(A6) $$F_S(R,S) = W'(S) = \frac{1}{\rho-\alpha_S} \text{ and } F_R(R,S) = V'(R) = \frac{1}{\rho-\alpha_R}.$$

Collapse this partial differential equation into one dimension. $F(\cdot)$ is homogeneous of degree one in R and S, so define $s = S/R$ and note that $F(R,S) = Rf(S/R) = Rf(s)$, where $f(s)$ is the function to find. Now $F_S(R,S) = f'(s)$, $F_R(R,S) = f(s) - sf'(s)$, $F_{SS}(R,S) = f''(s)/R$, $F_{RS}(R,S) = -sf''(s)/R$, and $F_{RR}(R,S) = s^2f''(s)/R$, so substitute these into (A4) and simplify:

(A7) $$\tfrac{1}{2}s^2 f''(s)\left(\sigma_R^2 - 2\gamma\sigma_R\sigma_S + \sigma_S^2\right) + (\alpha_S - \alpha_R)sf'(s) + (\alpha_R - \rho)f(s) = 0.$$

For this ordinary differential equation, value matching and two smooth pasting conditions are

(A8) $$f(s) = \frac{s}{\rho-\alpha_S} - \frac{1}{\rho-\alpha_R}$$

(A9) $$f'(s) = \frac{1}{\rho-\alpha_S} \text{ and } f(s) - sf'(s) = \frac{1}{\rho-\alpha_R}.$$

Because any one of these conditions can be derived from the other two, select (A8) and the first smooth pasting conditions from (A9) to solve the ordinary differential equation.

As a second order, homogeneous linear equation, the solution for (A7) is a linear combination of two linearly independent solutions: $f(s) = A_1 s^{\beta_1} + A_2 s^{\beta_2}$, where A_1 and A_2 are constants to be determined and β_1 and β_2 are the roots of the fundamental quadratic equation:

(A10) $$\tfrac{1}{2}\left(\sigma_R^2 - 2\gamma\sigma_R\sigma_S + \sigma_S^2\right)\beta(\beta-1) + (\alpha_S - \alpha_R)\beta + \alpha_R - \rho = 0\,.$$

To solve for s^*, the s at which it is optimal to switch, note that as s approaches zero, it becomes unlikely that it will increase to reach the threshold. To ensure that $f(s^*)$ approaches zero as s approaches zero, set the coefficient for the negative power of s to zero: $A_2 = 0$. Next, the value matching condition (A8) and the first smooth pasting condition (A9) give:

(A11) $$A_1 s^{*\beta_1} = \frac{s^*}{\rho - \alpha_S} - \frac{1}{\rho - \alpha_R}\,,$$

(A12) $$\beta_1 A_1 s^{*\beta_1 - 1} = \frac{1}{\rho - \alpha_S}\,.$$

Solve (A11) and (A12) for the two unknowns, s^* and A_1. First solving (A12) for A_1 gives

$A_1 = \dfrac{s}{(\rho - \alpha_S)\beta_1 s^{\beta_1}}$ and then substituting this into (A12) and simplifying gives

(A13) $$s^* = \frac{\beta_1}{(\beta_1 - 1)}\frac{(\rho - \alpha_S)}{(\rho - \alpha_R)}\,.$$

Next, use the original definition of $s = S/R$ to recover the solution in terms of S and R:

(A14) $$S^* = \frac{\beta}{(\beta - 1)}\frac{(\rho - \alpha_S)}{(\rho - \alpha_R)}R\,,$$

where $\beta = \beta_1$, the positive root of the fundamental quadratic equation (A10).