EFFECTS OF FEDERAL RISK MANAGEMENT PROGRAMS ON INVESTMENT, PRODUCTION, AND CONTRACT DESIGN UNDER UNCERTAINTY

A Dissertation

by

SANGTAEK SEO

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2004

Major Subject: Agricultural Economics

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Approved as to style and content by:

David J. Leatham (Chair of Committee)	Bruce A. McCarl (Member)
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ABSTRACT

Effects of Federal Risk Management Programs on Investment, Production, and Contract Design under Uncertainty. (December 2004)

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Agricultural producers face uncertain agricultural production and market conditions. Much of the uncertainty faced by agricultural producers cannot be controlled by the producer, but can be managed. Several risk management programs are available in the U.S. to help manage uncertainties in agricultural production, marketing, and finance. This study focuses on the farm level economic implications of the federal risk management programs. In particular, the effects of the federal risk management programs on investment, production, and contract design are investigated.

The dissertation is comprised of three essays. The unifying theme of these essays is the economic analysis of crop insurance programs. The first essay examines the effects of revenue insurance on the entry and exit thresholds of table grape producers using a real option approach. The results show that revenue insurance decreases the entry and exit thresholds compared with no revenue insurance, thus increasing the investment and current farming operation. If the policy goal is to induce more farmers

in grape farming, the insurance policy with a high coverage level and high subsidy rate is effective.

In the second essay, a mathematical programming model is used to examine the effects of federal risk management programs on optimal nitrogen fertilizer use and land allocation simultaneously. Current insurance programs and the Marketing Loan Program increase the optimal fertilizer rate 2% and increase the optimal cotton acreage 119-130% in a Texas cotton-sorghum system. Assuming nitrogen is harmful to the environment and cotton requires higher nitrogen use, these risk management programs counteract federal environmental programs.

The third essay uses a principal-agent model to examine the optimal contract design that induces the best effort from the farmer when crop insurance is purchased. With the introduction of crop insurance, the investor's optimal equity financing contract requires that the farmer bear more risk in order to have the incentive to work hard, which is achieved by increasing variable compensation and decreasing fixed compensation.

DEDICATION

To my parents, my wife, and my kids

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TABLE OF CONTENTS

CHAPTER Page

LIST OF FIGURES

FIGURE Page

LIST OF TABLES

CHAPTER I

INTRODUCTION

Agricultural producers face uncertain agricultural production and market conditions. Yield and price fluctuations largely define this uncertainty. Yield uncertainty is mainly caused by weather. Price uncertainty arises from the interaction of supply and demand conditions ultimately involving many underlying international and domestic factors, including weather. This uncertainty makes agricultural income unstable. Much of the uncertainty faced by agricultural producers cannot be controlled by the producer but can be managed. Thus risk management is important to farmers and agricultural policy makers.

Several risk management approaches are available in the U.S. to help manage uncertainties in agricultural production, marketing, and finance. Two widely adopted risk management programs are the crop insurance and marketing loan programs provided by the federal government. These programs protect income and market prices in the face of uncertain production and market conditions.

Yield insurance and revenue insurance are the most commonly used among the crop insurance programs. Yield insurance guarantees a minimum level of yield (however, the indemnity is given in terms of monetary value) and revenue insurance guarantees a minimum level of revenue. The Agricultural Risk Protection Act (ARPA) of 2000 resulted in increased premium subsidies from the government and an expansion

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This dissertation follows the style and format of the *American Journal of Agricultural Economics*.

in the types of policies available, the crops covered, and the geographic availability. Total acres covered by crop insurance increased from 182 million in 1998 to 216 million in 2002 with total liability, a maximum indemnity that should be paid in case of total loss, increasing from $28 billion to $37 billion (USDA-RMA 2002a).

The Farm Security and Rural Investment Act of 2002 continued the nonrecourse marketing assistance loan program and loan deficiency program (LDP) that guarantees the minimum level of selected commodity prices, called the marketing loan rate. The former provides a marketing assistance loan to meet cash flow needs of farmers at harvest time by requiring commodities as collateral. This loan is non-recourse because the farmer can repay the loan with principal plus interest or forfeit the commodity to the government. The LDP is defined as the difference between the marketing loan rate and the posted county price (PCP) provided by the government at harvest time. If the PCP falls below the marketing loan rate at harvest time, then the farmer benefits from the LDP. Unlike crop insurance, those programs do not require the payment of a premium for participation. Marketing loan gain and the magnitude of LDP payments exceeded $1 billion and $6 billion for the 2000 crop year (USDA-FSA 2002a), respectively.

Risk management programs reduce downside risk faced by the farmer. Such provisions affect crop returns and thus farm investment and production decisions as well as leasing contracts. Those programs may induce farmers to grow crops that use more nitrogen, herbicides, and insecticides with possible detrimental effects on the environment (Goodwin and Smith; Skees). Crop insurance may encourage or discourage investment in perennial crops and may lead existing farmers to stay in farming longer or leave earlier. Crop insurance may alter agricultural contracts. The impacts that these decisions have need to be considered by policy makers and farm decision makers.

This study focuses on the farm level economic implications of federal risk management programs. Specifically, the work will focus on crop insurance and the marketing loan program that are used to protect farmers from yield, income, and price uncertainties. In particular, the effects of federal risk management programs on the investment, production, and contract design will be investigated.

The dissertation will be comprised of three essays. The sections that follow include a description of the three essays, each with its own purpose and procedure. The unifying theme of these essays is the economic analysis of crop insurance programs. Collectively through the three studies we will examine how the presence of crop insurance and LDP provisions changes farm decisions regarding investment in risky assets, choice of crops and input uses, and contract provisions between investors and farmers.

CHAPTER II

EFFECT OF REVENUE INSURANCE ON ENTRY AND EXIT DECISIONS IN TABLE GRAPE PRODUCTION: A REAL OPTION APPROACH

2.1. Introduction

The passage of the Agricultural Risk Protection Act (ARPA) in 2000 greatly expanded the availability of crop insurance to farmers. Not only have premium subsidies increased, but also the types of policies available and the crops that can be insured. As a result, total acres covered by crop insurance increased from 182 million in 1998 to 216 million in 2002 (USDA-RMA 2002a). By buying crop insurance, farmers reduce the risk that they face in exchange for some premiums. This behavior changes the expected future cash flow and its distribution and thus affects the investment or disinvestments decisions. Also, increased subsidies affect those decisions through the change in the expected cash flow and its distribution. Thus, the effect of crop insurance on the investment and disinvestments decision needs to be investigated for policy makers and farmers so that they make better decision-making. However, the effect of crop insurance on the investment and disinvestments decisions has not been studied yet.

Many investment studies in agricultural literature have focused on the land valuation (Robison, Hanson, and Lins), asset replacement decision (Leatham and Baker; Perrin), and facility purchase (Griffin et al.) using the net present value (NPV) approach. Some studies include the effect of the government tax policy on the agricultural investment decision using the NPV (Musser, Tew, and Clifton; Rossi). Musser, Tew, and Clifton studied the tax benefit of the investment in irrigation equipment and Rossi studied the impact of the Tax Reform Act of 1986 on feeding investments using NPV. Also Baker, Leatham, and Schrader studied the effect of inflation on a confinement swine operation. However, no studies include crop insurance in the investment analysis using the NPV.

The decision rule of NPV requires that the NPV be nonnegative for the investment to be acceptable and then choose the highest NPV among different scenarios. These decisions are made at current time and the opportunity cost from the loss of future possible investments is not reflected in the NPV. That is, the NPV ignores the investment timing (called the investment flexibility). The investment flexibility is valuable because, by adjusting investment timing, the investor may possibly avoid investing in projects that results in large sunk costs if there are subsequent unfavorable market conditions. Thus, the NPV approach has been criticized because it only considers the current decision, not the investment flexibility to invest at later date (Myer).

As an alternative to NPV, the concept of real options has been used to overcome the shortcomings of standard NPV (Trigeorgis). Dixit (1991) analyzed the effect of price ceiling and price floor on the investment decision using a real option approach. This study incorporates the investment flexibility and investment timing. The investment criterion is a trigger value that specifies when to enter the business (called entry threshold). An investor currently in business must also make the decision to continue operating or exit the business. In this case, the trigger value to exit the business (called exit threshold) is given as a disinvestment decision criterion. This approach applies the financial option concept to the investment in real assets when the decision is made under uncertainty (Dixit and Pindyck; Trigeorgis). That is, this approach regards the investment flexibility in real assets as an option to undertake an investment over a given period. This is similar to an American option in which the holder of the option can exercise the option at any point of time from when the option is purchased.

Recent real option studies in the agricultural economics literature include the entry-exit decision (Price and Wetzstein; Isik et al., 2003), the equipment replacement decision (Hyde, Stokes, and Engel), the sequential investment decision in crop management (Isik, Khanna, and Winter-Nelson), and technology adoption (Purvis et al.). Salin studied the impact of food safety risks on capital investment. However, no studies use the real option approach to consider the effect of crop insurance on the investment decision. This study incorporates crop insurance into real option model to see the effect of crop insurance on investment decision.

Specifically, the purpose of this study is to set up a real option model with crop insurance and investigate the effect that crop insurance has on the entry threshold as an investment criterion and exit threshold as a disinvestment criterion. For the application, we choose table grape production in California that accounts for 90% of domestic grape production (USDA-ERS). Currently, only yield insurance is available for table grapes as a crop specific insurance in California. However, adjusted gross revenue (AGR) and the recently developed AGR-Lite provides revenue insurance as whole farm insurances that include several crops in several states such as California, Oregon, and Florida (USDA-RMA 2003). There is a high potential to introduce revenue insurance for table grapes as a crop specific insurance in other states including California according to the ARPA in 2000. Thus revenue insurance also is considered in this study.

It is expected that using the real option approach to evaluate the effect of crop insurance on investment decisions will contribute to the investment literature. This study also will include the effects of crop insurance on investment decision, such as the effect of minimum level of revenue guarantee or subsidy effect on investment decisions. In addition, the results of this study will be useful to other potential regions, such as southern Arizona, northern New Mexico, and Texas that may grow table grapes (Stein and McEachern).

In the following section, we intuitively explain the entry and exit thresholds for standard NPV and real option approaches. Then the actual model, data, and results follow.

2.2. Entry and Exit Thresholds for Standard NPV and Real Options

Entry and exit thresholds are part of the decision criterion when using the real option method. The entry and exit thresholds can be different when the NPV is used instead of real options. This section illustrates these differences. To make the comparison easier, we assume a totally irreversible investment that produces no salvage value. The inclusion of the salvage value complicates the model derivation without adding anything to the comparison. This assumption is relaxed in the section 2.3 so that the effect of the salvage value on investment decision is explored using the real option approach.

2.2.1. Entry and Exit Thresholds with Standard NPV

The NPV is defined as the discounted value of the difference between future revenue flow R_t and future cost flow C_t minus initial investment cost (sunk cost) I_0. With finite time horizon and discrete time notation, standard NPV can be denoted as

$$NPV = \sum_{t=0}^{T}\left(\frac{R_t}{(1+\rho)^t} - \frac{C_t}{(1+\rho)^t}\right) - I_0 , \tag{2.1}$$

where ρ is the risk adjusted rate that consists of the risk free rate and the risk premium rate and T is the number of years of the project's life. It requires a non-negative NPV at $t=0$ for the investment to be acceptable.

To maintain the consistency with the real option approach, the investment is assumed to be perpetual, and R and C are constant through time. In addition, the risk free rate, r, is chosen to discount the relatively stable cost C. By assuming a rate of growth or drift (trend) rate α in revenue, the NPV is

$$NPV = \frac{R}{\delta} - \frac{C}{r} - I , \tag{2.2}$$

where δ is the risk and growth adjusted discount rate that is ρ minus the drift rate α, such that $\delta = \rho - \alpha$ (Dixit and Pindyck). This adjustment is justified when the revenue flow has a constant-growth rate (trend) because it prevents underestimating the true revenue flow. The use of continuous time analytics is helpful to make the transition from the standard NPV decision criterion to the revised decision criterion for investments under real options. The first step is to consider the decision criterion, the entry threshold, to answer the question of "when" to invest, not simply invest or not invest that is inherent in the NPV criterion. In equation (2.2), the entry threshold is denoted as R_H and is defined as the level of revenue flow R that makes the NPV zero and thus guarantees at least no loss from investment. The entry threshold provides a trigger value such that a decision maker invests when R is at least as high as R_H. Thus the entry threshold R_H is denoted as

$$R_H = \frac{\delta C}{r} + \delta I , \tag{2.3}$$

where the right hand side of equation (2.3) is the long-run average cost. The decision rule of equation (2.3) is to enter the business if the revenue flow is equal to or greater than the entry threshold R_H and not to enter the business otherwise.

After the investor enters the business, the investor must decide when to disinvest. The investor must consider the loss of revenue that is incurred from disinvestment, the savings in costs, and the exit cost E. Thus, the NPV in equation (2.2) can be altered to reflect the decision to disinvest and is written as

$$NPV = -\frac{R}{\delta} + \frac{C}{r} - E . \tag{2.4}$$

In equation (2.4), the exit threshold denoting R_L, the trigger value to disinvest, is defined as the level of revenue flow R that makes the NPV zero and thus guarantees at least no loss from disinvestments. Thus, the exit threshold R_L is denoted as

$$R_L = \frac{\delta C}{r} - \delta E . \tag{2.5}$$

The decision rule of equation (2.5) is to exit the business if revenue flow is less than the trigger value R_L and to stay in business otherwise. The entry and exit thresholds with the real options are compared with those with the NPV approach in the following section.

2.2.2. Entry and Exit Thresholds with Real Options

In this section, intuitive explanations of the real option approach are provided. The differences between the entry and exit thresholds using NPV and the real option approach are presented for the intuitive understanding.

To determine the entry threshold with real options, we assume that the farmer has an exclusive right to invest so that the revenue movement is not restricted from competition. This assumption makes the model derivation easier but this assumption is relaxed later and a competitive market is modeled. Also the disinvestment (exit) decision is not considered for the entry threshold decision here because it requires simultaneous decision making with entry decision and this makes the comparison with standard NPV difficult.

An inactive farmer is a farmer who is currently not farming but can potentially invest in a farming operation. If an inactive farmer gets in farming production, he must buy land and machinery. While the farmer is inactive, he has an option to invest and this option has a value, $V_0(R)$. The value of this option results because of the uncertainty and irreversibility of the investment. By waiting, the inactive farmer gains more information and can avoid investing if later the investment turns out to be unprofitable. If an inactive farmer enters farming by exercising an option to invest, he/she looses the option to invest and instead becomes an active farmer who is currently engaged in farming. That is, by entering farming, an inactive farmer gets a value of $V_1(R)$ with the expense of the investment cost I and becomes an active farmer. The entry decision is made when the $V_1(R) - I$ is at least greater than or equal to $V_0(R)$, where the entry threshold to exactly meet this condition is denoted by R_H. Intuitively, the value of $V_1(R) - I$ represents the NPV but the value of the option to invest $V_0(R)$ is unique in the real options approach.

For the mathematical comparison with NPV, denote $V_1(R)$ as the value of an active (current) farm, $V_0(R)$ the value of an inactive (potential) farm that is called the value of waiting or the value of the option to invest, I as the investment cost, and R is the revenue flow with a Brownian Motion process.[1] Then the value of waiting $V_0(R)$ is defined as

(2.6) $$V_0(R) = A_1 R^{\beta_1},$$

where $A_1 > 0$ and $\beta_1 > 1$ and A_1 is the constant to be determined, and β_1 is the positive root of the fundamental quadratic equation (The derivation of this formula is obtained in the equation (A.22) through (A.24) of the appendix A). The option value of waiting $V_0(R)$ is nonnegative because the farmer can avoid the bad state of nature by waiting. This value is also an increasing function of revenue flow R because the option to invest works as the American call option, where the call option value increases with the market price of the underlying asset.

[1] The origins of Brownian motion processes are in physics, specifically the characteristics of a heavy particle being bombarded by lighter particles (Salin).

The value of an active farm $V_1(R)$ is assumed as the same as the standard NPV without investment cost from equation (2.2) for the comparison purpose. A more specific derivation of the value of an active farm is obtained from Appendix A. Then the value of an active farm $V_1(R)$ is defined as

(2.7) $$V_1(R) = \frac{R}{\delta} - \frac{C}{r},$$

where δ and r are defined in section 2.2.1.

The two value functions $V_0(R)$ and $V_1(R)$, are graphed in the figure 2.1 (Dixit 1992) to examine the investment (entry) decision with the real option approach. In the graph, the vertical axe V denotes the project value and – I denotes the initial investment cost. The horizon axe denotes revenue flow R.

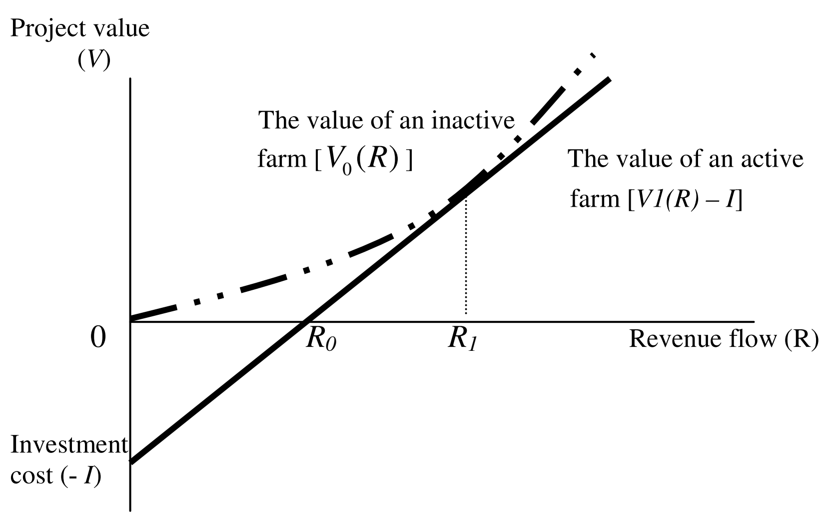

Figure 2.1. Entry thresholds with real options and standard NPV

In the figure 2.1, the R_0 and R_1 are the entry thresholds with standard NPV and the real option approaches, respectively, and $V_0(R)$ and $V_1(R) - I$ are the value of an inactive farm and the value of an active farm net of investment cost (sunk cost), respectively. As mentioned, standard NPV requires a non-negative project value as the investment rule so that the entry threshold hits the zero project value at R_0 (see equation (2.3)). On the other hand, the real option approach requires two conditions, value matching condition and smooth pasting condition, for the investment criterion. Value matching condition is a condition that the value of an active farm is equal to the value of an inactive farm. That is, it requires an entry threshold R_H that makes the value of an inactive farm (potential farm) $V_0(R)$ equal the value of an active farm $V_1(R)$ when an inactive farm spends the investment cost I and in return gets a project value $V_1(R)$. Smooth pasting condition is a tangency condition that requires the marginal value of an inactive farm is equal to the marginal value of an active farm. That is, it requires that, at the entry threshold R_H, the slopes of the value of an inactive farm and the value of an active farm net of the investment cost be the same. In the figure 2.1, the restriction of smooth pasting condition pushes the curve of $V_0(R)$ above that of $V_1(R)$ and makes a tangency point by adjusting unknown A_1. This tangency point determines the entry threshold that makes the marginal value of inactive farm equal to the marginal value of an active farmer.

In the figure 2.1, the entry threshold R_1 meets those conditions. If revenue flow R is less than the entry threshold R_1, then the value of an inactive farm $V_0(R)$, called the value of waiting, is greater than the value of an active farm $V_1(R)$ net of investment cost

I and thus waiting is the better policy. If revenue flow R exceeds at least the entry threshold R_1, then exercising the investment option by spending investment cost I and getting a project is the better policy. At this time, by exercising the investment option and getting a project, the farmer loses the option value of waiting.

The real option approach requires higher entry threshold than standard NPV by the difference between R_1 and R_0. The difference of entry thresholds between the two approaches is caused by the option value of waiting. The real option approach captures the value of waiting, while the NPV does not. In reality, business decision-making should consider operating flexibility and thus requires higher investment threshold than the NPV (Donaldson and Lorsch). If the option value of waiting is zero, then the real option approach produces the same entry threshold R_0 as standard NPV.

Mathematically, the value matching condition and the smooth pasting condition for the entry decision are represented as

$$V_0(R_H) = V_1(R_H) - I, \tag{2.8}$$

$$V_0^{'}(R_H) = V_1^{'}(R_H)\ . \tag{2.9}$$

Equation (2.8) and (2.9) can be solved for R_H from equation (2.6) and (2.7), where A_1 and R_H are unknowns to be determined. To get the solution for R_H, first replace equation (2.8) and (2.9) with equation (2.6) and (2.7). Then divide equation (2.8) by equation (2.9) and then rearrange for R_H. The solution for the entry threshold is

$$R_H = \frac{\beta_1}{\beta_1 - 1}\left(\frac{\delta C}{r} + \delta I\right), \tag{2.10}$$

where $\beta_1/(\beta_1\text{-}1)$ is greater than 1 because $\beta_1 > 1$. Equation (2.10) shows that the entry threshold with real options is greater than the entry threshold with standard NPV in equation (2.3) by a factor of $\beta_1/(\beta_1\text{-}1)$.

Second, the exit threshold in a real option approach can be easily derived and compared with the exit threshold in standard NPV when we follow the same procedure explained in the entry threshold with real options. All the definitions and terms used for the entry threshold both in NPV and real options and used for the exit threshold in NPV are used for the exit threshold in real options. The exclusive right to exit and no investment (entry) decision are assumed with the same reasons as in the entry threshold.

An active farmer can exit the farming when he/she expects unfavorable market or production conditions. The exit decision can be done any time in the future depending on the state of nature. Thus, the exit decision at the current time creates an opportunity cost by losing the future opportunity for the decision-making and this is referred to as the option value to exit. The Real options approach can capture this disinvestment (exit) flexibility as the option value to exit. This option value increases the project value and thus decreases the exit threshold compared with NPV. For the understanding of the exit threshold in real options, we simply present the mathematical comparison between the NPV and real options approaches.

Given the assumptions and definitions above, the value function for an inactive farm $V_0(R)$ is zero and the value function of an active farm $V_1(R)$ is defined as

(2.11) $$V_1(R) = B_2 R^{\beta_2} + \frac{R}{\delta} - \frac{C}{r},$$

where $B_2 > 0$ and $\beta_2 < 0$ and B_2 is the constant to be determined, β_2 is the negative root of the fundamental quadratic equation (The derivation of this formula is obtained in the equation (A.22) through (A.24) of the appendix A), and $B_2R^{\beta_2}$ is the option value to exit. The option value to exit $B_2R^{\beta_2}$ is nonnegative because the farmer can exit the farming whenever the bad state of nature is expected in the future. Thus as the possibility of the bad state of nature increases, the option value to exit increases, too. This value is also a decreasing function of revenue flow R because the possibility to exit the farming decreases as revenue flow increases.

To get the exit threshold in real option, value matching condition and smooth pasting conditions are required as in the entry threshold. Value matching condition is a condition that the value of an active farm is equal to the value of an inactive farm. That is, it requires an exit threshold R_L that makes the value of an active farm $V_1(R)$ equal the value of an inactive farm $V_0(R)$ when an active farm spends the exit cost E and in return gets the option value to invest $V_0(R)$. Smooth pasting condition is a tangency condition that the marginal value of an active farm is equal to the marginal value of an inactive farm. That is, it requires that, at the exit threshold R_L, the slopes of the value of an active farm and the value of an inactive farm net of the exit cost be the same.

Mathematically, the value matching condition and the smooth pasting condition for the exit decision are represented as

(2.12) $$V_1(R_L) = V_0(R_L) - E,$$

(2.13) $$V_1^{'}(R_L) = V_0^{'}(R_L) .$$

Equation (2.12) and (2.13) can be solved for R_L from equation (2.11) and $V_0(R) = 0$, where B_2 and R_L are unknowns to be determined. To get the solution for R_H, first replace equation (2.12) and (2.13) with equation (2.11) and $V_0(R) = 0$. Then divide equation (2.12) by equation (2.13) and then rearrange for R_L. The solution for the exit threshold is

$$R_L = \frac{\beta_2}{\beta_2 - 1}\left(\frac{\delta C}{r} - \delta E\right), \tag{2.14}$$

where $\beta_2/(\beta_2\text{-}1)$ is less than 1 because $\beta_2 < 0$. Equation (2.14) shows that the exit threshold with real options is less than the exit threshold with standard NPV in equation (2.5) by a factor of $\beta_2/(\beta_2\text{-}1)$.

2.3. Model

The entry and exit model in this study is set up with two cases, one without crop insurance, and the other with crop insurance to see the effect of crop insurance on investment decision-making. These models form simultaneous equations to be solved for the entry and exit threshold. The assumptions to derive the models are presented. Then the entry and exit models, without and with revenue insurance, are presented, respectively.

2.3.1. Model Assumptions

First, we assume a competitive industry to derive the entry and exit model (Leahy). At the farm level, an investment or capital budgeting choice is a long-term and strategic decision. In a long-term perspective, many farmers can join or leave grape farming according to market conditions. They act competitively so that abnormal project values, either higher or lower project value compared with zero project value, disappear. That is, in a competitive industry, positive project values induce more inactive farmers to enter farming, where inactive farmers are farmers who could potentially enter grape farming. Negative project values lead to active farmers leaving the business, where active farmers are farmers who are currently engaged in farming. The competition leads to a dynamic equilibrium in the long run through price and thus revenue adjustment. To emphasize the entry and exit thresholds in a competitive market, following Leahy, the upper and lower reflecting barriers are interchangeably used for the entry and exit thresholds in model derivation. In a competitive market, when the price flow or revenue flow reaches the entry threshold, new farmers enter the business that increases the output quantities in the market. As a result, the market price or revenue is slightly brought back to a lower level from the entry threshold immediately. When the market price or revenue reaches the exit threshold, active farmers exit the farming, thus increasing market price or revenue slightly. Thus entry and exit thresholds work as the upper and lower reflecting barriers in a competitive market, respectively. However, in any case, the arbitrage drives the market price and revenue into the entry threshold for inactive farms and exit threshold for active farms, thus resulting in the equilibrium prices or revenues, respectively. Thus, when making an investment decision, the farmer needs to consider the potential entrance of competitive farmers. We assume that there are many grape farmers and their competitive investment decisions affect market price. We also assume a homogeneous product so that each farmer has the same price.

Uncertainty in the competitive industry could be farm specific or industry-wide (or aggregate uncertainty), where the former can be explained by the uncertainty of management skill (or technology) and commodity specific demand and the latter can be explained by aggregate demand uncertainty or a widespread disaster in production. In this paper, we focus on the industry-wide uncertainty because much of the uncertainties in agriculture are caused by market conditions or production dependency on nature. In a competitive industry, price is an endogenous variable determined by the demand and production relationships, where both are assumed uncertain, thus, price moves stochastically. Yield also changes stochastically because of production uncertainty. The yield and price correlation is included in the specification of price and yield stochastic processes in the next section.

In the model, the investment costs are assumed partially reversible, which results in salvage values from the project, such as lands, facilities, and machinery. On the other hand, the exit from the farming entails costs, such as the cost to remove the vineyard. In this study, we assume that the exit costs totally counteract the salvage values so that both factors can be eliminated in the model. However, we conduct sensitivity analysis to see the effect of the exit costs and salvage values on the entry and exit thresholds. Once a farmer exits farming, investment costs to enter farming again are the same as before, so that a temporary suspension and resumption without a penalty is not allowed. Variable cost is assumed relatively predictable and thus the risk free rate is used to discount it (Pindyck; Price and Wetzstein).

To derive the entry and exit model, we can use a dynamic programming approach or contingent claim analysis that lead to the same solution (Dixit and Pindyck). The latter requires a risk free portfolio with existing assets to evaluate the option value to invest. However, a dynamic programming approach can be used to maximize the present value of cash flow without such assumption. This approach requires the assumption of risk preferences or risk adjusted discount rates. In this study, we follow the dynamic programming approach because the agricultural uncertainty cannot be easily replicated. We use the risk-adjusted discount rate to discount uncertain revenue flow.

2.3.2. Entry and Exit Model with No Revenue Insurance[2]

The stochastic evolution of the value of a project over time affects the investment decision. The stochastic processes of relevant variables are needed to obtain the stochastic evolution. We assume price and yield are stochastic variables that follow geometric Brownian motion (Turvey 1992b; Price and Wetzstein). When price and yield follow geometric Brownian motions, revenue R also follows a geometric Brownian motion:

$$dR = \alpha_R R dt + \sigma_R R dz_R, \tag{2.15}$$

where α is the drift rate, σ is the volatility rate, dt is a small time increment, and dz is the increment of the standard Brownian motion (or Wiener process).

[2] The mathematical procedures to derive the entry and exit model by Dixit and Pindyck are provided in appendix A.

Given the stochastic process of equation (2.15), the value of an inactive farm that has the opportunity to enter the farming, and the value of an active farm that has the option value to exit the farming are determined simultaneously. In a competitive industry, the entry and exit thresholds play roles as the upper and lower reflecting barriers that are the equilibrium revenues for inactive farmers and active farmers, respectively (Leahy). Dixit and Pindyck provide the simultaneous equations for the solution of thresholds with price uncertainty under dynamic equilibrium in a competitive industry.[3] The simultaneous equations are given as

(2.16) $$(B_1 - A_1)R_H^{\beta_1} + (B_2 - A_2)R_H^{\beta_2} + \frac{R_H}{\delta} - \frac{C}{r} = I$$

(2.17) $$\beta_1(B_1 - A_1)R_H^{\beta_1 - 1} + \beta_2(B_2 - A_2)R_H^{\beta_2 - 1} + \frac{1}{\delta} = 0$$

(2.18) $$(B_1 - A_1)R_L^{\beta_1} + (B_2 - A_2)R_L^{\beta_2} + \frac{R_L}{\delta} - \frac{C}{r} = -E$$

(2.19) $$\beta_1(B_1 - A_1)R_H^{\beta_1 - 1} + \beta_2(B_2 - A_2)R_H^{\beta_2 - 1} + \frac{1}{\delta} = 0,$$

where β_i are the roots of the fundamental quadratic equation. A_i and B_i are constants to be determined, where $A_1 R^{\beta_1}$ is the value of the option to invest for an inactive farm and $B_2 R^{\beta_2}$ is the value of the option to exit for an active farm. $A_2 R^{\beta_2}$ is the increase in the value of an inactive farm from the lower reflecting barrier and $B_1 R^{\beta_1}$ is the decrease in the value of an active farm from the upper reflecting barrier caused by competitions. As explained in section 2.3.1, in a competitive market, the arbitrage drives the market price

[3] Detailed procedures are provided in appendix A.

or revenue at the upper reflecting barrier for an inactive farm but does not allow them to rise above that barrier. Thus the value of an inactive farm must be adjusted to the downward direction. Also the arbitrage prevents the market price or revenue from going down below the lower reflecting barrier for an active farm. Thus the value of an active farm must be adjusted the upward direction. C is the variable cost, I is the investment cost, r is the risk free rate of return, δ is the risk and growth adjusted discount rate. E is the exit cost adjusted by the salvage value. δ is commonly assumed to be greater than zero ($\rho > \alpha$) otherwise no optimum exists and waiting is the best decision.

Equations (2.16) and (2.18) are value-matching conditions, one for the entry threshold and the other for the exit threshold, that require the value of waiting to equal the value of investing at the entry and exit thresholds, respectively. Equations (2.17) and (2.19) are smooth-pasting conditions, one for the entry threshold and the other for the exit threshold, that require the same slopes of the value of waiting and the value of investing at each threshold level. However, in a perspective of the upper and lower reflecting barriers caused by a competitive equilibrium, those conditions can be interpreted as the results of the arbitrage among inactive farmers and active farmers, respectively. The last two terms in equations (2.16) and (2.18) denote the expected net present values of an infinite annuity of profit, where revenue flow is discounted by the risk and growth adjusted discount rate and constant cost is discounted by risk free rate. By setting (B_1-A_1) and (B_2-A_2) as K_1 and K_2, we can solve the simultaneous equation with four unknowns, K_1, K_2, R_H, and R_L. These equations are highly non-linear in the thresholds, R_H and R_L, thus the symbolic solution cannot be obtained and instead a numerical procedure is required to get the solution. We use the MathCad 8 Professional to solve this simultaneous equation. In the model, the optimal entry and exit thresholds are equilibrium revenue levels worked as upper and lower reflecting barriers, respectively, which result in zero option value of waiting for inactive farmers (A_1=A_2=0). From the entry and exit thresholds, the inaction gap is defined as the difference between the entry threshold and the exit threshold that leads to no action to exit the farming from entering the farming. This concept of inaction gap is sometimes useful for the interpretation of the results.

2.3.3. Entry and Exit Model with Revenue Insurance

Revenue insurance guarantees a revenue floor ($\underline{R}$) but also requires a constant insurance premium, thus increasing the variable cost. Thus, the revenue insurance affects the entry and exit thresholds. The revenue guarantee induces more inactive farmers to invest and more active farmers to stay in farming. However, revenue insurance requires that an active producer pay the insurance premium, which reduces the net revenue flow and decreases the attractiveness of entry, so that we need to consider the trade off between the revenue guarantee and insurance premium.

To see the effect of revenue insurance on the entry and exit decision, the model can be set up in two cases. The first case is when the revenue guarantee, $\underline{R}$, is greater than the exit threshold, R_L, but less than the variable cost C_Φ, ($R_L \le \underline{R} \le \frac{\delta}{r} C_\Phi$), where the variable cost includes insurance premium Φ, thus defined as $C_\Phi = C + \Phi$. The second case is when the revenue guarantee is greater than the variable cost but less than the long run average cost ($\frac{\delta}{r}C_\Phi \le \underline{R} \le \frac{\delta}{r}C_\Phi + \delta I$). In this study, we focus on the first case because it is rare for the revenue guarantee from crop insurance to exceed the variable cost otherwise buying revenue insurance always guarantees nonnegative profit that is not common in agricultural production. Even though the revenue guarantee is less than the variable cost, two sub-cases must be considered (figure 2.2). Figure 2.2 shows these two sub-cases of revenue flow to be modeled for the study, where R_L is the exit threshold, R is the revenue flow, $\underline{R}$ is the revenue guarantee, and R_H is the entry threshold. In the figure 2.2, the first sub-case is $R_L \le R \le \underline{R}$ and the second sub-case is $\underline{R} \le R \le R_H$. In the first sub-case, where revenue is greater than the exit threshold but less than the revenue guarantee, $R_L \le R \le \underline{R}$, the revenue guarantee is binding. In the second sub-case, where revenue is greater than the revenue guarantee but less than entry threshold, $\underline{R} \le R \le R_H$, the revenue guarantee is not binding.

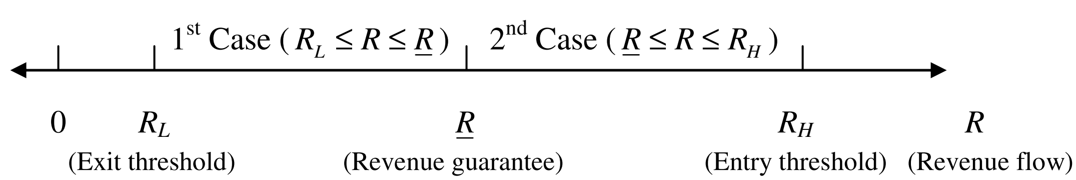

Figure 2.2. Two cases of revenue flow to derive the entry and exit model under revenue insurance

Consider the first sub-case, $R_L \le R \le \underline{R}$. If revenue is greater than the exit threshold and less than the revenue guarantee, then the value of investing for the active farmer[4] is

(2.20) $$V(R) = \frac{\underline{R}}{r} - \frac{C_\Phi}{r} + B_1 R^{\beta_1} + B_2 R^{\beta_2},$$

where C_Φ is the variable cost with insurance premium, which includes a subsidy from the government, and B_1 and B_2 are the constants to be determined. The first two terms in equation (2.20) are the expected present value of an infinite annuity of profit with revenue insurance, where the revenue has the lower boundary caused by revenue guarantee and thus discounted by the risk free rate. The other two terms are the value of an active farm adjusted by reaching the revenue guarantee and the option value to exit for an active farm, respectively, which are caused by revenue insurance and competitions.

As before, we also have the value matching condition $V(R_L) = -E$ and smooth-pasting condition $V'(R_L) = 0$. This value matching condition is obtained by setting the option value of waiting to zero ($V_0(R) = 0$) because the option value of waiting in a competitive market is zero from competitions. The positive option value of waiting means the possibility of the positive project value, which induces more farmers to the farming and thus makes the option value of waiting disappear in a competitive market. However, the value of an active farm is adjusted from the reflecting barrier caused by

[4] The derivation of equation (2.20) is provided in appendix A.

competitions. This adjusted value in a competitive market works like the option value of waiting for an inactive farm with the exclusive right to invest.

For the second sub-case when revenue is greater than the revenue guarantee, but less than the entry threshold, $\underline{R} \leq R \leq R_H$, the project value is

$$V(R) = \frac{R}{\delta} - \frac{C_\Phi}{r} + B_3 R^{\beta_1} + B_4 R^{\beta_2} , \tag{2.21}$$

where B_3 and B_4 are the constants to be determined. In equation (2.21), the expected present value of an annuity of revenue is discounted by the risk and growth adjusted discount rate, where the revenue is not bounded from the floor, but the cost is discounted by the risk free rate.

The key parameter of the real option model affected by crop insurance is the discount rate. Thus given crop insurance, we need to adjust the discount rate of revenue because the revenue guarantee eliminates downside risk, thus changing the distribution of revenue. We reduce the risk premium rate in the discount rate of revenue by the insurance coverage level (50-75%) of the expected revenue because the farmer can eliminate the downside risk by that much. However, we still use the same volatility rate to consider the potential movement of revenue flow in equation (2.20) and (2.21) even though the actual revenue flow is bounded by the revenue floor. When the potential revenue in a competitive industry is far below the revenue guarantee, the farmer knows that the actual revenue received stays at the revenue guarantee longer than if the potential revenue were close to the revenue guarantee. The farmer prefers the latter to the former for the investment decision. Thus, the potential movement of revenue is an important factor for the farmer's investment decision with crop insurance, which is consistent with the assumption used by Dixit and Pindyck. Given the parameters and adjustments for crop insurance, the derivation of the option value model proceeds in the usual way. The other two terms in equation (2.21) are the value of an active farm adjusted by reaching the revenue guarantee and the value of the option to exit for an active farm, respectively, which are caused by revenue insurance and competitions. The respective value matching and smooth-pasting conditions are $V(R_H) = I$ and $V'(R_H) = 0$.

Assuming the value function $V(R)$ is continuously differentiable around $\underline{R}$, we get the following equation (2.22) by equating equations (2.20) and (2.21) at $\underline{R}$ and rearranging them. Then by differentiating equation (2.22) with respect to R at $\underline{R}$, equation (2.23) is obtained. These are value matching and smooth pasting conditions to connect the first sub-case and the second sub-case under the continuous revenue flow in the figure 2.2.

(2.22) $$\frac{\underline{R}}{r} - \frac{\underline{R}}{\delta} + (B_1 - B_3)\underline{R}^{\beta_1} + (B_2 - B_4)\underline{R}^{\beta_2} = 0$$

(2.23) $$-\frac{1}{\delta} + \beta_1(B_1 - B_3)\underline{R}^{\beta_1 - 1} + \beta_2(B_2 - B_4)\underline{R}^{\beta_2 - 1} = 0.$$

Additionally, from the value matching and smooth-pasting conditions, $V(R_L) = -E$ and $V'(R_L) = 0$ for the exit threshold from equation (2.20) and $V(R_H) = I$ and $V'(R_H) = 0$ for the entry threshold from equation (2.21), we have four more equations to solve.

(2.24) $$\frac{\underline{R}}{r} - \frac{C_\Phi}{r} + B_1 R_L^{\beta_1} + B_2 R_L^{\beta_2} = -E$$

(2.25) $$\beta_1 B_1 R_L^{\beta_1 - 1} + \beta_2 B_2 R_L^{\beta_2 - 1} = 0$$

(2.26) $$\frac{R_H}{\delta} - \frac{C_\Phi}{r} + B_3 R_H^{\beta_1} + B_4 R_H^{\beta_2} = I$$

(2.27) $$\frac{1}{\delta} + \beta_1 B_3 R_H^{\beta_1 - 1} + \beta_2 B_4 R_H^{\beta_2 - 1} = 0 .$$

Now we have six simultaneous equations from (2.22) to (2.27) and six unknowns that include four constants, B_1, B_2, B_3, and B_4, and two thresholds, R_H and R_L. These equations also are highly non-linear in the thresholds, R_H and R_L, thus analytical solution cannot be obtained and thus numerical solution is required.

2.4. Data

Table 2.1 summarizes data on California table grapes used in this study (California Agricultural Statistics Service). The price and yield series are statewide from 1987 to 2002. In the next section, we provide data with and without revenue insurance.

2.4.1. Data without Revenue Insurance

Yield and price volatility rates and drift rates are estimated from the logarithm of data because the real option approach in this study assumes the geometric Brownian motion of the stochastic process, where the volatility rate is the rate for variability of revenue flow and the drift rate is the rate for trend of revenue flow. The yield and price series show positive drift rates (trends) of 0.003 and 0.033, respectively, and the yield and price volatility rates are 0.142 and 0.202, respectively. The correlation between the yield and price is –0.58. Given the drift rates and volatility rates in yield and price, those of revenue are 0.019 and 0.167 that are calculated by considering correlation. Appendix A shows the mathematical procedure how to get those parameters in details.

The economic life of a table grape vineyard is twenty-five years and grape harvesting begins in the fourth year (University of California-Cooperative Extension). Grape farming is an ongoing business, and we assume that the grape vineyard is replaced at the end of twenty-five years with a similar vineyard (Price and Wetzstein). Thus we assume an infinite horizon model. The investment cost includes the initial investment cost and three years of operating cost for vineyard establishment. Initial investment costs with land, irrigation system, buildings, tools, fuel tanks and pump, vineyard establishment, and equipment are $11,921 per acre and the first three years of operating costs with planting costs, cultural costs, harvest costs, and cash overhead costs are $4,951 per acre, thus making the total investment cost $16,872 per acre (University of California-Cooperative Extension). In our infinity model, we just assume that the initial investment cost and the three years' operating costs take place at a time. And the revenue flow is assumed constant from the beginning of the business. The operating costs with cultural costs, harvest costs, post-harvest costs, and cash overhead costs are $5,676 per acre, per year.

The risk free rate and risk-adjusted rate are assumed as 0.057 and 0.07, respectively, where the risk free rate is the average rate obtained from 3-year Treasury constant maturity rate from 1997 to 2000 (Financial Forecast Center) to match with the 1998 budget data used in this study. Both rates are comparable to 0.08 and 0.06 from Price and Wetzstein. Given the risk-adjusted rate, the risk and growth adjusted discount

Table 2.1. Parameters Used for Table Grape Farming with and without Revenue Insurance

Parameters	Insurances or Stochastic Variables	Parameter Values
Investment Cost ($/acre)		16,872
Variable Cost ($/acre)	No Insurance	5,676
	60% Coverage Insurance	5,771
	75% Coverage Insurance	5,898
Expected Revenue ($/acre)		7,000
Guaranteed Revenue ($/acre)	60% Coverage Insurance	4,200
	75% Coverage Insurance	5,250
Insurance Premium Rate (%)[a]	60% Coverage Insurance	6.3
	75% Coverage Insurance	9.4
Producer Premium Rate (%)[a]	60% Coverage Insurance	36.0
	75% Coverage Insurance	45.0
Drift Rate	Yield	0.003
	Price	0.033
	Revenue	0.019
Volatility Rate	Yield	0.142
	Price	0.202
	Revenue	0.167
Correlation between Price and Yield		-0.58
Positive Beta	No Insurance	2.065
	60% Coverage Insurance	2.000
	75% Coverage Insurance	1.984
Negative Beta	No Insurance	-2.422
	60% Coverage Insurance	-2.357
	75% Coverage Insurance	-2.341
Risk Adjusted Rate	No Insurance	0.070
	60% Coverage Insurance	0.066
	75% Coverage Insurance	0.065
Risk Free Rate		0.057
Risk Premium Rate	No Insurance	0.013
	60% Coverage Insurance	0.009
	75% Coverage Insurance	0.008
Risk and Growth Adjusted Discount Rate	No Insurance	0.051
	60% Coverage Insurance	0.047
	75% Coverage Insurance	0.046

[a] Includes the insurance premium subsidy.

rate defined as the difference between the risk-adjusted rate 0.07 and the drift rate of revenue 0.019, is 0.051. Given parameters obtained above, the positive root of the fundamental quadratic equation β_1 is 2.065 and the negative root of the fundamental quadratic equation β_2 is –2.422, respectively.

2.4.2. Data with Revenue Insurance

Revenue insurance provides a revenue coverage level ranging from 50% to 85% by 5% increments of expected revenue, and a producer premium rate (subsidized) ranging from 33% to 62% of the expected indemnity, respectively (table 2.1). For each coverage level, a price election factor of either 95% or 100% is available. The 60% and 75% coverage levels of approved revenue with price election factor of 100% are chosen for the study because 75% coverage level is most common among whole revenue coverage levels and 60% coverage level is most common among low revenue coverage levels across all crops with revenue insurance in 2004 crop year in California (USDA-RMA 2004a), resulting in the producer premium rate of 36% and 45%, respectively (table 2.1). Thompson seedless grapes in San Joaquin County California in 2002 is used to calculate the producer premium. The expected revenue is \$7,000, thus the guaranteed revenues with coverage levels of 60% and 75% are \$4,200 and \$5,250, respectively (University of California-Cooperative Extension). The base premium rates are assumed 6.3% for 60% coverage level and 9.4% for 75% coverage level based on grower yield certification (GYC) insurance, a yield insurance mainly applied to some perennial crops, resulting in the premium of \$95 and \$222, respectively (USDA-RMA 2004b).

Operating costs after the insurance premiums are \$5,771 for 60% coverage level and \$5,898 for 75% coverage level. The risk-adjusted rate is adjusted to consider the change in the risk premium rate because revenue insurance reduces downside risk. The risk premium rate with 60% insurance coverage level is reduced by 30%. The effect of different level of risk premium rate can be observed by doing sensitivity analysis. The new risk premium rate and risk adjusted-rate with 60% insurance coverage level are 0.009 and 0.066, respectively. The risk premium rate with 75% insurance coverage level is reduced by 37.5% that results in the new risk premium rate 0.008 and risk-adjusted rate 0.065. The new the risk and growth adjusted discount rates with 60% insurance coverage level and 75% coverage level are 0.047 and 0.046, respectively. The changes in risk-adjusted rate produce new roots of the quadratic equation, β_1 and β_2, where the positive roots with 60% coverage level and 75% coverage level are 2.000 and 1.984, respectively, and the negative roots with 60% coverage level and 75% coverage level are –2.357 and –2.341, respectively.

2.5. Results

In what follows, the entry and exit thresholds with a real option approach are provided for the base case. Also, the results using sensitivity analysis are presented. Then the effects of revenue insurance on the entry and exit thresholds are provided.

2.5.1. The Entry and Exit Thresholds with Real Options Approach

The entry and exit thresholds, market revenues, derived from a standard NPV, based on the Marshallian long run average cost and average variable cost, are \$5,939/acre and \$5,079/acre, respectively (table 2.2). The former is the entry threshold that allows the inactive farmer to enter the grape farming as long as the market revenue is greater than or equal to that number. On the other hand, the latter is the exit threshold that allows the active farmer to gets out of the farming when the market revenue reaches that level. Given the parameters, the simultaneous equations from equation (2.16) to equation (2.19) produce the entry and exit thresholds with the real option, where the entry threshold is \$10,790/acre and the exit threshold is \$4,867/acre. The former explains that the inactive farmer enters the farming when the market revenue reaches that level of revenue and the latter explains that the active farmer exits the farming when the market revenue reaches that level of revenue. The entry threshold with real option approach is higher than that of standard NPV by 81.7 percent and the exit threshold with real option is lower than that of standard NPV by 4.2 percent. These results support the literature in finding a significant effect of accounting for uncertainty in the investment decision. The entry threshold of revenue with real option that would stimulate investment is almost double the entry threshold of revenue under standard NPV analysis.

Table 2.2. Entry and Exit Thresholds by NPV and Real Options Approaches

Items	NPV[b]	Real Options[c]	Percentage Change
Entry Threshold ($/acre)[a]	5,939	10,790	81.7
Exit Threshold ($/acre)[a]	5,079	4,867	-4.2

[a] Entry and exit thresholds are the levels of current revenue flows to trigger the entry and the exit for the farming.
[b] Those are calculated from the equation (2.3) and (2.5), respectively.
[c] Those are calculated from the simultaneous equation (2.16) through (2.19).

The sensitivity of the results is considered by changing the value of one parameter while holding all other parameters constant (table 2.3). The magnitude of change for each parameter values was selected to give reasonable results. The sensitivity of the variable cost, investment cost, exit cost, risk premium rate, risk free rate, drift rate, and volatility rate is tested.

The variable cost was increased by $1,000/acre to determine the sensitivity of entry and exit thresholds to the variable cost (Table 2.3). The entry and exit thresholds are increased by $1,520/acre (14.1%) and $950/acre (19.5%), respectively. The increase in variable cost reduces the profit from the farming so that the inactive farmer requires a higher revenue flow to enter the farming and the current farmer exits the farming earlier to reduce the subsequent loss. As expected, a higher variable cost results in less investment in table grape farming and faster exit from the table grape farming. Higher variable costs reduce the inaction gap, defined as the difference between the entry threshold and the exit threshold.

The investment cost was increased by $4,000/acre to determine the sensitivity of entry and exit thresholds to the investment cost (table 2.3). The entry threshold is increased by \$490/acre (4.5%) and the exit threshold is decreased by \$104/acre (2.1%), respectively. This is because a large investment cost entails a large sunk cost so that the inactive farmer needs a large return from the investment and the inactive farmer wants to recover the large sunk cost, if possible, by waiting further. Higher initial investment costs widen the inaction gap, thus inducing less investment and less departure from farming operation.

The exit cost was increased by \$3,000/acre to determine the sensitivity of entry and exit thresholds to the exit cost (table 2.3). The entry threshold is increased by \$110/acre (1.0%) and exit threshold is decreased by \$238/acre (4.9%), respectively. The inactive farmer requires a higher revenue threshold to offset the exit cost and the active farmer needs to wait longer because that decision entails the exit cost. The change in the entry threshold is not sensitive to the change in the exit cost compared with the case of the investment cost because the length of the investment is expected to be long and the discount factor used to discount the exit cost is high. Thus, the increase in the exit cost discourages the investment and disinvestments and thus widens the inaction gap but not very much.

The risk premium was increased by 0.013 to determine the sensitivity of entry and exit thresholds to the risk premium (table 2.3). The entry and exit thresholds are increased by\$1,800/acre (16.7%) and \$1,047/acre (21.5%), respectively. Thus, the increase in the risk premium rate induces less investment by inactive farmers and induces more active producers to exit the table grape farming. This is because the higher discount factor in revenue caused by higher risk premium rate decreases the expected present value of revenue flow while constant discount factor in variable cost does not change the expected present value of cost flow. Thus, a higher revenue threshold is required to compensate for the reduced present value of revenue flow.

The risk free rate was increased by 0.02 to determine the sensitivity of entry and exit thresholds to the risk free rate (table 2.3). The entry and exit thresholds are decreased by $100/acre (0.9%) and $192/acre (3.9%), respectively. This result is opposite to that of the NPV approach that increases both the entry and exit thresholds, where only higher discount rate discourages the investment decision. This difference is caused by the assumption of a competitive market in real options. When the project value is decreased, then many active farmers will leave the farming immediately. However, this leads to the decrease in the output that falls short of market demand, thus increasing market price and revenue. This increases the option to exit for the active farmer and makes him/her stay in farming longer. The inactive farmer also expects higher market price and revenue from the low project value that causes the shortage of output for the market demand. Thus, the inactive farmer has the incentive to invest when the risk free rate increases.

The drift rate of revenue was increased by 0.016 to determine the sensitivity of entry and exit thresholds to the drift rate (table 2.3). The entry and exit thresholds are decreased by $380/acre (3.5%) and $246/acre (5.1%), respectively. Thus, the higher the drift rate, the higher the investment in table grape farming and the slower the exit from table grape farming. When the expectation that grape production revenue will increase goes up, more farmers that are inactive will invest in grape production and active farmers will tend to stay in farming and require lower levels of revenue before exiting the business.

The volatility rate was increased by 0.052 to determine the sensitivity of entry and exit thresholds to the volatility rate (table 2.3). The entry threshold is increased by \$940/acre (8.7%) and the exit threshold is decreased by \$253/acre (5.2%). These results imply that as uncertainty increases, both the inactive farmer and the active farmer must wait longer because the inactive farmer requires more rewards and the option to exit for the active farm is more valuable. It widens the inaction gap, thus inducing less investment and less leaving in table grape farming.

Table 2.3. Entry and Exit Thresholds and Their Sensitivity to Changes in Selected Parameters

Parameters		Entry Threshold ($/acre)[a]			Exit Threshold ($/acre)[a]		
Name	Value	NPV[b]	Real Options[c]	Percentage Change	NPV[b]	Real Options[c]	Percentage Change
Variable Cost ($/acre)	4,676	5,044	9,257	-14.2	4,184	3,932	-19.2
	5,676	5,939	10,790		5,079	4,867	
	6,676	6,834	12,310	14.1	5,973	5,817	19.5
Investment Cost ($/acre)	12,872	5,735	10,270	-4.8	5,079	4,998	2.7
	16,872	5,939	10,790		5,079	4,867	
	20,872	6,143	11,280	4.5	5,079	4,763	-2.1
Exit Cost ($/acre)	-3,000	5,939	10,670	-1.1	5,232	5,127	5.3
	0	5,939	10,790		5,079	4,867	
	3,000	5,939	10,900	1.0	4,926	4,629	-4.9
Risk Premium Rate	0	4,425	8,969	-16.9	3,784	3,839	-21.1
	0.013	5,939	10,790		5,079	4,867	
	0.026	7,453	12,590	16.7	6,373	5,914	21.5
Risk Free Rate	0.032	5,297	11,360	5.3	4,756	5,337	9.7
	0.052	5,939	10,790		5,079	4,867	
	0.072	6,432	10,690	-0.9	5,234	4,675	-3.9
Drift Rate	0.003	7,802	11,220	4.0	6,672	5,106	4.9
	0.019	5,939	10,790		5,079	4,867	
	0.035	4,076	10,410	-3.5	3,485	4,621	-5.1
Volatility Rate	0.114	5,939	9,808	-9.1	5,079	5,161	6.0
	0.167	5,939	10,790		5,079	4,867	
	0.219	5,939	11,730	8.7	5,079	4,614	-5.2

[a] Entry and exit thresholds are the levels of current revenue flows to trigger the entry and the exit for the farming.
[b] Those are calculated from the equation (2.3) and (2.5), respectively.
[c] Those are calculated from the simultaneous equation (2.16) through (2.19).

2.5.2. The Effect of Revenue Insurance on the Entry and Exit Thresholds

The entry and exit thresholds with 60% coverage level with actual (subsidized) insurance premium rate of 6.3% are \$10,360 and \$4,765, respectively (table 2.4). The revenue guarantee of \$4,200 is less than the exit threshold, \$4,765, thus it has no effect on the entry and exit thresholds and all of the effects are from the risk reducing effect through the risk premium change. Revenue insurance with 60% coverage level decreases the entry threshold by 4% and the exit threshold by 2% compared with no insurance, resulting in the encouragement of the investment and current farming operation.

The entry and exit thresholds with 75% coverage level with actual (subsidized) insurance premium of 9.4% are \$10,380 and \$4,097, respectively (table 2.4). The revenue guarantee of \$5,250 is greater than the exit threshold, \$4,077, thus the guarantee affects both the entry and exit thresholds that are also affected by the risk premium change. Revenue insurance with 75% coverage level decreases the entry threshold by 4% and the exit threshold by 16%, resulting in the encouragement of the investment and current farming operation.

Results show that the entry and exit thresholds with revenue insurance are lower than with no revenue insurance (table 2.4). The entry threshold with 75% coverage level is higher than with 60% coverage level but the exit threshold with 75% coverage level is less than with 60% coverage level. The revenue floor that is greater than the exit threshold in 75% coverage level and less than the threshold in 60% coverage level is the main cause of the difference. Thus, the size of the revenue guarantee is important as well as the risk reducing effect of revenue insurance to affect the entry and exit thresholds.

The sensitivity analysis with the change in insurance premium rate shows that the increase of insurance premium rate increases both the entry and exit thresholds, thus discouraging both the investment and current farming operation (table 2.4). At high insurance premium rate of 30%, both the entry and exit thresholds exceed the entry and exit thresholds with no insurance in both coverage levels. Thus, the high insurance premium rate discourages the investment and current farming operation. On the other hand, at low insurance premium rate, both the entry and exit thresholds are lower than no insurance in both coverage levels. Thus, the lower insurance coverage level encourages the investment and current farming operation.

This result implies that an increasing subsidy rate, that decreases the insurance premium rate, results in the encouragement of the investment and current farming operation. On the other hand, given the insurance premium rate, the insurance policy with high revenue guarantee above the exit threshold has a stronger effect on the exit threshold as well as the entry threshold than with low revenue guarantee. This implies that if a policy goal is to induce more farmers to grow a certain crop, the insurance policy with higher coverage level is more effective.

Table 2.4. Entry and Exit Thresholds by Insurance Premium Rate

Item	Insurance Premium Rate (%)	Entry Threshold ($/acre)[a] NPV[b]	Entry Threshold ($/acre)[a] Real Options[c]	Entry Threshold ($/acre)[a] Percent Change	Exit Threshold ($/acre)[a] NPV[b]	Exit Threshold ($/acre)[a] Real Options[c]	Exit Threshold ($/acre)[a] Percent Change
No Insurance		5,939	10,790		5,079	4,867	
Insurance							
60%	0	5,473	10,230	-5.2	4,680	4,668	-4.1
Coverage	6.3	5,552	10,360	-4.0	4,759	4,765	-2.1
Level	20	5,722	10,660	-1.2	4,929	4,963	2.0
	30	5,848	10,870	0.7	5,055	5,097	4.7
75%	0	5,357	10,020	-7.1	4,581	3,486	-28.4
Coverage	9.4	5,536	10,380	-3.8	4,760	4,097	-15.8
Level	20	5,738	10,760	-0.3	4,962	4,610	-5.3
	30	5,929	11,100	2.9	5,153	4,995	2.6

[a] Entry and exit thresholds are the levels of current revenue flows to trigger the entry and the exit for the farming.
[b] Those are calculated from the equation (2.3) and (2.5), respectively.
[c] Those are calculated from the simultaneous equation (2.22) through (2.27).

2.6. Conclusion

This study applies the real options approach to investigate the effect that crop insurance has on agricultural investment. Specifically, we set up the entry and exit model using real options in a competitive market. With this model, we determine the entry and exit thresholds using real option approach of table grape farming in California assuming irreversible investments under uncertainty.

The results show that the entry and exit thresholds for grape production in California using the real option approach are $10,790 and $4,867, respectively. This means that revenues per acre from grape production would need to be at least $10,790/acre before an inactive farmer would invest in grape production. Moreover, grape revenues would need to drop below $4867/acre before an exiting grape producer would leave grape production. Compared with the entry and exit threshold values calculated using NPV, $5,939 and $5,079, respectively, the entry threshold with real option approach is higher and the exit threshold with real option is lower. Analysis that only uses NPV does not adequately model the timing of investment and disinvestment and can provide incorrect investment and disinvestment signals.

The sensitivity of the model parameters was investigated. The magnitude of the entry and exit threshold changes varies according to the parameter selected. For example, when the volatility rate is increased by 0.052, the entry threshold is increased by $940/acre (8.7%) while when the exit cost is increased by $3,000/acre, the entry threshold is only increased by $100/acre (4.5%). Thus, to affect the investment and disinvestment decisions, the selection of the parameter needs to be considered. Also, the appropriate parameter values suitable for each potential region must be chosen when making investment decision in table grapes.

Revenue insurance with actual (subsidized) insurance premium decreases the entry and exit thresholds compared with no revenue insurance. Thus, the revenue insurance encourages new investment and encourages current farming operation to stay in business. Increasing insurance premium rate increases both the entry and exit threshold, thus discouraging new investment and giving more incentive for current farming operation to leave grape production. This implies that a government subsidy that decreases the insurance premium rate, results in the encouragement of new investment and encouragement for current farmers to stay in business. On the other hand, given the insurance premium rate, the insurance policy with a high revenue guarantee above the exit threshold has a stronger effect on the exit threshold as well as the entry threshold than insurance polices with a low revenue guarantee. This implies that if a policy goal is to induce more farmers to produce a certain crop, the insurance policy with higher coverage level is more effective.

These results also can be applied to the regions, such as southern Arizona, northern New Mexico, and Texas that may grow table grapes with some modification of the parameters. Also, this study can be extended to include other risk management programs and other crops for the investment analysis.

CHAPTER III

EFFECTS OF FEDERAL RISK MANAGEMENT PROGRAMS ON OPTIMAL ACREAGE ALLOCATION AND NITROGEN USE IN A TEXAS COTTON-SORGHUM SYSTEM

3.1. Introduction

Federal risk management programs such as federal crop insurance and the Marketing Loan Program (MLP) have effects beyond directly improving farmer welfare. The income and risk changes that result from farmer participation in these and similar programs affect crop acreage allocation (the extensive margin) and the use of inputs on each crop (the intensive margin). The extensive and intensive margin effects are important, since these effects can counteract or enhance the goals of other programs. These effects can induce farmers to increase or decrease acreage of more erosive or chemically intensive crops, or to use more or less chemicals on land already allocated to specific crops. For example, Goodwin and Smith find that about half of the reductions in soil erosion due to the Conservation Reserve Program (CRP) were offset by increases in erosion from farmer responses to income support programs. Similarly, Babcock and Hennessy and Smith and Goodwin find that farmers purchasing crop insurance have incentives to reduce use of fertilizer and other chemicals. However, Horowitz and Lichtenberg find that crop insurance increases the use of agricultural chemicals.

The extensive and intensive margin effects of federal risk management programs continue to be a pertinent issue as the availability and subsidization of federal risk management programs has increased in recent years. The Agricultural Risk Protection Act (ARPA) of 2000 has resulted in increased premium subsidies and an expansion in the types of policies available, the crops covered, and the geographic availability. Total acres covered by crop insurance increased from 182 million in 1998 to 216 million in 2002, with total liability increasing from $28 billion to $37 billion (USDA-RMA 2002c). Among the most popular insurance programs are Actual Production History (APH) yield insurance and Crop Revenue Coverage (CRC) revenue insurance, with liabilities in 2002 of $15 billion and $8 billion respectively (USDA-RMA 2002c). The Farm Security and Rural Investment Act of 2002 continued the Marketing Loan Program (MLP), which provides loan deficiency payments as a form of price insurance that protects farmers from low prices, much as APH protects from low yields. Loan deficiency payments equaled $6 billion for the 2000 crop year (USDA-FSA 2002a).

Many studies have analyzed the effects of crop insurance and other federal programs to quantify their intensive and/or extensive margin effects and interactions among different programs. These studies have been econometric (Goodwin and Smith; Horowitz and Lichtenberg; Smith and Goodwin; Wu), simulation-based (Babcock and Hennessy; Chavas and Holt), or mathematical programming based (Kaylen, Loehman, and Preckel; Turvey 1992a). Most studies examine the intensive margin or the extensive margin effects of crop insurance in isolation. An exception is Wu, who found that in Nebraska, crop insurance increased acreage for chemically intensive crops at the extensive margin and decreased chemical use on crops at the intensive margin, with an overall increase in chemical use. Also, Smith and Goodwin and Goodwin and Smith show the importance of accounting for the endogeneity of farmer behavior when examining the intensive or extensive margins and farmer participation in risk management programs.

Among those using a mathematical programming approach, Kaylen, Loehman, and Preckel examined the effect of crop insurance on production decisions. However, their analysis did not endogenize the choice of insurance coverage level and the price election factor. Turvey developed a mathematical programming model for a Canadian example to examine optimal acreage allocations and farmer welfare with different policies and parameters, but did not endogenize input use.

We develop a mathematical programming model of a representative Texas farmer to determine how federal risk management programs affect optimal farm level acreage allocation to cotton and sorghum (extensive margin) and the optimal use of nitrogen fertilizer on each crop (intensive margin). We endogenize input use and land allocation decisions, as well as the farmer's participation in federal risk management programs for each crop, specifically APH yield insurance, CRC revenue insurance, and the MLP. In addition, we endogenize the farmer's choice of coverage level and the price election factor for APH and CRC. We combine the mathematical programming and simulation-based approaches by using direct expected utility maximizing non-linear programming (Lambert and McCarl). What follows first is a brief review of crop insurance programs and the MLP. Next, we specify the model objective function and constraints, and then explain the data and estimation of model parameters. Finally, we present and discuss our empirical results relative to previously published results.

3.2. Federal Risk Management Programs

A farmer with APH insurance coverage receives an indemnity if the harvested yield is less than the yield guarantee. Farmers choose a yield coverage level ranging from 50% to 75% (up to 85% in some counties) by 5% increments of the approved APH yield and a price election factor ranging from 55% to 100% by 1% increments of the officially announced expected market price. A farmer with CRC insurance receives an indemnity if the guaranteed revenue exceeds calculated revenue. The price for calculating revenue is derived from the daily settlement price of futures contracts for a given period for an appropriate month for the crop. Again, the farmer must choose a coverage level (50% to 85% by 5% increments) and either a 95% or 100% price election. Farmers receive a smaller indemnity with CRC than with APH when the realized market price used to calculate the APH indemnity exceeds the CRC base price or harvest price used to calculate CRC indemnities. Farmers participating in the MLP receive a loan deficiency payment (LDP) when the marketing loan rate exceeds the posted county price or the world market price depending on the crop. A LDP can be utilized when the eligible crop is still owned by the farmer at the time of harvest.

The specified model includes all eight possible combinations of APH crop insurance, CRC revenue insurance, and the MLP. In each case, the participation in insurance programs and/or the MLP is chosen separately for each crop among the available alternatives, so that the insurance policy type, the coverage level, and price election factor can differ for each crop. The eight combinations (and their abbreviations) are: no program, Marketing Loan Program only, APH crop insurance only, APH crop insurance with the Marketing Loan Program (APH+MLP), CRC revenue insurance only, CRC revenue insurance with the Marketing Loan Program (CRC+MLP), both APH crop insurance and CRC revenue insurance available (APH+CRC), and both APH crop insurance and CRC revenue insurance available with the Marketing Loan Program (APH+CRC+MLP).

3.3. Conceptual Framework

The modeled representative farmer earns income by allocating total acreage A and a purchased input x to crops j = 1 to J. The farmer can also purchase crop or revenue insurance and choose to participate in the Marketing Loan Program. Thus, the farmer also chooses the price election factor (PEF_{ij}) and coverage level (CVG_{ij}) for each insurance policy i = 1 to I and crop j. The farmer can purchase only one type of insurance for each crop and if a crop is insured, all planted acres of that crop are insured, all with the same price election and coverage level. However, the farmer can purchase different types of insurance for different crops. These restrictions are in accordance with current federal crop insurance programs.

Per acre income with crop insurance program i and crop j for the most general case when all risk management programs are available is:

$$(3.1) \quad \pi_j = p_j y_j(x_j) - c_j - rx_j + \lambda_j LDP_j + \sum_i \left(I_{ij}(PEF_{ij}, CVG_{ij}) - M_{ij}(PEF_{ij}, CVG_{ij}) \right),$$

where p_j is the random crop price, y_j is the random crop yield as a function of the input level x_j, c_j is the non-random variable cost, and r is the non-random price of the input x.

LDP_j is the random loan deficiency payment and λ_j is an indicator variable for participation in the marketing loan program (λ_j = 1 if the farmer chooses to participate, 0 otherwise). I_{ij} is the random insurance indemnity and M_{ij} is the non-random insurance premium for policy *i*, which both depend on the chosen price election factor (PEF_{ij}) and coverage level (CVG_{ij}). Because only one type of insurance can be purchased for any crop *j*, at most $PEF_{ij} > 0$ and $CVG_{ij} > 0$ for only one policy *i* for each crop *j*. Income per crop is $A_j\pi_j$, where A_j is acreage planted to crop *j*, and total crop income π is the sum of income over all crops: $\pi = \sum_j A_j \pi_j$.

The representative farmer maximizes the expected utility of income, choosing the acreage allocation A_j, input use x_j, and participation in the MLP λ_j for all *j*, the price election factor PEF_{ij} and coverage level CVG_{ij} for all *i* and *j*, and insurance program *i*:

(3.2) $$\max_{A_j, x_j, i, PEF_{ij}, CVG_{ij}, \lambda_j} \int u(\pi) dF(p_1, p_2, ..., p_J, y_1, y_2, ..., y_J),$$

where $u(\cdot)$ is the farmer's utility function ($u' > 0$, $u'' < 0$) and $F(\cdot)$ is the joint distribution function of prices and yields. Constraints include an acreage allocation constraint ($A \geq \sum_j A_j$), as well as technical constraints on the insurance programs (e.g., one policy per crop, and a *PEF* and a *CVG* from available levels). Solving this optimization program gives the optimal acreage allocation and input use for each crop (A_j and x_j for all *j*), as well as the optimal participation in risk management programs (PEF_{ij}, CVG_{ij} for all *i* and *j*, and λ_j for all *j*).

The intensive margin effect of each risk management program for a crop is the difference in the optimal use of the input x_j when the program is available versus when it is not. Similarly, the extensive margin effect is the change in optimal acreage A_j when the program is available versus when it is not. Determining the intensive and extensive margin effects of these federal risk management programs requires finding the solutions to problem (3.2) for the eight possible combinations of program availability. However, once the details of each program are accurately specified, analytical solutions generally become intractable. As a result, we use numerical methods to solve problem (3.2) for a representative farmer and sensitivity analysis to generalize from this specific case.

3.4. Empirical Model

For empirical analysis, we develop data and a model for a case farm in San Patricio County, Texas, near Corpus Christi. Texas accounted for 41% and 33% of total U.S. planted acres of cotton and sorghum respectively in 2002 and San Patricio County accounted for 2.2% and 2.9% of total cotton and sorghum acres planted in Texas in 2002 (USDA-NASS). Followings are the model specifications and data used for the empirical analysis. More detailed mathematical representation is provided in appendix B, where it is represented using Mixed Integer Nonlinear Programming Model.

3.4.1. Utility and Profit

The analysis uses direct expected utility maximizing non-linear programming (DEMP) in combination with a simulation approach (Lambert and McCarl). DEMP uses mathematical programming to find the crop acreage, input use, and risk management program parameters that maximize expected utility as a function of randomly drawn prices and yields. We use DEMP to maximize expected utility directly, as opposed to using quadrature (Kaylen, Loehman, and Preckel), Monte Carlo integration combined with a grid search (Hurley, Mitchell and Rice), or a small set of observations as an empirical distribution (Turvey; Lambert and McCarl).

The empirical analysis here uses a negative-exponential (constant absolute risk aversion) utility function. As a result, wealth effects (including those from premiums) do not affect production decisions, and so all other income is ignored. With negative-exponential utility, the DEMP objective function for problem (3.2) is

$$\sum_k [1-\exp(-R\pi_k)], \tag{3.3}$$

where k indexes each state (Monte Carlo random draw), R is the coefficient of absolute risk aversion, and $\pi_k = \sum_j A_j \pi_{jk}$ is profit in state k. Income from crop j in state k is

$$\pi_{jk} = p_{jk} y_{jk}(x_j) - c_j - rx_j + \lambda_j LDP_{jk} + \sum_i \left(I_{ijk}(PEF_{ij}, CVG_{ij}) - M_{ij}(PEF_{ij}, CVG_{ij}) \right), \tag{3.4}$$

which is the same as equation (3.1) except that each random variable has an index k. Values for R were chosen so the farmer's risk premium was a reasonable percentage of the income standard deviation (Babcock, Choi and Feinerman), which also satisfies the upper bound suggested by McCarl and Bessler.

The APH and CRC insurance indemnities for any state k and crop j are

$$I_{APH,jk} = PEF_{APH,j} P_j^e \max\{CVG_{APH,j} \bar{y}_j - y_{jk}, 0\}, \tag{3.5}$$

$$I_{CRC,jk} = \max\{PEF_{CRC,j} \max\{p_j^b, p_j^h\} CVG_{CRC,j} \bar{y}_j - p_{jk} y_{jk}, 0\}, \tag{3.6}$$

where $\bar{y}_j$ is the average yield used by both APH and CRC, p_j^e is the expected price used to calculate the APH indemnity, and p_j^b and p_j^h are the futures price before planting (base price) and the futures price before harvest (harvest price) used to calculate CRC indemnities. Available APH and CRC coverage levels in San Patricio County range 50% to 85% for cotton and 50% to 75% for sorghum, both by 5% increments. The available APH price election factor ranges from 55% to 100% by 1% increments, but with CRC the price election factor is either 95% or 100% (USDA-RMA 2002b).

The non-random insurance premium for each crop depends on the chosen coverage level and the price election factor. The analysis uses the actual (subsidized) premium the representative farmer would pay (USDA-RMA 2002b). The expected net indemnity is the expected difference between the indemnity and the premium. Since the premium is nonrandom, the expected net indemnity is the expected indemnity minus the actual premium. Because the integration required to calculate the expected indemnity is analytically intractable for the model, Monte Carlo integration is used to numerically estimate the expected indemnity (Greene, pp. 181-183). Thus, the expected indemnity is the average indemnity for each policy over all states *k*: $\sum_k I_{ijk}(PEF_{ij}, CVG_{ij})$.

The per acre loan deficiency payment (*LDP*) for any crop *j* in state *k* is

(3.7) $$LDP_{jk} = \max\{MLR_j - p_{jk}, 0\} y_{jk},$$

where MLR_j is the marketing loan rate set for crop *j*. The marketing loan rate guarantees a minimum price and so this program serves as price insurance without a premium. The marketing loan rate for this region in 2002 was \$0.52/lb for cotton and \$2.17/bu for sorghum (USDA-FSA 2002b).

3.4.2. Prices, Yields, and Correlations

The four-year county average yield and the four-year state average price from 1997 to 2000 are used for the mean price and yield for each crop (USDA-NASS). Mean yields are 677.0 lb/ac for cotton and 70.0 bu/ac for sorghum. Because field level yield variability is greater than the variability of county average yield, the empirical analysis uses a yield standard deviation of 256.3 lb/ac for cotton and 19.96 bu/ac for sorghum, which are 1.5 times greater than for the county data. These levels were chosen to be comparable to results from crop insurance studies (Coble, Zuniga, and Heifner).

For cotton, the mean price is \$0.51/lb, with a standard deviation of \$0.08/lb. For sorghum, the mean price is \$1.98/bu, with a standard deviation of \$0.41/bu. APH price guarantees in 2002 were \$0.50/lb for cotton and \$1.85/bu for sorghum. Base prices (futures price before planting) in 2002 for CRC were \$0.42/lb for cotton and \$2.18/bu for sorghum (USDA-RMA 2002a). The base price was used for the CRC harvest price for both crops, since it is a commonly used estimate of the harvest price at planting time. The price of nitrogen (\$0.20/lb), nitrogen application rates of 75 lbs/ac for cotton and 60 lbs/ac for sorghum, and the variable costs of production (\$316.40/ac for cotton and \$116.70/ac for sorghum) are from crop budgets (Texas Cooperative Extension).

USDA-NASS county average yield and state price data from 1982-2000 were used to estimate the price-yield variance-covariance matrix. The respective correlation coefficients between own price and yield are –0.45 for cotton and –0.54 for sorghum.

However, since county data normally have higher correlation between price and yield than farm level data, we reduced the correlations by one-third and used an own price and yield correlation coefficient of –0.30 for cotton and –0.36 for sorghum, which are comparable to values reported by Coble, Heifner and Zuniga. The correlation coefficient between cotton and sorghum prices is 0.43 and between cotton and sorghum yields is 0.56. Lastly, the correlation coefficient between cotton yield and sorghum price is -0.30 and between sorghum yield and cotton price is -0.26.

Cotton has a larger yield coefficient of variation, 37.9% versus 28.5% for sorghum, and sorghum has a larger price coefficient of variation, 20.9% versus 16.4% for cotton. These coefficients of variation for price and yield are comparable to those reported by Coble, Zuniga, and Heifner using crop insurance data. They report cotton yield coefficients of variation that range 32–61% and 22–25% for the cotton price. Following crop budgets, cotton seed proportionally increases cotton revenue by 12% (Texas Cooperative Extension). When no risk management programs are used, cotton has the larger mean and standard deviation for income, \$60.00/ac and \$142.90/ac respectively, versus \$29.30/ac and \$40.60 respectively for sorghum, and so is generally considered riskier than sorghum.

3.5. Crop Production Function

Random crop yield follows a beta distribution with mean and variance that depend on applied nitrogen fertilizer. The beta distribution is commonly used for crop insurance analyses (Goodwin and Ker review several examples). The beta density function for yield y is

(3.8) $$b(y) = \frac{(y-A)^{\nu-1}(B-y)^{\gamma-1}\Gamma(\nu+\gamma)}{(B-A)^{\nu+\gamma+1}\Gamma(\nu)\Gamma(\gamma)},$$

where A is the minimum, B is the maximum, ν and γ are shape parameters, and $\Gamma(\cdot)$ is the gamma function (Evans, Hastings, and Peacock).

As developed by Nelson and Preckel, the conditional beta density for crop yields requires the specification of the parameters ν and γ as functions of inputs such as fertilizer and either the estimation or imposition of values for the minimum and maximum. Nelson and Preckel use Cobb-Douglas functions for the parameters ν and γ, but for the analysis here, the method described by Mitchell, Gray, and Steffey is used for the conditional beta density. First the mean and variance of crop yield as functions of the fertilizer rate are specified, and then the implied functions for the parameters ν and γ are derived.

For a crop yield following a beta density, the mean and variance are

(3.9) $$\mu_y = (B-A)\nu/(\nu+\gamma)$$

(3.10) $$\sigma_y^2 = (B-A)^2\nu\gamma/[(\nu+\gamma)^2(\nu+\gamma+1)].$$

Solving these equations for ν and γ gives:

(3.11) $$\nu = \frac{(\mu_y-A)^2(B-\mu_y)-\sigma_y^2(\mu_y-A)}{\sigma_y^2(B-A)},$$

(3.12) $$\gamma = \frac{(\mu_y-A)(B-\mu_y)^2-\sigma_y^2(B-\mu_y)}{\sigma_y^2(B-A)}.$$

Using a conditional beta density for crop yield requires specifying or estimating the mean μ_y and the variance σ_y^2 as functions of the nitrogen fertilizer rate, and then substituting these functions into equations (3.11) and (3.12) to obtain values for ν and γ.

With this conditional distribution for yield, the farmer directly chooses the mean and the variance of the yield distribution when choosing the nitrogen fertilizer rate. With the Nelson and Preckel conditional yield distribution, the farmer's choice of the nitrogen fertilizer rate also determines the mean and variance of the yield distribution, but the choice is indirect through the approximating functions used for the parameters ν and γ.

For the analysis here, the functions for the dependence of the mean and variance of cotton yield on the nitrogen application rate were estimated using unpublished data from experiments conducted in 1999, 2001, and 2002 in Wharton County, Texas, near San Patricio County (McFarland). Nitrogen fertilizer rates were experimentally varied from 0 to 150 lbs/acre and cotton lint yields measured for each plot for a total of 48 observations. Polynomial terms in the fertilizer rate were added successively for both the mean and variance until coefficient estimates were insignificant. The final result was a quadratic equation for both the yield mean and the variance, with all estimated coefficients significant at the 1% level.

The estimated coefficients were calibrated so that the optimal risk neutral nitrogen application rate matched that reported in crop budgets (Texas Cooperative Extension) and the associated mean and variance of yield matched the observed county data. For the mean, this calibration primarily required changing the intercept term, and then slightly changing the quadratic term to increase the curvature. For the variance, only the intercept term was changed. The final equations for the mean (μ_c) and variance (σ_c^2) of cotton yield as a function of the nitrogen rate (x_c) are

(3.13) $$\mu_c = 63.5 + 16.25x_c - 0.108x_c^2,$$

(3.14) $$\sigma_c^2 = 12{,}500 + 453.6x_c + 2.800x_c^2.$$

Since experimental data were not available for sorghum, published estimates from Preckel, Loehman, and Kaylen for sorghum were calibrated in a similar manner so that again the optimal risk neutral nitrogen application rate matched that reported in crop budgets and the mean and variance of yield matched observed county data. The final equations for the mean (μ_g) and variance (σ_g^2) of sorghum yield as a function of the nitrogen rate (x_g) are

(3.15) $$\mu_g = 16.5 + 1.68x_g - 0.013x_g^2,$$

(3.16) $$\sigma_g^2 = 40.0 - 5.40x_g + 0.400x_g^2 - 0.004x_g^3.$$

3.5.1. Model Implementation

The model was solved using the nonlinear program (NLP) solver or the simple branch and bound (SBB) solver in GAMS (General Algebraic Modeling System). The optimal fertilizer rate was determined as an integer variable by specifying fertilizer rates in 0.1 lb/ac increments centered at the county mean for each crop. Output was examined to ensure that the fertilizer rate on the boundary was never optimal.

To draw yields from the beta distribution with the mean and variance implied by the fertilizer rate, GAMS was linked to Excel using the GDXXRW program distributed with GAMS. GAMS sends the required means and variances to Excel, then Excel generates appropriately correlated yields and prices using the method of Richardson and Condra. This method begins with appropriately correlated uniform random variables, the inverse beta cumulative distribution function in Excel is used to obtain yields with a beta distribution and transformed normal random variables are used to obtain prices with a lognormal distribution. Experimentation indicated that 5,000 random draws were needed for model results to stabilize.

3.6. Empirical Results and Discussion

Tables 3.1 and 3.2 report the optimal fertilizer use, acreage allocation, and insurance coverage level when the current subsidized insurance is available. Table 3.1 reports results without the MLP and table 3.2 reports results with the MLP to indicate the effect of the MLP. Results for the price election factor *PEF* are not reported since the optimum in all cases was the maximum available (100%).

Table 3.1 shows that APH and CRC crop insurance both generally have a small positive effect on the optimal nitrogen fertilizer rate for both cotton and sorghum. Depending on the crop and the farmer's level of risk aversion, the optimal rate increases about 1-2 lbs/ac, or 1-3%. Crop insurance has a large effect on the optimal acreage allocation. When APH is available, optimal cotton acreage more than doubles, accompanied by an appropriate decrease in sorghum acres. When only CRC is available, the acreage effect is qualitatively the same, but much smaller—optimal cotton acreage

Table 3.1. Optimal Farmer Choices without the Marketing Loan Program (MLP)

	Moderately Risk Averse[a]		Highly Risk Averse[a]	
	Cotton	Sorghum	Cotton	Sorghum
Government Program	-------- Optimal Nitrogen Fertilizer Rate (lbs/acre) -------			
No Program	70.7	57.8	70.4	56.8
APH only[b]	72.4	58.8	72.1	58.1
CRC only[c]	72.1	58.6	72.0	57.7
APH and CRC[d]	72.5	58.6	72.3	57.7
Government Program	------------- Optimal Acreage Allocation (acre) ------------			
No Program	561	1,139	295	1,281
APH only[b]	1,164	536	678	1,023
CRC only[c]	652	1,049	362	1,338
APH and CRC[d]	1,134	566	651	1,049
Government Program	--------- Optimal Insurance Coverage Level (%) ---------			
No Program	--	--	--	--
APH only[b]	70	70	70	70
CRC only[c]	60	70	60	75
APH and CRC[d]	70	70	70	75

[a] Coefficients of absolute risk aversion are 4.0 x 10^{-6} and 7.0 x 10^{-6} for moderately and highly risk averse, respectively.
[b] APH means the Actual Production History yield insurance.
[c] CRC means the Crop Revenue Coverage revenue insurance.
[d] Optimal choice when both insurance programs are available is APH for cotton and CRC for sorghum.

Table 3.2. Optimal Farmer Choices with the Marketing Loan Program (MLP)

	Moderately Risk Averse[a]		Highly Risk Averse[a]	
	Cotton	Sorghum	Cotton	Sorghum
Government Program	------- Optimal Nitrogen Fertilizer Rate (lbs/acre) -------			
MLP only[b]	70.5	58.2	70.0	56.7
APH and MLP[c]	71.8	59.2	71.3	58.3
CRC and MLP[d]	71.8	59.1	71.9	58.3
APH+CRC+MLP[e]	71.8	59.1	71.5	58.2
Government Program	---------- Optimal Acreage Allocation (acre) ----------			
MLP only[b]	569	1,131	265	1,435
APH and MLP[c]	1,255	445	697	1,003
CRC and MLP[d]	673	1,027	367	1,333
APH+CRC+MLP[e]	1,230	470	678	1,022
Government Program	------ Optimal Insurance Coverage Level (%) ------			
MLP only[b]	--	--	--	--
APH and MLP[c]	70	70	70	75
CRC and MLP[d]	60	70	70	75
APH+CRC+MLP[e]	70	70	70	75

[a] Coefficients of absolute risk aversion are 4.0×10^{-6} and 7.0×10^{-6} for moderately and highly risk averse, respectively.
[b] MLP means the Marketing Loan Program.
[c] APH means the Actual Production History yield insurance.
[d] CRC means the Crop Revenue Coverage revenue insurance.
[e] Optimal choice when both insurance programs are available is APH for cotton and CRC for sorghum.

increases 16-23% depending on the level of risk aversion. When both APH and CRC available, the optimal purchase is APH for cotton and CRC for sorghum, with a 70% coverage level for cotton APH and a 70% or 75% coverage level of CRC sorghum, depending on the farmer's risk aversion. When only CRC is available, it is optimal to purchase cotton CRC, but the optimal coverage level is relatively smaller than for APH.

Comparing tables 3.1 and 3.2 indicates the effect of the Marketing Loan Program on optimal nitrogen fertilizer rates and acreage allocations. The MLP decreases optimal nitrogen rates for cotton and increases optimal nitrogen rates for sorghum, but the effect is quite small, generally less than a 1% change. The MLP increases cotton acres 1-9% depending on the program and farmer risk aversion, with an accompanying decrease in sorghum acres. The only exception is the difference between the no program and MLP only cases, for which cotton acres decrease about 10%. This case is different because for the no program case, it is optimal to plant only a total of 1575 acres for both crops, less than the 1700 available. Once the MLP is available, it becomes optimal to plant 1700 acres, with a net decrease in cotton acres. Lastly, the MLP has no effect on insurance participation, except that the optimal coverage level for sorghum when only APH is available increases from 70% to 75%.

The results in tables 3.1 and 3.2 also show that as farmer risk aversion increases, the optimal nitrogen rate decreases for all alternatives regardless of the crop because nitrogen is used as a risk increasing input in this study. In addition, optimal cotton acreage decreases and optimal sorghum acreage increases, because cotton is the riskier crop. For the range of risk aversion levels explored, the optimal insurance coverage level did not change for cotton, but increased for sorghum. To understand this result, table 3.3 reports the expected net indemnity (expected indemnity minus the premium) for each case.

Table 3.3. Expected Net Indemnity ($/acre) for Each Insurance Program[a]

Crop-Program	Coverage Level (%)						
	55	60	65	70	75	80	85
Cotton APH[b]	3.04	4.47	4.91	5.77	4.22	-0.90	-11.85
Sorghum APH[b]	-0.76	-0.61	-0.83	-0.91	-1.82	--	--
Cotton CRC[c]	-1.77	-1.77	-3.19	-4.45	-8.67	-16.98	-31.58
Sorghum CRC[c]	-1.02	-0.74	-0.91	-0.77	-1.71	--	--

[a] Using a nitrogen application rate of 70 lbs/acre for cotton and 60 lbs/acre for sorghum.
[b] APH means the Actual Production History yield insurance.
[c] CRC means the Crop Revenue Coverage revenue insurance.

Table 3.3 indicates that for cotton APH, the 70% coverage level has the largest expected net indemnity by a substantial amount and so is optimal over a wide range of risk aversion levels. For sorghum APH, the expected net indemnity is always negative and fairly similar in value for many coverage levels. Though the 60% coverage level has the highest expected net indemnity, the 70% coverage level is optimal over the range of risk aversion levels explored because the added risk benefit it provides exceeds the small decrease in the expected net indemnity. For CRC for both crops, the optimal coverage level is higher than the coverage with the largest expected net indemnity because again the added risk benefit exceeds the slight decrease in the net indemnity.

The results in table 3.3 also explain the optimal choice of APH for cotton and CRC for sorghum when both insurance programs are available. For cotton, APH has a positive expected net indemnity up to the 75% coverage level, while expected net indemnities are negative for CRC, indicating why APH is preferred to CRC. Sorghum has negative expected net indemnities for all coverage levels for both programs, but expected net indemnities are largest for CRC, indicating why CRC is preferred to APH. These results are consistent with the actual farmer behavior in San Patricio County. In 2002, 98.6% of farmers in the county buying crop insurance for cotton bought APH and 62.3% of those buying crop insurance for sorghum bought CRC (USDA-RMA 2002d).

The magnitude and direction of intensive and extensive margin effects vary according to the crops and regions, largely depending on the effects of inputs such as fertilizer and specific crops on the variability of income. In our study, the small positive effect of crop insurance on the intensive margin occurs for both crops and both APH and CRC. This result is generally consistent with the econometric analysis of Horowitz and Lichtenberg, who report that crop insurance increases fertilizer use for corn in the Midwest. However, Smith and Goodwin in their econometric study of wheat farmers in Kansas find that crop insurance decreases fertilizer use, as do Babcock and Hennessy in their simulation-based analysis of corn in Iowa.

The difference between our findings and those of Babcock and Hennessy is largely due to the effect of nitrogen fertilizer on the variance of crop yield. In the range of the fertilizer rates that Babcock and Hennessy report, nitrogen is a variance decreasing input for corn, while for the rates in tables 3.1 and 3.2, nitrogen is a variance increasing input for cotton and sorghum in our study. Regardless of the yield distribution, when crop insurance is available, farmers find it optimal to bear more risk and so choose fertilizer rates accordingly. For the Babcock and Hennessy conditional yield distribution, this implies a reduction in the fertilizer rate. For our conditional yield distributions, this implies an increase in the fertilizer rate. However, focusing only on the variance effect of fertilizer on crop yields is a simplification of our analysis, since the farmer also simultaneously chooses the crop acreage allocation and insurance coverage levels.

Our simulation-based results are generally consistent with the results of Wu's econometric analysis of Nebraska corn-soybean farmers, since he finds that crop insurance increases fertilizer use and acreage of the riskier crop (corn). Similarly, Chavas and Holt find that price supports (comparable to the Marketing Loan Program) create moderate acreage increases in the supported crop (corn) and that cross-commodity risk reductions are important to consider, much as we find. Turvey's method of analysis is similar to our method, but only focuses on acreage effects. However, he finds that the Canadian crop insurance program increases optimal acreage devoted to riskier crops, just as we find for the U.S. insurance program.

Table 3.4 reports farmer certainty equivalents when implementing the optimal choices reported in tables 3.1 and 3.2. From the farmer's perspective, having all three federal risk management programs available is preferred—APH+CRC+MLP has the highest certainty equivalent regardless of the risk aversion level. Relative to the no program case, these programs increase the farmer's certainty equivalent 170-240% depending on the level of risk aversion. About 2/3 of this increase is due to MLP and about 1/3 is due to crop insurance. Also, the optimal farmer response for all scenarios examined is to change fertilizer use and crop acreage to increase the standard deviation of income (along with the mean). These responses indicate that these risk management programs encourage farmers to bear more risk.

Fixing the nitrogen fertilizer rate and endogenizing the acreage allocation, or fixing the acreage allocation and only endogenizing the nitrogen fertilizer rate, the bias that results from analyzing the intensive and extensive margin effects in isolation from one another, as opposed to simultaneously, can be determined. Results are not reported, but the bias is rather small for this empirical example. In general, the magnitude of both the intensive and extensive margin effects is larger when analyzed in isolation, as opposed to simultaneously. This result is not surprising, since the farmer uses two instruments (both nitrogen fertilizer and crop acreage) to respond to changes in risk for the simultaneous case, but only one when the effects are examined in isolation. However, the magnitude of the resulting bias is not substantial for this empirical example—the optimal nitrogen fertilizer rate is 1-2 lbs/ac different and the crop acreage allocation is generally less than 5% different.

Table 3.4. Certainty Equivalent and Mean and Standard Deviation of Profit ($1,000's) with Optimal Farmer Choices

	Moderately Risk Averse[a]			Highly Risk Averse[a]		
Govt. Program	Certainty Equivalent	Mean Profit	Standard Deviation	Certainty Equivalent	Mean Profit	Standard Deviation
No Program	32.7	54.7	104.9	20.6	41.4	77.3
APH only[b]	48.4	85.4	144.1	32.5	62.2	98.2
CRC only[c]	36.4	56.5	102.9	26.8	43.6	72.8
APH and CRC[d]	48.9	84.1	140.4	34.2	60.2	92.2
MLP only[e]	68.1	95.6	115.5	52.6	80.6	87.4
APH+MLP	88.0	135.6	162.0	67.8	103.8	106.9
CRC+MLP	72.8	98.8	115.2	60.4	81.8	80.3
APH+CRC+MLP[d]	88.4	134.3	158.9	69.2	102.8	103.1

[a] Coefficients of absolute risk aversion are 4.0×10^{-6} and 7.0×10^{-6} for moderately and highly risk averse, respectively.
[b] APH means the Actual Production History yield insurance.
[c] CRC means the Crop Revenue Coverage revenue insurance.
[d] Optimal choice when both insurance programs are available is APH for cotton and CRC for sorghum.
[e] MLP means the Marketing Loan Program.

3.7. Conclusion

To examine the effects of federal risk management programs on optimal nitrogen fertilizer use and land allocation to crops, this study developed a mathematical programming model of a representative cotton-sorghum farm in San Patricio County, Texas. The model endogenizes nitrogen fertilizer rates and land allocation, as well as the insurance coverage levels, price election factors, and participation in insurance programs and the Marketing Loan Program (MLP). This study uses direct expected utility maximizing non-linear programming in combination with a simulation approach. We assume a conditional beta distribution for crop yields, a lognormal distribution for crop prices, and impose historical correlations on yields and prices.

Results show that with current crop insurance programs, the optimal nitrogen fertilizer rate slightly increases (1-3%) and the optimal cotton acreage substantially increases (16-129%). The MLP only slightly changes optimal nitrogen fertilizer rates for both cotton and sorghum (less than a 1% change), but increases optimal cotton acreage an additional 1-9%. These results depend crucially on the variance increasing effect of nitrogen fertilizer and of cotton in our model. Other intensive and extensive margin responses would be optimal for other specifications for the stochastic revenue functions.

Optimal participation in the available federal risk management programs includes using the MLP for both cotton and sorghum and purchasing APH insurance for cotton and CRC for sorghum. Optimal coverage levels are 70% for cotton APH and 70% or 75% corn sorghum CRC. The optimal price election factor is always the maximum available (100%). The farmer's expected net indemnity from these insurance programs largely explains the optimal insurance participation choices and coverage levels. Together, all three federal risk management programs increase farmer certainty equivalents 170-240%, of which about 1/3 is from crop insurance and 2/3 from the MLP.

In general, the modeled farm responds optimally to these federal risk management programs by changing input use and crop acreage allocations to bear more risk. The intensive and extensive margin effects of these and other federal programs have associated environmental effects that are being increasingly scrutinized since they can enhance or counteract the goals of other programs (Goodwin and Smith; Skees). Assuming the environmental effects of crop insurance and the MLP are positively related to nitrogen fertilizer use, both types of risk management programs imply negative environmental effects. Crop insurance increases optimal nitrogen use through both the intensive and extensive margin effects. The MLP increases optimal nitrogen use through the extensive margin effect, which dominates the slight decrease in optimal nitrogen use it creates for cotton. The extensive margin effect of both types of programs is the dominant effect in our empirical analysis and of sufficient magnitude that it should probably be included in any comprehensive analysis of the environmental effects of federal policies.

CHAPTER IV

RISK SHARING AND INCENTIVES WITH CROP INSURANCE AND EXTERNAL EQUITY FINANCING

4.1. Introduction

Farmers have several risk management alternatives available, such as crop insurance, futures and options, and government programs. Among these subsidized crop insurance is widely adopted by farmers. For instance, the Agricultural Risk Protection Act (ARPA) in 2000 greatly expanded the availability of crop insurance to farmers. Not only have premium subsidies increased, but also the types of policies available and the crops that can be insured. Thus the effect of crop insurance on risk management behaviors continues to be a pertinent issue. By purchasing crop insurance, a farmer may change the risks he faces and this may affect production decisions depending on his risk attitudes and the fairness of insurance (Ahsan, Ali, and Kurian). The most studied production decisions include land allocation and variable input use, especially nutrients and pesticides (Babcock and Hennessey; Horowitz and Lichtenberg; Smith and Goodwin). To maintain focus on the effect of crop insurance on risk management behaviors, this paper only considers land allocation as a production decision.

Crop insurance also affects the external equity investor who provides equity capital to the farmer, where external equity is procured from non-farmers or other sources that do not include owner equity such as retained earnings, gifts, off-farm income, and inheritance. Arrangements such as land leases, partnerships and corporations, and vertical integration have been the traditional channels through which farmers have obtained external equity. Because crop insurance affect the external equity investor, the investor may require crop insurance or specify a certain level of coverage in the contract (Leatham, McCarl, and Richardson). The investor also may want to adjust the contract design to reflect the farmer's production decision and risk changes induced by the availability of crop insurance. The contract should include the expected utility maximizing behavior of both the farmer and the investor under crop insurance. Also, the contract should specify the risk sharing and economic incentives to induce the farmer's best effort under crop insurance. To better understand these relationships, we develop a principal-agent model of the contract between the external equity investor and the farmer when the farmer can purchase crop insurance.

Many principal-agent models of sharecropping and crop insurance have been developed, primarily focused on the design of optimal contracts to prevent adverse selection and moral hazard (e.g. Canjels and Volz; Chambers; Nelson and Loehman; Skees and Reed; Ahsan, Ali, and Kurian; Raviv; Allen and Lueck). Principal-agent models have also been used to analyze agricultural financing contracts (e.g., Wang, Leatham, and Chaisantikulawat; Santos). Among many researchers, Wang, Leatham, and Chaisantikulawat studied risk sharing and incentives with external equity financing. However, they did not consider the effects of risk management tools such as crop insurance on financing contracts. Unfortunately, no analysis of the effects of the government programs on contracts in agricultural production exists (Allen and Lueck). In this paper, external equity contracts between investors and farmers are modeled to determine how the contracts should change when crop insurance is used in order to maintain equitable contracts.

This study analytically examines the optimal contract between the investor and the farmer when crop insurance and external equity are available to the farmer. This contract incorporates the production decision of farmers with crop insurance. For the contract between the investor and the farmer, we assume a risk averse investor and a risk averse farmer with fair and unfair crop insurance, and use the case of no crop insurance for comparison.

4.2. Principal-Agent Model of an External Equity Investor and a Farmer

We develop a principal-agent model of the contractual relationship between an external equity investor and a farmer. This model extends the work of Wang, Leatham, and Chaisantikulawat by assuming a risk averse investor and allowing the farmer to incorporate production decision and purchase crop insurance.

An investor and a farmer share an investment cost for total acres M using external equity and owner equity. The farmer's share is δ and the investor provides the remainder $(1 - \delta)$, where $0 < \delta < 1$. There are two crops, a risky crop and a safe crop, where the safe crop is assumed risk free. Denoting investment in the risky crop as the acreage A, then the investment in the safe crop is $M - A$ with per acre revenue r. Following Ashan, Ali, and Kurian, we define the revenue function R as

$$R = F(A) + r(M\text{-}A), \tag{4.1}$$

where $F(\cdot)$ is the revenue production function normalized by the price of the risky crop ($F' > 0$ and $F'' < 0$). The risky crop's yield is random, following a normal distribution with mean $\bar{\theta} = E[F(A)]$ and variance $\sigma^2 = V[F(A)]$, i.e. $\theta \sim N(\bar{\theta}, \sigma^2)$. Thus revenue R is stochastic and also has a normal distribution with mean $\mu = E[F(A)] + r(M-A)$ and variance $\sigma^2 = V[F(A)]$, i.e. $R \sim N(\mu, \sigma^2)$ (Weninger and Just). The means $\bar{\theta}$ and μ are increasing functions of risky crop acreage A, $\frac{\partial \bar{\theta}}{\partial A} > 0$ and $\frac{\partial \mu}{\partial A} > 0$, at least up to the optimal level of risky crop acreage. Also the variance σ^2 is assumed to be an increasing function of risky crop acreage A, $\frac{\partial \sigma^2}{\partial A} > 0$. However, σ^2 is assumed to be a decreasing function of crop insurance because crop insurance reduces downside risk. We denote $r(M-A)$ as v for notational convenience. To include effort e explicitly as a choice variable in equation (4.1), we follow the Linear-Exponential-Normal (LEN) model of Spremann, where effort linearly affects revenue. Then the revenue production function is redefined as

(4.2) $$y = e + F(A) + r(M-A),$$

where the farmer's effort level e is a continuous choice variable for the farmer that affects the distribution of revenue. For notation, denote the conditional probability density function for revenue as $f(y|e)$. The revenue distribution when the farmer exerts effort level e_1 first order stochastically dominates the revenue distribution when the farmer exerts effort level $e_0 < e_1$. The crop revenue is observable, but not the farmer's effort, which creates a moral hazard problem that may include underreports of crop yield or quality, input use, and management times.

Because effort causes disutility for the farmer, the farmer is willing to tradeoff effort and the associated shift in the revenue distribution. However, because of the effect of effort on the revenue distribution, the investor prefers the farmer to exert higher effort, since effort has no direct cost to the investor. To induce the farmer to exert the desired effort, the investor must create a contract that gives the farmer the correct incentive. However, the contract can only compensate the farmer based on the observable revenue, not on the unobservable effort. Denote this compensation as $t(y)$, where y depends on the farmer's effort level e, stochastic yield θ, and revenue ν for a safe crop.

From the investment, the investor and the farmer's payoff are proportional to revenue y minus the compensation $t(y)$ to the farmer. The investor and the farmer's profit functions are

(4.3) $$\pi_p = (1-\delta)\big(y(e,\theta,\nu) - t(y)\big)$$

(4.4) $$\pi_a = \delta\big(y(e,\theta,\nu) - t(y)\big) + t(y) - c(e),$$

where the subscripts p and a denote the investor (principal) and the farmer (agent), respectively, and $c(e)$ denotes farmer's effort cost function. Following standard assumptions, we assume farmer's effort cost function $c(e)$ is separable from the utility function, where $c' > 0$ and $c'' > 0$ (Laffont and Martimort). To ensure that the farmer is willing to take the contract, the investor must ensure that the farmer's expected utility with the contract equals or exceeds his reservation utility $\overline{U}$, the expected utility from his next best option. This participation or individual rationality constraint (IRC) is

$$\int_y U(\pi_a) f(y \mid e) dy - c(e) \geq \overline{U}. \tag{4.5}$$

Since the farmer's effort is unobservable, the investor must also ensure that the contract gives the farmer the incentive to exert the desired effort. This incentive compatibility constraint (ICC) requires that if the farmer accepts the contract, his expected utility when exerting the best effort equals or exceeds his expected utility with any other effort levels. Mathematically, this ICC can be expressed as follows:

$$\arg\max_e \int_y U(\pi_a) f(y \mid e) dy - c(e). \tag{4.6}$$

As specified, condition (4.6) cannot be implemented when solving the investor's optimization problem. The First Order Approach (Laffont and Martimort) is commonly used to replace this global condition with a local condition consisting of the first order condition for problem (4.6):

$$\int_y U'(\pi_a) \frac{\partial \pi_a}{\partial e} f_e(y \mid e) dy - c'(e) = 0. \tag{4.7}$$

Thus the investor's problem is to find the contractual compensation $t(y)$ and effort level e that maximize his expected utility $V(\cdot)$ of profit π_p:

$$\max_{t(y),e} \int_y V(\pi_p) f(y \mid e) dy, \tag{4.8}$$

subject to the individual rationality constraint (4.5) and the incentive compatibility constraint (4.7).

We expand the model to include crop insurance so that the revenue with crop insurance y_I depends on the farmer's effort level *e*, stochastic revenue *R*, crop insurance indemnity $I(\hat{\theta},\theta)$, and crop insurance premium $p(\hat{\theta},\gamma)$, where the indemnity depends on the guaranteed yield $\hat{\theta}=\tau\bar{\theta}$ (τ: insurance coverage level) and stochastic yield θ, and premium $p(\hat{\theta},\gamma)$ depends on the guaranteed yield and the per acre premium γ. The normalized price is assumed as the expected price for yield shortfall as with the revenue production function. The revenue with crop insurance is:

$$y_I(e,\theta,\hat{\theta},\nu,\gamma)=e+R(\theta,\nu)+I(\hat{\theta},\theta)-p(\hat{\theta},\gamma), \tag{4.9}$$

where $I(\hat{\theta},\theta)$ is defined as ($\max[(\hat{\theta}-\theta),0]$). When crop insurance is actuarially fair, the insurance premium equals the expected indemnity, and when it is unfair, the insurance premium exceeds the expected indemnity: $p(\hat{\theta},\gamma)\geq E[I(\hat{\theta},\theta)]=\int_{-\infty}^{\hat{\theta}}(\hat{\theta}-\theta)f(\theta)d\theta$.

A farmer's compensation scheme is assumed linear in revenue (Laffont and Martimort). The investor pays a fixed payment *w* and a varying payment *b* that is proportional to revenue: $t(y) = w + by$. Note that *w* can be negative, implying that the farmer may make some expenditure in addition to the investment share. However, *b* must be positive, otherwise the farmer would have no incentive to exert any effort. A convex quadratic function is used for the farmer's effort cost function: $c(e) = e^2$, implying increasing marginal disutility for effort.

A constant absolute risk aversion (CARA) utility function is used for both the investor and the farmer. Since revenue without crop insurance has a normal distribution, the investor's profit also has a normal distribution. In addition, since the compensation function is a linear transformation of revenue, the farmer's profit also has a normal distribution. As a result, both the investor's and the farmer's expected utility functions are equivalent to the mean variance models of their respective profits, V_p for the investor and V_a for the farmer, respectively:

(4.10) $$V_p = \mathrm{E}[\pi_p] - 0.5\alpha_p \, \mathrm{var}(\pi_p)$$

(4.11) $$V_a = \mathrm{E}[\pi_a] - 0.5\alpha_a \, \mathrm{var}(\pi_a)$$

where α_p and α_a are the coefficients of absolute risk aversion for the investor and farmer.

4.3. Optimal Contract for External Equity Financing with Crop Insurance

For the specified model, farmer profit is:

(4.12) $$\pi_a = \left[\delta + (1-\delta)b\right]\left[e + R(\theta,\nu) + I(\widehat{\theta},\theta) - p(\widehat{\theta},\gamma)\right] - e^2 .$$

Based on the specified model with fair insurance, the mean and variance of farmer profit is then:

(4.13) $$E[\pi_a] = [\delta + (1-\delta)b](\mu_f + e) + (1-\delta)w - e^2$$

(4.14) $$Var(\pi_a) = [\delta + (1-\delta)b]^2 \sigma_f^2 ,$$

where the subscript f denotes a risk averse farmer with fair insurance. The variance is defined as $\sigma_f^2 = Var[\theta + I(\widehat{\theta},\theta)]$, in which low revenues are truncated because fair crop insurance removes downside risk by $V[I(\widehat{\theta},\theta)] = \int_{-\infty}^{\widehat{\theta}} (\widehat{\theta}-\theta)^2 f(\theta) d\theta$, where $\dfrac{\partial V[I(\widehat{\theta},\theta)]}{\partial \widehat{\theta}} > 0$. As a result, profit variance with crop insurance is less than without crop insurance. Also with the increase of insurance coverage level τ and thus the guaranteed level $\hat{\theta}$ $(=\tau\bar{\theta})$, the variance gets smaller, $\frac{\partial \sigma_f^2}{\partial \tau} < 0$, through $\frac{\partial \hat{\theta}}{\partial \tau} > 0$ and $\frac{\partial V[I(\hat{\theta},\theta)]}{\partial \hat{\theta}} > 0$. If crop insurance is unfair such as $p(\hat{\theta},\gamma) = (1+\beta)E[I(\hat{\theta},\theta)]$ and μ_f is fixed, where β is the insurance premium load (*0* < β < *1*) such as an administration cost for insurance company, then equation (4.13) decreases by $\beta[\delta+(1-\delta)b]E[I(\hat{\theta},\theta)]$. The variance with unfair insurance σ_u^2 increases by $\beta^2 V[I(\hat{\theta},\theta)]$ compared with σ_f^2 in equation (4.14) through the decrease of indemnity, where the subscript *u* denotes a risk averse farmer with unfair insurance.

Given the compensation parameters *w* and *b* along with actuarially fair insurance, the farmer chooses his effort and risky crop acreage to maximize his expected utility:

(4.15) $$\max_{e,A}\ [\delta+(1-\delta)b](\mu_f+e)+(1-\delta)w-e^2-0.5\alpha_a[\delta+(1-\delta)b]^2\sigma_f^2 .$$

Solving the first order conditions for this problem gives the farmer's optimal effort e^*:

(4.16) $$e^* = 0.5[\delta+(1-\delta)b].$$

Denoting μ_f and σ_f^2 as functions of *A*, we also get the optimal risky crop acreage *A*. Rearranging the first order condition for *A* gives

(4.17) $$E[F'(A_f)] = r+\alpha_a[\delta+(1-\delta)b]^2 V[F'(A_f)+I(\tau E[F'(A_f)],F'(A_f))],$$

where the second term in the right hand side is marginal risk premium (MRP), which is positive as long as τ < *1* (not full coverage), for an unit increase in risky crop acreage.

Thus the optimal risky crop acreage is determined at $E[(F'(A_f)] > r$. Compared with $E[(F'(A_0)] = r$ for a risk neutral farmer from Ashan, Ali, and Kurian, where the subscript 0 denotes a risk neutral farmer, we get the relationship $A_f < A_0$ as long as $\tau < 1$. With the increase of insurance coverage level τ, MRP decrease and thus the optimal risk crop acreage increases. In case of full insurance ($\tau = 1$), MRP is zero, thus resulting in $A_f = A_0$ (Ashan, Ali, and Kurian). Without crop insurance, MRP is greater than that with fair crop insurance, thus requiring $A_n < A_f$, where the subscript n denotes a risk averse farmer without insurance. Unfair insurance reduces the first term in the right hand side of (4.17) by $\beta E[I(\tau E[F'(A_f)], F'(A_f))]$ and increases MRP by $\beta^2 V[I(\tau E[F'(A_f)], F'(A_f))]$, thus resulting in risky crop acreage $A_u < A_f$. Also, if the decrease in the expected revenue dominates the decrease in the variance under unfair insurance compared with no insurance, the risky crop acreage is $A_u < A_n$. On the other hand, if the decrease in the variance dominates the expected revenue under unfair insurance compared with no insurance, then the risky crop acreage is $A_u > A_n$. For unfair insurance to be acceptable, the latter case is more appropriate, thus we assume $A_u > A_n$. Then the optimal acreage ordering, $A_0 > A_f > A_u > A_n$ gives the following ordering for the revenue and variance: $\mu_0 > \mu_f > \mu_u > \mu_n$ and $\sigma_0^2 > \sigma_n^2 > \sigma_u^2 > \sigma_f^2$, where the order of variance may change according to the size of the risk crop acreage and insurance coverage level. In this study, we assume the difference of risky crop acreage is not so big and the insurance coverage level is high enough so that the above relationship is maintained. The optimal risky crop acreage in (4.17) is too complicated to get the analytical solution. However, numerical solution can be obtained by risk attitude with and without crop insurance.

Substituting this effort level into the individual rationality constraint (4.5) and solving for w gives:

$$w^{*}=\frac{1}{1-\delta}\left\{\bar{U}-[\delta+(1-\delta)b]\mu_{f}-0.25[\delta+(1-\delta)b]^{2}*\left(1-2\alpha_{a}\sigma_{f}^{2}\right)\right\}. \tag{4.18}$$

The investor's optimal fixed compensation w increases with respect to the farmer's reservation utility $\bar{U}$ and decreases with respect to the farmer's expected revenue and thus the risky crop acreage. If the risk aversion parameter, α_a, and variance term, σ_f^2, are positive and small enough, the fixed compensation decreases with the introduction of crop insurance because it has an effect of decreasing risk, thus making $\left(1-2\alpha_a\sigma_f^2\right)$ increase.

The investor's profit with crop insurance is:

$$\pi_{p}=(1-\delta)\Big[(1-b)(e+R(\theta,\nu)+I(\hat{\theta},\theta)-p(\hat{\theta},\gamma))-w\Big]. \tag{4.19}$$

Based on the specified model, the mean and variance of the investor's profit is:

$$E(\pi_{p})=(1-\delta)[(1-b)(\mu_{f}+e)-w] \tag{4.20}$$

$$Var(\pi_{p})=(1-\delta)^{2}(1-b)^{2}\sigma_{f}^{2}. \tag{4.21}$$

Expected profits with and without insurance are equal because the insurance is fair. The variance depends on farmer's risk attitude, the existence of crop insurance, the fairness of crop insurance, and insurance coverage level. Substituting equations (4.20) and (4.21) into the investor's objective in equation (4.10) and simplifying gives:

$$(4.22) \qquad \underset{b}{Max}\begin{pmatrix} (1-\delta)\Big[(1-b)\big(0.5[\delta+(1-\delta)b]+\mu_f\big)\Big] \\ -\Big\{\bar{U}-[\delta+(1-\delta)b]\mu_f-0.25[\delta+(1-\delta)b]^2*\big(1-2\alpha_a\sigma_f^2\big)\Big\} \\ -0.5\alpha_p(1-\delta)^2(1-b)^2\sigma_f^2 \end{pmatrix}.$$

Solving the first order condition for *b* gives:

$$(4.23) \qquad b^*=\frac{1}{1-\delta}\left[\frac{\left(1+2\alpha_p\sigma_f^2\right)}{\left(1+2(\alpha_a+\alpha_p)\sigma_f^2\right)}-\delta\right].$$

Using this result, several comparative static results can be obtained (table 4.1). The optimal variable compensation rate b^* depends inversely on the farmer's share of investment with decreasing rate: $\frac{\partial b^*}{\partial \delta}<0$. This occurs because the greater the farmer's share of the investment, the greater farmer's incentive to exert effort. The variable compensation rate b^* decreases with the farmer's risk aversion in increasing rate because the farmer needs to bear less risk: $\frac{\partial b^*}{\partial \alpha_a}<0$. On the other hand, as the investor's risk aversion increases, the variable compensation rate b^* also increases, $\frac{\partial b^*}{\partial \alpha_p}>0$ at a decreasing rate, because the investor wants to share more risk with the farmer. As the variance of revenue increases, the variable compensation rate b^* decreases, $\frac{\partial b^*}{\partial \sigma_f^2}<0$, because a smaller b^* gives the farmer relatively less risk. Thus overall, crop insurance leads to the increase in variable compensation because crop insurance reduces the risk by $\frac{\partial \sigma_f^2}{\partial \tau}<0$. Because of this effect of crop insurance, the investor must increase the farmer's risk share from the contract to motivate high effort. In effect, crop insurance insulates the farmer from incentives to motivate high effort, so the investor compensates by increasing the variable compensation rate to increase the farmer's risk share. Furthermore, we know that the variable compensation rate increases with an increase in the insurance coverage level, $\frac{\partial b^*}{\partial \tau} > 0$, because $\frac{\partial \sigma_f^2}{\partial \tau} < 0$ and $\frac{\partial b^*}{\partial \sigma_f^2} < 0$.

Substituting the optimal b^* into equations (4.15) and (4.16) gives the optimal w^* and e^*:

(4.24)
$$e^* = 0.5\left[\frac{\left(1+2\alpha_p\sigma_f^2\right)}{\left(1+2(\alpha_a+\alpha_p)\sigma_f^2\right)}\right]$$

(4.25)
$$w^* = \frac{1}{(1-\delta)}\left[\bar{U} - \left(\frac{\left(1+2\alpha_p\sigma_f^2\right)}{\left(1+2(\alpha_a+\alpha_p)\sigma_f^2\right)}\right)\mu_f - 0.25\left(\frac{\left(1+2\alpha_p\sigma_f^2\right)}{\left(1+2(\alpha_a+\alpha_p)\sigma_f^2\right)}\right)^2\left(1-2\alpha_a\sigma_f^2\right)\right].$$

Again, several comparative static results can be obtained (table 4.1). The optimal level of effort increases with the investor's risk aversion and decreases with the farmer's risk aversion and the variance of revenue: $\frac{\partial e^*}{\partial \alpha_p} > 0$, $\frac{\partial e^*}{\partial \alpha_a} < 0$, and $\frac{\partial e^*}{\partial \sigma_f^2} < 0$. Because the farmer's compensation with crop insurance is highly dependent on revenue, the farmer must exert more effort relative to the case without insurance. Also the insurance coverage level increases the optimal level of effort, $\frac{\partial e^*}{\partial \tau} > 0$, because $\frac{\partial \sigma_f^2}{\partial \tau} < 0$ and $\frac{\partial e^*}{\partial \sigma_f^2} < 0$.

The optimal level of the fixed compensation *w* decreases with the investor's risk aversion $\frac{\partial w^*}{\partial \alpha_p} < 0$. This means that the risk averse investor wants to share more risk with the farmer, and thus decreases the fixed compensation. The optimal level of the fixed compensation increases with the variance of revenue $\frac{\partial w^*}{\partial \sigma_f^2} > 0$, resulting in the decrease with the insurance coverage level, $\frac{\partial w}{\partial \tau} < 0$, because $\frac{\partial \sigma^2}{\partial \tau} < 0$ and $\frac{\partial w^*}{\partial \sigma_f^2} > 0$. It also increases with the farmer's risk aversion $\frac{\partial w^*}{\partial \alpha_a} > 0$. Thus the investor needs to increase the fixed compensation to induce the participation of the risk averse farmer in the contract. The optimal level of fixed compensation also increases with the farmer's investment share $\frac{\partial w^*}{\partial \delta} > 0$ in increasing rate. The farmer with high investment share would be willing to exert effort, thus the investor increases fixed compensation instead of variable compensation. Similarly, the optimal level of fixed compensation increases with the farmer's reservation utility, $\frac{\partial w^*}{\partial \bar{U}} > 0$, and decreases with expected revenue, $\frac{\partial w^*}{\partial \mu_f} < 0$. Crop insurance leads to increase the optimal level of effort through the

Table 4.1. Comparative Static Results of the External Equity Financing with Crop Insurance on Optimal Level of Effort e^*, Variable Compensation b^*, and Fixed Compensation w^{*a}

	First Derivative		Second Derivative	
	Derivative	Sign	Derivative	Sign
Effect of investment share δ on variable compensation b^*	$\frac{\partial b^*}{\partial \delta}$	–	$\frac{\partial^2 b^*}{\partial \delta^2}$	–
Effect of farmer's risk aversion α_a on variable compensation b^*	$\frac{\partial b^*}{\partial \alpha_a}$	–	$\frac{\partial^2 b^*}{\partial \alpha_a^2}$	+
Effect of investor's risk aversion α_p on variable compensation b^*	$\frac{\partial b^*}{\partial \alpha_p}$	+	$\frac{\partial^2 b^*}{\partial \alpha_p^2}$	–
Effect of coverage level τ on variable compensation b^*	$\frac{\partial b^*}{\partial \tau} = \frac{\partial b^*}{\partial \sigma^2}\frac{\partial \sigma^2}{\partial \tau}$	+	$\frac{\partial^2 b^*}{\partial \tau^2}$	?[b]
Effect of investor's risk aversion α_p on effort level e^*	$\frac{\partial e^*}{\partial \alpha_p}$	+	$\frac{\partial^2 e^*}{\partial \alpha_p^2}$	–
Effect of farmer's risk aversion α_a on effort level e^*	$\frac{\partial e^*}{\partial \alpha_a}$	–	$\frac{\partial^2 e^*}{\partial \alpha_a^2}$	+
Effect of coverage level τ on effort level e^*	$\frac{\partial e^*}{\partial \tau} = \frac{\partial e^*}{\partial \sigma^2}\frac{\partial \sigma^2}{\partial \tau}$	+	$\frac{\partial^2 e^*}{\partial \tau^2}$	?[b]
Effect of investor's risk aversion α_p on fixed compensation w^*	$\frac{\partial w^*}{\partial \alpha_p}$	–	$\frac{\partial^2 w^*}{\partial \alpha_p^2}$	?[b]
Effect of coverage level τ on fixed compensation w^*	$\frac{\partial w^*}{\partial \tau} = \frac{\partial w^*}{\partial \sigma^2}\frac{\partial \sigma^2}{\partial \tau}$	–	$\frac{\partial^2 w^*}{\partial \tau^2}$	?[b]
Effect of farmer's risk aversion α_a on fixed compensation w^*	$\frac{\partial w^*}{\partial \alpha_a}$	+	$\frac{\partial^2 w^*}{\partial \alpha_a^2}$	?[b]
Effect of investment share δ on fixed compensation w^*	$\frac{\partial w^*}{\partial \delta}$	+	$\frac{\partial^2 w^*}{\partial \delta^2}$	+
Effect of reservation utility $\bar{U}$ on fixed compensation w^*	$\frac{\partial w^*}{\partial \bar{U}}$	+	$\frac{\partial^2 w^*}{\partial \bar{U}^2}$	na[c]
Effect of expected revenue μ on fixed compensation w^*	$\frac{\partial w^*}{\partial \mu}$	–	$\frac{\partial^2 w^*}{\partial \mu^2}$	na[c]

[a] More detailed comparative static are given in appendix C

[b] The effect is uncertain.

[c] Not available

increase in variable compensation, and decreases the optimal level of fixed compensation. Thus it induces more risk sharing between the investor and the farmer.

4.4. Empirical Analysis

For empirical analysis, we review similar contract types to our model and then develop a representative farm to apply our model to see the effect of crop insurance on the contract change. One example is a joint venture in mid-west region in the United State, where there are ten investors and two operating managers (farmers) who also are investors. Both farmers can choose any crop they want and each are paid with the fixed compensation of $60,000/year and variable compensation of 5% for prices and production yields that exceed county averages. After payment to the farmers, the investors share the profits according to the share of the 12,000 total acres they personally contributed. Another example is a joint venture in Canada. This joint venture consists of five investors and three managers, where one manager is an investor. Managers can choose any crop and receive a base salary of $60,000/year for each but do not have any variable compensation. The remaining net farm income is distributed to the investors based on the percentage of the 15,500 total tillable acres that each investor contributed. These contracts were chosen because they match the external equity financing contracts modeled in this study and can be used to help quantify the effect of crop insurance on the contract terms for similar kinds of contracts.

The joint ventures considered are private and detailed information about them is not available. Thus, we developed data for a representative farming situation in San

Patricio County, Texas, near Corpus Christi. The representative farm grows cotton and grain sorghum, where cotton is riskier crop than sorghum in terms of income. Cotton has a mean income of \$60.0 per acre with standard deviation of \$142.9 and sorghum has a mean income of \$29.3 per acre with standard deviation of \$40.6 (Seo, Mitchell, and Leatham). Total acreage is 1,700 acre that is available for both crops. The representative farmer is assumed to share 50% of the investment cost for total acres and has a reservation utility of \$60,000/year based on the two examples above.

Seo, Mitchell and Leatham estimated that a moderate risk averse representative farmer would allocate 700 acres to cotton production and 1,000 acres to sorghum production if crop insurance was unavailable. They also estimated that the representative farmer would choose to plant 1,100 acres of cotton and 600 acres if the crops are insured at the 85% coverage level.

Given the information for the representative farm above, table 4.2 shows the optimal levels of effort, variable compensation rate, and fixed compensation rate. Also table 4.2 provides how each parameter including investor's risk aversion parameter, farmer's risk averse parameter, insurance coverage level, investment share, and reservation utility affects the optimal level of effort, variable compensation rate, and fixed compensation rate. Given the parameters, the variable compensations without and with crop insurance are 0.44% and 0.48% of total revenue before paying base salary in earlier empirical examples (fixed compensation in our model), respectively, and the fixed compensations are \$48,404 and \$36,030, respectively. From these results, we know that crop insurance increases the variable compensation and decrease the fixed compensation. Also, crop insurance increases the farmer's effort level. However, their magnitudes depend on the parameters selected.

When the principal's risk aversion increases from moderately risk averse level of 4×10^{-6} to highly risk averse level of 7×10^{-6}, the variable compensation and effort level increase and the fixed compensation decreases in both cases, which are consistent with the signs reported earlier (table 4.1). This is because the risk averse investor wants to share more risk with the farmer. However, the magnitude of change is greater in the case with crop insurance because the investor knows that the farmer with crop insurance can bear more risk as a result of buying crop insurance. When the farmer's risk aversion parameter increases, the opposite results are obtained compared with the case of principal's risk aversion parameter change.

When the insurance coverage level decreases from the highest of 85% to the lowest of 50%, the variable compensation decreases by 0.11 percentage points and the fixed compensation increases by $98/year. Crop insurance increases the farm capacity to bear more risk and the incentive to moral hazard so that the higher coverage level increases the variable compensation and decreases the fixed compensation. That is, if the farmer buys crop insurance, then he/she would be willing to share more risk with the investor and be induced to moral hazard than before he/she buys crop insurance. Thus the risk averse investor increases the variable compensation to share more risk with the farmer and to reduce moral hazard when the farmer buys crop insurance. When the investment share of the farmer decreases by 20%, the variable compensation increases by 28.4 percentage points in both cases of without and with crop insurances and fixed compensation decreases by $13,830 with no insurance and by $10,294 with crop insurance, which are consistent with the signs reported earlier (table 4.1). This is because the higher the investment share of the farmer, the farmer is willing to effort to secure his portion of investment. Thus the investor does not need to give a high incentive but secure the farmer's reward from the investment by guaranteeing high fixed compensation.

As the reservation utility decreases by $15,000/year, the principal decreases only the fixed compensation by $30,000 in both cases of without and with crop insurances. This large amount of change is found in equation (4.25), where the fixed compensation is doubled from the investment share of 50%. In summery, crop insurance increases the variable compensation and thus the farmer's effort level and decreases the fixed compensation. And it's effect gets higher as the insurance coverage level and the risk aversion parameter increase.

Table 4.2. Sensitivity Analysis of Selected Variables on Optimal Level of Effort e^*, Variable Compensation b^*, and Fixed Compensation w^*

Parameters	Without Crop Insurance			With Crop Insurance		
	e^*	b^*	w^*($/yr)	e^*	b^*	w^*($/yr)
Investor's Risk Aversion						
4×10^{-6}	0.2511	0.0044	48,404	0.2512	0.0048	36,030
7×10^{-6}	0.2520	0.0081	48,140	0.3188	0.2753	13,433
Farmer's Risk Aversion						
4×10^{-6}	0.2511	0.0044	48,404	0.2512	0.0048	36,030
7×10^{-6}	0.2502	0.0006	48,670	0.1829	-0.2683	58,854
Insurance Coverage Level						
85%	0.2511	0.0044	48,404	0.2512	0.0048	36,030
50%	0.2511	0.0044	48,404	0.2509	0.0037	36,128
Investment Share						
50%	0.2511	0.0044	48,404	0.2512	0.0048	36,030
30%	0.2511	0.2888	34,574	0.2512	0.2892	25,736
Reservation Utility ($/yr)						
60,000	0.2511	0.0044	48,404	0.2512	0.0048	36,030
45,000	0.2511	0.0044	18,404	0.2512	0.0048	6,030

4.5. Conclusion

Farmers have several risk management programs such as crop insurance, futures and options, and government programs. Among these, subsidized crop insurance is widely adopted by the farmer. By purchasing crop insurance, a farmer may change the risks both the farmer and the investor face and this may affect production decisions depending on his risk attitudes and the fairness of insurance (Ahsan, Ali, and Kurian). Thus, an investor that provides external equity to a farmer also may want to adjust the investment contract design to reflect farmer's production decision and risk changes induced by the availability of crop insurance.

To better understand these relationships, we developed a principal-agent model of the contract between the external equity investor and the farmer when the farmer can purchase crop insurance. This study examines how the optimal contract design that induces the best effort from the farmer using a variable compensation rate and a fixed compensation rate is altered by the presence of crop insurance. We use the principal agent model to solve the issue, where the principal is the agricultural investor who provides external equity to a farmer and the agent is the farmer who makes production decisions such as land allocation and input use in addition to providing internal equity.

The results show that the investor's optimal contract with crop insurance employs a larger variable compensation rate than it does without insurance. This is because crop insurance reduces the risk farmers faced, thus allowing the farmer to bear more risk. Thus the larger variable compensation rate gives more incentive for the farmer to work harder. The variable compensation rate also increases with the crop insurance coverage level. The optimal contract with fair insurance uses a larger variable compensation rate than unfair insurance, where fair insurance means that the expected indemnity is equal to the insurance premium while unfair insurance means that the expected indemnity is less than insurance premium. The farmer can reduce more risk by buying fair insurance and thus can bear more risk. This leads to a larger variable compensation rate compared with unfair insurance. This shows an implication that when the government subsidy increases, the risk sharing increases through the increase in variable compensation. The risk averse investor prefers that the optimal contract depend more on variable compensation than the risk neutral investor because the risk averse investor prefers to share more risk with farmer than the risk neutral investor. The risk averse farmer is given a smaller variable compensation rate than the risk neutral farmer. This is because the risk averse farmer would not take many risks and thus prefers a fixed compensation rate instead of a variable compensation rate.

The optimal contract with crop insurance requires the farmer to bear more risk compared with no crop insurance so that the farmer has the appropriate incentives to work hard. Thus by making the compensation scheme depend more on variable compensation when crop insurance is used, the investor may induce more effort from the farmer and share more risk with the farmer. On the other hand, the farmer who buys crop insurance to reduce risk may have an additional risk caused by the adjustment of a contract with the investor. However, the farmer is compensated with the increased variable compensation.

CHAPTER V

SUMMARY AND CONCLUSIONS

Agricultural producers face uncertain agricultural production and market conditions. This uncertainty makes agricultural income unstable. Much of the uncertainty faced by agricultural producers cannot be controlled by the producer but can be managed. Several risk management approaches are available in the U.S. to help manage uncertainties in agricultural production, marketing, and finance. Two widely adopted risk management programs are crop insurance and marketing loan programs provided by the federal government.

These risk management programs reduce downside risk faced by the farmer. Program provisions also affect crop returns and thus farm investment and production decisions as well as agricultural contracts. For instance, farmers may be induced to grow crops that use more nitrogen, herbicides, and insecticides with possible detrimental effect on the environment. Risk management programs also may encourage or discourage investment in perennial crops. It may lead to existing farmers to stay in farming longer or leave earlier. Crop Insurance may alter agricultural contracts. Thus the impacts that these decisions have need to be considered by policy makers and farm decision makers.

This study focuses on the farm level economic implications of the federal risk management programs. Specifically the work focuses on the impacts that crop insurance and marketing loan programs that protect farmers from yield, income, and price uncertainties have on investment, production, and contract design.

The first essay sets up a real option model with crop insurance and investigates the effect that crop (revenue) insurance has on the entry threshold as an investment criterion and exit threshold as a disinvestment criterion. For the application, we choose table grape production in California that accounts for 90% of domestic grape production (USDA-ERS).

The results show that revenue insurance with actual (subsidized) insurance premium decreases the entry and exit thresholds compared with no revenue insurance. Thus the revenue insurance encourages both the investment and current farming operation. Increasing insurance premium rate increases both the entry and exit threshold, thus discouraging the investment and current farming operation. This implies that an increase in the subsidy rate, that decreases the insurance premium rate, results in the encouragement of grape production investment and current grape farming operations. On the other hand, given the insurance premium rate, the insurance policy with high revenue guarantee above the exit threshold has a stronger effect on the exit threshold as well as the entry threshold than with low revenue guarantee. This implies that if a policy goal is to induce more farmers in a certain crop, the insurance policy with higher coverage level is more effective.

In the second essay, we examine the effects of federal risk management programs on optimal nitrogen fertilizer use and land allocation to crops. To do this we developed a mathematical programming model of a case cotton-sorghum farm in San Patricio

County, Texas. The model endogenizes nitrogen fertilizer rates and land allocation, as well as the insurance coverage levels, price election factors, and participation in insurance programs and the Marketing Loan Program (MLP). In particular we use direct expected utility maximizing non-linear programming in combination with a simulation approach.

We find that the optimal participation in the available crop insurance and the MLP includes using the MLP for both cotton and sorghum and purchasing APH insurance for cotton and CRC for sorghum. Chosen optimal coverage levels are 70% for cotton APH and 70% or 75% corn sorghum CRC. The optimal price election factor is always the maximum available (100%). The farmer's expected net indemnity from these insurance programs largely explains the optimal insurance participation choices and coverage levels. Together, all three federal risk management programs increase farmer certainty equivalents 170-240%, of which about 1/3 is from crop insurance and 2/3 from the MLP.

Results also show current crop insurance program increases optimal nitrogen fertilizer rate (1-3%) and optimal cotton acreage (16-129%). The MLP only slightly changes optimal nitrogen fertilizer rates for both cotton and sorghum (less than a 1% change), but increases optimal cotton acreage an additional 1-9%.

In general, farmers respond optimally to these federal risk management programs by changing input use and crop acreage allocations to bear more risk. They are associated with environmental effects that are being increasingly scrutinized since they can enhance or counteract the goals of other programs (Goodwin and Smith; Skees).

Assuming the environmental effects of crop insurance and the MLP are positively related to nitrogen fertilizer use, both types of risk management programs imply negative environmental effects.

The third essay examines how optimal contract design that induces the best effort from the farmer using a variable compensation rate and a fixed compensation rate is altered by the presence of crop insurance. We use the principal agent model to examine this, where the principal is the agricultural investor who provides the external equity to the farmer and the agent is the farmer who makes production decisions such as land allocation and input use.

The results show that the investor's optimal contract with crop insurance employs a larger variable compensation rate than it does without insurance. This is because crop insurance reduces the risk farmers face, thus increasing the farm capacity to bear more risk. Thus, the larger variable compensation rate gives more incentive for the farmer to work harder. The variable compensation rate also increases with the coverage level because the higher coverage level increases the farm capacity to bear risk. The optimal contract with fair insurance uses a larger variable compensation rate than unfair insurance, where fair insurance means that the expected indemnity is equal to the insurance premium while unfair insurance means that the expected indemnity is less than insurance premium. The farmer can reduce more risk by buying fair insurance and thus can increases the farm capacity to bear more risk. This leads to a larger variable compensation rate compared with unfair insurance. This implies that when the government subsidy increases, the risk sharing increases through the increase in variable compensation. The risk averse investor prefers that the optimal contract depends more on variable compensation than the risk neutral investor because the risk averse investor prefers to share more risk with farmer than the risk neutral investor. The risk averse farmer is given a smaller variable compensation rate than the risk neutral farmer. This is because the risk averse farmer would not take many risks and thus prefers a fixed compensation rate instead of a variable compensation rate.

The optimal contract with crop insurance requires the farmer to bear more risk compared with no crop insurance so that the farmer has the appropriate incentives to work hard. Thus by making the compensation scheme depend more on variable compensation when crop insurance is used, the investor may induce more effort from the farmer and share more risk with the farmer.

Collectively this study investigates the effect of federal risk management programs on the investment, production decisions, and contract design. Results show that risk management programs, especially crop insurance, affect farmer's decision-makings and also investor's contract design. We suggest the farmer to consider the irreversibility and uncertainty when making investment decision by adopting real option approach because both conditions produce the option values of waiting, thus changing the entry and exit decisions compared with NPV approach. Also crop insurance must be considered because it affects the entry and exit thresholds by reducing risks faced by the farmer. We also suggest that the simultaneous decision making with crop insurance need to be adopted in production decisions for the optimal input allocation and optimal choice of insurance parameters. Also the effects of federal risk management programs on environment need to be considered because those programs may counteract the environment programs. Finally, the agricultural investor needs to adjust the agricultural contract design to induce the farmer's best effort in farming under crop insurance. In addition, the policy maker needs to consider the farmer's decision-making behavior when designing and delivering risk management programs.

This dissertation has several limitations. First of all, this dissertation mainly focuses on crop insurance and the LDP as federal risk management programs. However, more federal risk management programs are available to the farmer, such as counter cyclical payment program, conservation reserve program, and nonrecourse marketing assistance loan program. Also other risk management programs are provided in private sector, such as the futures and options. Those programs may works as complements or substitutes each other. For better understanding of the effect of the risk management programs on farmer decision-making, more risk management programs must be considered in the analyses.

Second, our results are specific to crops and regions. The numeric results definitely change by crops and regions. Especially, the results from second essay may be reversed according to regions as shown by Horowitz and Lichtenberg and Smith and Goodwin. Thus to apply this results to other regions and crops need a caution. More extended empirical studies by regions and crops are needed in the future.

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APPENDIX A

A.1. Mathematics for Real Options[1]

Appendix A includes the mathematics for real option used in the text and derive the entry and exit model based on the mathematics. This section also includes the intuitive explanations of the entry and exit decisions in a competitive industry and data used in the chapter II.

A.1.1. The Wiener Process (Brownian Motion)

A Wiener process dz, a continuous-time stochastic process, is defined as

(A.1) $$dz = \varepsilon_t \sqrt{dt} \ ,$$

where ε_t is a normally distributed random variable with $\varepsilon_t \sim N(0, 1)$ and dt is a small time increment. The expected value and variance of the Wiener process are $E(dz) = 0$ and $V(dz)=E[(dz)^2]=dt$, respectively. However, the Wiener process has no time derivative because $dz/dt = \varepsilon_t(dt)^{-1/2}$ that approaches to infinity as dt approaches to zero.

When two Wiener processes are considered, we can write $E(dz_1dz_2)=\gamma_{12}dt$, where γ_{12} is the correlation coefficient between the two processes.

A.1.1.1. Brownian Motion with Drift

In more general form, the Brownian motion with drift of a continuous stochastic process x is

(A.2) $$dx = \alpha\, dt + \sigma\, dz,$$

[1] Most mathematics is cited from Dixit and Pindyck.

where α is called the drift rate and σ the volatility rate. Given the Wiener process in (A.1), the change in x, denoted by Δx, is normally distributed over any time interval t, and has expected value $E(x) = \alpha\, \Delta t$ and variance $V(x) = \sigma^2 \Delta t$, where the variance increases with the time.

A.1.2. Generalized Brownian Motion – Ito Process

A continuous time stochastic process $x(t)$ in equation (A.2) can be expressed as a general form, called *Ito process*.

(A.3) $$dx = a(x,t)dt + b(x,t)\, dz,$$

where the drift rate $a(x,t)$ and volatility rate $b(x,t)$ of the Ito process are known (nonrandom) functions with current state x and time t. In equation (A.3), the expected value and variance of the random process x are $E(dx) = a(x,t)dt$ and $V(dx) = E[dx^2] - (E[dx]^2) = b^2(x,t)\, dt$.

A.1.2.1. Geometric Brownian Motion

A geometric Brownian motion with drift in equation (A.4) is an important special case of the Ito process from equation (A.3).

(A.4) $$dx = \alpha x\, dt + \sigma x\, dz.$$

From equation (A.1) and equation (A.2), we know that the percentage changes in x, $\Delta x/x$, are also normally distributed. Because these are changes in the natural logarithm of x, absolute changes in x, Δx, are lognormally distributed.

A.1.3. Ito's Lemma

We need to use differentials to solve the functions with Ito process in real options. However, the Ito process in equation (A.3) is not differentiable even though it is continuous in time. Ito's Lemma can be used to differentiate or integrate functions of Ito processes.

Let's consider a function $F(x,t)$, where $x(t)$ is an Ito process. A Taylor series expansion produces

(A.5) $$dF = \frac{\partial F}{\partial x}dx + \frac{\partial F}{\partial t}dt + \frac{1}{2}\frac{\partial^2 F}{\partial x^2}(dx)^2 + \frac{1}{6}\frac{\partial^3 F}{\partial x^3}(dx)^3 + \ldots\ldots.$$

The higher order terms beyond $(dt)^2$ and $(dx)^3$ in equation (A.5) vanish in the limit. However, the second order term $(dx)^2$ does not vanish unlike ordinary calculus. For the proof, by inserting dx in equation (A.3) into $(dx)^2$, we have

(A.6) $$(dx)^2 = a^2(x,t)\,(dt)^2 + 2a(x,t)b(x,t)(dt)^{3/2} + b^2(x,t)dt,$$

where the terms $(dt)^{3/2}$ and $(dt)^2$ go to zero faster than dt in the limit but $b^2(x,t)dt$ remains in the formula. Thus we have the following differential equation dF from Ito's Lemma.

(A.7) $$dF = \frac{\partial F}{\partial x}dx + \frac{\partial F}{\partial t}dt + \frac{1}{2}\frac{\partial^2 F}{\partial x^2}(dx)^2.$$

By inserting dx from equation (A.3) into equation (A.7), we have

(A.8) $$dF = \left[\frac{\partial F}{\partial t} + a(x,t)\frac{\partial F}{\partial x} + \frac{1}{2}b^2(x,t)\frac{\partial^2 F}{\partial x^2}\right]dt + b(x,t)\frac{\partial F}{\partial x}dz.$$

We can extend the differential equation with m Ito processes, where

(A.9) $$dx_i = a_i(x_1, \ldots\ldots, x_m, t)dt + b_i(x_1, \ldots\ldots, x_m, t)dz_i, \quad i = 1, \ldots\ldots, m,$$

with $E(dz_i dz_j)=\gamma_{ij}dt$. Then we have the differential dF by Ito's Lemma as

(A.10) $$dF = \frac{\partial F}{\partial t}dt + \sum_i \frac{\partial F}{\partial x_i}dx_i + \frac{1}{2}\sum_i\sum_j \frac{\partial^2 F}{\partial x_i \partial x_j}dx_i dx_j \ .$$

By replacing *dx* with equation (A.3), we have the expanded form of differential *dF* as

(A.11) $$dF = [\frac{\partial F}{\partial t} + \sum_i a_i(x_1,....,t)\frac{\partial F}{\partial x_i} + \frac{1}{2}\sum_i b_i^2(x_1,....,t)\frac{\partial^2 F}{\partial x_i^2}$$

$$+\frac{1}{2}\sum_{i\neq j}\gamma_{ij}b_i(x_1,....,t)b_j(x_1,....,t)\frac{\partial^2 F}{\partial x_i \partial x_j}]dt + \sum_i b_i(x_1,....,t)\frac{\partial F}{\partial x_i}dz_i \ .$$

A.1.4. Derivation of Geometric Brownian Motion of Revenue

Consider the function $F(p,y) = R = py$, where R is revenue, p is price and y is yield. If price and yield follow geometric Brownian motion, uncertainty of price p and yield y can be expressed as

(A.12) $$dp = \alpha_p p dt + \sigma_p p dz_p$$

(A.13) $$dy = \alpha_y y dt + \sigma_y y dz_y,$$

where dp and dy are the changes in price and yield and $E(dz_p dz_y) = \gamma_{py} dt$. α is the drift rate, σ is the volatility rate, dt is the small change in time, and dz is the increment of Wiener process. Given $R = py$, we get $\partial R/\partial t = 0$, $\partial^2 R/\partial p^2 = \partial^2 R/\partial y^2 = 0$, and $\partial^2 R/\partial p \partial y = 1$. Then equation (A.14) is obtained from equation (A.7).

(A.14) $$dR = p\ dy + y\ dp + dp\ dy.$$

By replacing dp and dy with equation (A.12) and (A.13), respectively, we have

(A.15) $$dR = (\alpha_p + \alpha_y + \gamma_{py}\sigma_p\sigma_y)\ Rdt + \sigma_p R dz_p + \sigma_y R dz_y.$$

Equation (A.15) has the same form as equation (A.12) and (A.13) so that we know revenue also follows the geometric Brownian motion when both the price and yield follow geometric Brownian motions.

When we assume $r = \log R = \log (py)$, we obtain $\partial r/\partial t = 0$, $\partial r/\partial p = 1/p$, $\partial r/\partial y = 1/y$ and $\partial^2 r/\partial p^2 = -1/p^2$, $\partial^2 r/\partial y^2 = -1/y^2$, and $\partial^2 r/\partial p\partial y = 0$. Then we get the equation (A.16) from equation (A.7).

(A.16) $$dr = \frac{1}{p}dp + \frac{1}{y}dy - \frac{1}{2p^2}dp^2 - \frac{1}{2y^2}dy^2 .$$

By replacing *dp* and *dy* with equation (A.12) and (A.13), respectively, we have

(A.17) $$dr = (\alpha_p + \alpha_y - \frac{1}{2}\sigma_p^2 - \frac{1}{2}\sigma_y^2)dt + \sigma_p dz_p + \sigma_y dz_y .$$

Equation (A.17) has the same form as equation (A.2) so that we know the change in logarithm of revenue also follows a simple Brownian motion. Over the small time interval dt, it is normally distributed with mean $(\alpha_p + \alpha_y - \frac{1}{2}\sigma_p^2 - \frac{1}{2}\sigma_y^2)dt$ and variance $(\sigma_p^2 + \sigma_y^2 + 2\gamma_{py}\sigma_p\sigma_y)dt$.

A.1.5. Derivation of the Entry and Exit Threshold Model in a Competitive Industry

The value of a farm is a function of stochastic revenue and state variable that is either active (1) or inactive (0). We denote the values of the inactive and active farms as $V_0(R)$ and $V_1(R)$, respectively. First consider the inactive farm. In equilibrium, the expected rate of capital gain of the value of the investment opportunity $E[dV_0(R)]$ should equal the total expected return on the investment opportunity $\rho V_0(R)dt$.

(A.18) $$\rho V_0(R)dt = E[dV_0(R)],$$

where ρ is the risk-adjusted rate of return. Denoting $V_0'(R)=dV_0/dR$ and $V_0''(R)=d^2V_0/dR^2$, the stochastic movement of $dV_0(R)$ is expanded by Ito's Lemma as in equation (A.8). Noting that $\partial V_0(R)/\partial t = 0$, we get

(A.19) $$dV_0(R) = [V_0'(R)\alpha R + ½\, V_0''(R)\sigma^2R^2]dt + V_0'(R)\, \sigma R\, dz.$$

Taking expectation in both sides of equation (A.19) and noting $E(dz) = 0$ from (A.1), we have

(A.20) $$E[dV_0(R)] = \alpha R\, V_0'(R)\, dt + ½\, \sigma^2R^2\, V_0''(R)dt.$$

Substituting equation (A.18) with equation (A.20) and dividing by dt, we get

(A.21) $$½\, \sigma^2R^2V_0''(R) + (\rho - \delta)\, R\, V_0'(R) - \rho V_0(R) = 0,$$

where δ is the rate of return shortfall defined as the difference between the risk adjusted rate and the drift rate ($\delta = \rho - \alpha$). In equation (A.21), the second-order homogeneous differential equation is linear in the dependent variable V_0 and its derivatives and thus its general solution can be expressed as a linear combination of any two independent solutions. If we try the function $V_0(R) = AV^{\beta}$, the following quadratic equation is obtained from equation (A.21).

(A.22) $$½\, \sigma^2\beta(\beta - 1) + (\rho - \delta)\beta - \rho = 0,$$

where β is a root of the quadratic equation and the two roots are

(A.23) $$\beta_1 = \frac{1}{2} - \frac{(\rho-\delta)}{\sigma^2} + \sqrt{\left[\frac{(\rho-\delta)}{\sigma^2} - \frac{1}{2}\right]^2 + \frac{2\rho}{\sigma^2}} > 1,$$

(A.24) $$\beta_2 = \frac{1}{2} - \frac{(\rho-\delta)}{\sigma^2} - \sqrt{\left[\frac{(\rho-\delta)}{\sigma^2} - \frac{1}{2}\right]^2 + \frac{2\rho}{\sigma^2}} < 0,$$

so the general solution to equation (A.21) can be written as

(A.25) $$V_0(R) = A_1 R^{\beta_1} + A_2 R^{\beta_2}$$

The explanation of each term is given in equation (2.5) of chapter II.

Similarly, the value of the active farm can be calculated from the addition of net cash flow $(R\text{-}C)dt$, where C is the variable cost. In this case, we have the equation as in (A.18)

(A.26) $$\rho V_1(R)dt = E[dV_1(R)] + (R - C)dt,$$

Following the same procedures as the inactive farm, we have

(A.27) $$\tfrac{1}{2}\,\sigma^2 R^2 V_1''(R) + (\rho - \delta)\,RV_1'(R) - \rho V_1(R) + R - C = 0.$$

The form of the solution in equation (A.27) is

(A.28) $$V_1(R) = B_1 R^{\beta_1} + B_2 R^{\beta_2} + \frac{R}{\delta} - \frac{C}{r}$$

Also the explanation of equation (A.28) is given in chapter II.

Now suppose the entry threshold is R_H and the exit threshold R_L. These satisfy the value-matching and smooth-pasting conditions. Equation (A.29) and equation (A.30) are value-matching conditions that require the value of waiting to equal the value of investing at the entry and exit thresholds. Equation (A.31) and equation (A.32) are smooth-pasting conditions that require the same slopes of the value of waiting and the value of investing at each threshold level. However, in a perspective of the upper and lower reflecting barriers caused by a competitive equilibrium, those conditions can be interpreted as the results of the arbitrage among inactive farmers and active farmers, respectively.

(A.29) $$V_0(R_H) = V_1(R_H) - I,$$

(A.30) $$V_1(R_L) = V_0(R_L) - E,$$

(A.31) $$V_0'(R_H) = V_1'(R_H),$$

(A.32) $$V_1'(R_L) = V_0'(R_L).$$

By substituting the equation (A.25) and (A.28) into value matching and smooth pasting conditions in equation (A.29) through (A.32), we have a simultaneous equation system as in chapter II.

(A.33) $$(B_1 - A_1)R_H^{\beta_1} + (B_2 - A_2)R_H^{\beta_2} + \frac{R_H}{\delta} - \frac{C}{r} = I$$

(A.34) $$\beta_1(B_1 - A_1)R_H^{\beta_1 - 1} + \beta_2(B_2 - A_2)R_H^{\beta_2 - 1} + \frac{1}{\delta} = 0$$

(A.35) $$(B_1 - A_1)R_L^{\beta_1} + (B_2 - A_2)R_L^{\beta_2} + \frac{R_L}{\delta} - \frac{C}{r} = -E$$

(A.36) $$\beta_1(B_1 - A_1)R_H^{\beta_1 - 1} + \beta_2(B_2 - A_2)R_H^{\beta_2 - 1} + \frac{1}{\delta} = 0.$$

In the model, the optimal entry and exit thresholds are equilibrium revenue levels with upper and lower reflecting barriers, respectively, which result in zero option value of waiting for inactive farmers (A_1=A_2=0).

A.2. Entry and Exit Decisions with Real Options and Standard NPV in a Competitive Industry

In this section, intuitive explanations of the entry and exit decisions between the real option approach and standard NPV approach in a competitive industry used in chapter II are presented.

A.2.1. Entry Decision

First, examine the entry decision using both standard NPV and the real option approach in a competitive industry. In a competitive industry, the option value of waiting $V_0(R)$ is zero because no abnormal project value can be expected. If a positive project value exists, many farmers enter the business and the positive project value disappears while, in earlier stage of investment, the participant can enjoy a positive project value temporarily. In aggregate level, many participants shift a market supply curve to the right so that the market price and farmer revenue decrease. That is, the marginal benefit from additional investment decreases until the equilibrium is obtained in a competitive industry. Thus, to invest in farming, a sufficient level of price or revenue is required. A real option approach captures this marginal effect caused by price or revenue change in the industry level. However, standard NPV approach cannot consider this effect because standard NPV analysis can only be conducted in the assumption of constant marginal benefit from an additional investment.

Now, consider a graph to compare the entry thresholds in both approaches, where $V_1(R)$ is the value of an active (current) farm, $V_0(R)$ is the value of an inactive (potential) farm, I is the sunk cost, and R is the revenue.

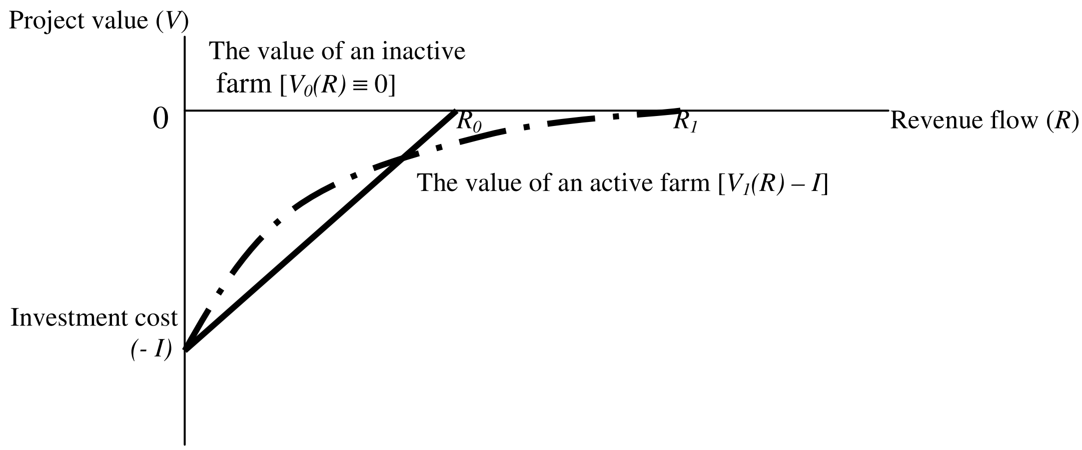

Figure A.1. Entry thresholds under real options and NPV approach

In the figure A.1, the R_0 and R_1 are the entry thresholds with standard NPV and the real option approaches, respectively, and $V_1(R) - I$ is the value of an active farm net of investment cost (sunk cost) that is bounded by zero project value caused by competition. The value of an active farm increases with revenue at a decreasing rate because it captures the decreasing marginal benefit from investment. Thus the difference between the two points, R_0 and R_1, is not caused by the option value of waiting but by the decreasing marginal benefit from investment under the real options and a constant marginal benefit from investment under standard NPV in a competitive industry. The entry threshold with the real options is greater than standard NPV approach because the entry decision with real option is affected by the competition in an industry level.

A.2.2. Exit Decision

Now we examine the exit thresholds in both approaches, standard NPV and the real options. Once the farmer joins the farming, he only considers the variable cost, not the investment (sunk) cost. Still the marginal benefit is a decreasing function of revenue in the real option approach while constant in standard NPV approach. The variable cost is usually less than the investment cost, so we shift up the value function $V_I(R)$ to the upper side relative to the value function in the figure A.1.

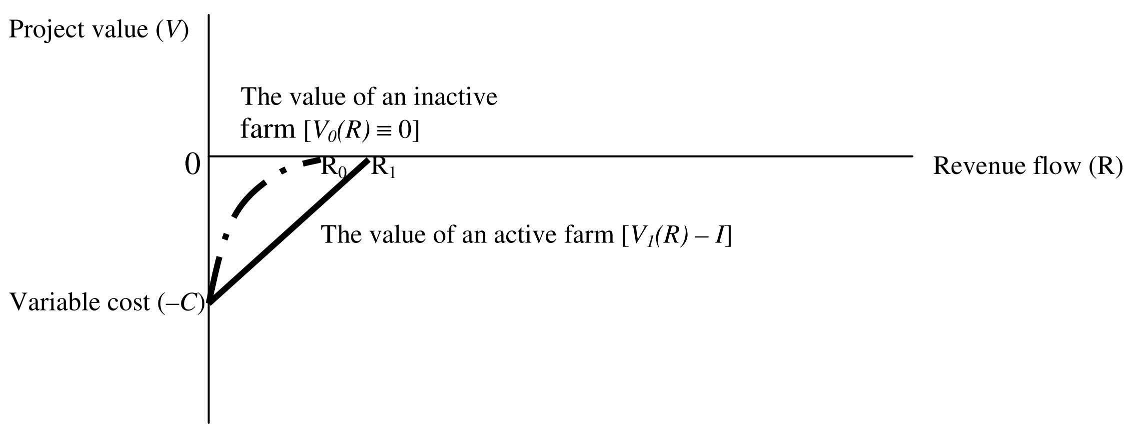

Figure A.2. Exit thresholds under real options and NPV approach

In the figure A.2, the R_0 and R_1 are the exit thresholds with the real option and standard NPV approaches, respectively, C is the variable cost, $V_1(R) - C$ is the value of an active farm net of the variable cost and $V_0(R)$ is the value of an inactive farm. We ignore the salvage value and exit cost for convenience. However, those values can be included in the value function if needed.

The exit threshold with the real options is usually less than standard NPV approach because it captures the effect of the competition in an industry level. That is, at the low level of revenue, all farmers in the industry expect the same choices for exit decision that result in the revenue floor. Thus an active farmer requires a sufficiently low exit threshold that can be captured by the value function of an active farm.

A.3. Parameters

Several parameters are needed in the real option approach, such as a drift rate, a volatility rate, a risk free rate, a risk-adjusted rate, a correlation coefficient, a rate of return shortfall, an investment (sunk) cost, a variable cost, a salvage value, and an exit cost. Among these parameters, a drift rate, a volatility rate, and a correlation coefficient are calculated from the logarithm of data because the real option approach in this study assumes the geometric Brownian motion of the stochastic process.

Here only the parameters with logarithm are briefly mentioned because other parameters are explained in section 2.4 of the text. An estimated drift rate can be obtained by regressing the log difference of each random variable, such as price and yield, on a constant, respectively. A volatility rate is the standard deviation from the log difference of each random variable. A correlation coefficient is needed only when two random variables are involved.

A.4. Data Used in Real Option Study

Table A.1. Price and Yield for Table Grapes

Year	Price ($/ton)	Yield (ton/acre)
1987	435	6.44
1988	363	9.02
1989	449	7.81
1990	429	8.27
1991	438	8.21
1992	356	8.34
1993	574	8.12
1994	515	7.74
1995	523	9.21
1996	650	7.89
1997	448	10.19
1998	499	8.75
1999	552	8.71
2000	565	8.7
2001	610	8.1
2002	618	8.4
Mean	501.5	8.4
Standard Deviation	89.26	0.80

Source: California Agricultural Statistics Service.

Table A.2. Operating Costs for the First 3 Years in Table Grape Production[a]

Item	Cost per Acre ($)		
	1st Year	2nd Year	3rd Year
Planting Costs	**2,432**	**2,142**	-
Land preparation – Subsoil 2X	250		
Land preparation – Disc 2X	50		
Land preparation – Level	80		
Land preparation – Fumigate 2X	550		
Survey & layout vineyard	140		
Plant vines: 454 per acre	1,362	64	
Install trellis system		2,078	
Cultural Costs	**246**	**560**	**762**
Prune & Tie – Dormant		47	101
Brush disposal			9
Fertilize		8	16
Irrigate	85	142	209
Pest control – Vertebrates	25	10	10
Disease control – Phomopsis			39
Training (Sucker, tie & train)		193	80
Weed control – Disc middle	7	7	7
Weed control – Mow middle	6	13	13
Weed control – Hand hoe	24		
Pest control		23	22
Disease control – Mildew – Wettable			9
Insect control – Leafhoppers 2X			29
Disease control – Mildew – SI			59
Disease control – Sulfur dust app			20
Weed control – Spot spray			22
Weed control –Winter strip spray	13	31	31
Miscellaneous costs	50	50	50
Pickup truck use	36	36	36
Harvest Costs	**-**	**-**	**270**
Harvest – Contract			270
Cash Overhead Costs	**161**	**163**	**165**
Office expense	38	38	38
Liability insurance	4	4	4
Property taxes	55	56	57
Property insurance	39	40	41
Investment repairs	25	25	25
Revenue	-	-	**-1,950**
Total	**2,839**	**2,865**	**-753**

[a] Interest cost and capital recovery cost are eliminated.
Source: University of California-Cooperative Extension.

Table A.3. Operating Costs in Table Grape after the Third Year of Production[a]

Item	Cost per Acre ($)
Cultural Costs	**2,100**
Prune vines	281
Brush disposal (Every middle)	10
Tie Vines	73
Disease control – Phomopsis	41
Insect control – Mealybug	36
Weed control – Winter strip	27
Weed control – Mow middles 4X	13
Irrigate	243
Disease control – Phomosis	17
Mildew control – Dust sulfur 12X	35
Remove trunk suckers	35
Canopy management – Shoot thin	150
Fertilize	20
Berry thin 2X	121
Fruit management	587
Berry size 2X	168
Girdling	80
Weed control – Spot spray	22
Sulfur application 12X	42
Pest control – Vertebrate pest	10
Miscellaneous costs	50
Pickup truck use	37
Harvest Costs	**3,045**
Pick, pack & supervise	1400
Box, spread, swamp & haul	1645
Post Harvest Costs	**317**
Precool, palletize & stor	175
Table grape commission	84
Quality control inspection	58
Cash Overhead Costs	**214**
Office expense	39
Liability insurance	4
Sanitation service	1
Property taxes	85
Property insurance	60
Investment repairs	25
Total	**5,676**

[a] Interest cost and capital recovery cost are eliminated.
Source: University of California-Cooperative Extension.

Table A.4. Investment Costs in Table Grape

Item[a]	Cost per Acre ($)
Land	4,696
Drip Irrigation System	1,036
Buildings	150
Shop Tools	87
Fuel Tanks & Pump	52
Vineyard Establishment	5,256
Equipment	645
Total	11,921

[a] Annual costs of depreciable items are assumed to be reinvested to maintain their capacity.
Source: University of California-Cooperative Extension.

APPENDIX B

B.1. Mixed Integer Nonlinear Programming Model (MINLP)

The general Mixed Integer Nonlinear Programming (MINLP) for expected utility of income maximization objective function (B.1) and constraints (B.2) and (B.3) can be expressed as follows:

(B.1) $Max \sum_k E[u(\pi_k)]$

(B.2) $f(v, h, z, b) \leq 0$

(B.3) $v \geq 0, h = \{0,1,2,...\}, z = \{0,1\}$

π_k : Income under state of nature k

k : State of nature index

f : A non-linear function

v : A vector of continuous choice variables

h : A vector of integer choice variables

z : A vector of binary choice variables

b : Total resources available

The constraint (B.2) represents a non-linear function incorporating technical relationship between variables and available resources. Constraint (B.3) represents non-negativity conditions for a vector of continuous choice variables, and a vector of integer variables and a vector of binary variables. Specifically, the constraints can be expressed as follows:

(B.4) $\sum_j (R_{kj} - C_j - rx_j + I_{kj} - M_j + LDP_{kj}) A_j - \sum_j F_j = \pi_k, \ \forall k$

j : Crop index

A : Acreage in production (continuous variable)

R_k : Revenue (\$/acre) without programs under state of nature k $(y_k * p_k)$

C : Variable cost (\$/acre)

r : Input cost (nitrogen cost (\$/lbs))

x : Input level (nitrogen level (lbs/acre))

I_k : Indemnity (\$/acre) under state of nature k

M : Premium (\$/acre)

LDP_k : Loan deficiency payment under state of nature k (\$/acre)

F : Administration fee (\$/crop)

Constraint (B.4) represents an income balance equation, in which revenue, the indemnity, and the LDP show positive contributions, and variable costs, the premium, and the administration fee show negative contributions.

(B.5)

$$\sum_{CVG} \sum_{\beta} \sum_i \begin{pmatrix} \left(p_j^e * PEF_{CVG} * Max[(CVG_{ij} * \bar{y}_j - y_{kj}), 0] \right)_{|i=APH} \\ + \left(Max[Max(p_j^b, \bar{p}_j^h) * \beta * g_{CVG,\beta ij} * CVG_{ij} * \bar{y}_j \text{ - } p_{kj} * y_{kj}, 0] \right)_{|i=CRC} \end{pmatrix} Z_{CVG,ij}$$
$$- I_{kj} = 0, \ \forall \, k, j$$

(B.6) $\sum_k \omega_k I_{kj} - EI_j = 0, \ \forall \ j$

(B.7) $Max[(MLR_j - p_{kj}), 0] * y_{kj} - LDP_{kj} = 0, \ \forall \ k, j$

i : Insurance program index (APH and CRC)

CVG : Yield coverage level (%)

β : CRC price election factor (95% and 100%)

PEF_{CVG} : APH price election factor by yield coverage level (integer variable)

$g_{CVG,\beta}$: CRC price election factor by yield coverage level (binary variable)

$\overline{y}$: APH yield guarantee (lbs/acre for APH and bu/acre for CRC)

p_k : Price under state of nature k ($/lbs for APH and $/bu for CRC)

y_k : Yield under state of nature k (lbs/acre for APH and bu/acre for CRC)

p^e : Estimated (guaranteed) price for APH ($/lbs for APH and $/bu for CRC)

p^b : Base price ($/lbs for APH and $/bu for CRC)

p^h : Harvest price ($/lbs for APH and $/bu for CRC)

MLR : Marketing loan rate ($/lb for APH and $/bu for CRC)

$Z_{CVG,i}$: Yield coverage level by insurance program (binary variable)

ω_k : Probability under state of nature k

Equations (B.5) and (B.6) define the indemnity and the expected indemnity. The per acre indemnity depends on the coverage level, price election factor, guaranteed price and yield, market price, and actual yield. Equation (B.7) reports the LDP under marketing loan program.

(B.8) $$\sum_{CVG}\sum_{i}\left(\begin{array}{l}\left(\overline{y}_j * p^e * Bpr_{CVG} * pr_{CVG} * PEF_{CVG}\right)_{|i=APH} \\ +\left(prm_{CVG} * pr_{CVG} * g_{CVG,j}\right)_{|i=CRC}\end{array}\right) * Z_{CVG,ij} - M_j = 0,\ \forall\ j$$

Bpr_{CVG} : Base premium rate by yield coverage level

pr_{CVG} : Premium rate by yield coverage level (1- subsidy rate)

prm_{CVG} : Premium by yield coverage level ($/acre)

Equation (B.8) defines the per acre premium, which depends on the coverage level, price election factor, subsidy rate, guaranteed price and yield, market price, and actual yield. The base premium rate and premium calculation procedures are rather complicated. The producer premium is the total premium minus the subsidy.

(B.9) $\sum_{CVG}\sum_{i} ADMF_{CVG} * Z_{CVG,ij} - F_j = 0, \ \forall\ j$

(B.10) $\sum_{j} A_j \leq L$

$ADMF_{CVG}$: Administration fee by yield coverage level ($/crop)

L : Total land available (acre)

The administration fees in equation (B.9) vary by yield coverage level. The constraint (B.10) represents the land balance equation.

(B.11) $\sum_{CVG}\sum_{i} Z_{CVG,ij} \leq 1, \ \forall\ j$

(B.12) $\sum_{\beta} g_{CVG,\beta ij|i=CRC} = 1, \ \forall\ CVG, j$

(B.13) $PEF^{L}_{CVG,i} = \underline{p}_{CVG,i|i=APH}\ ; PEF^{U}_{CVG,i} = \overline{p}_{CVG,i|i=APH}\ , \ \forall\ CVG$

(B.14) $A \geq 0,\ Z = \{0,1\},\ g = \{0,1\},\ PEF = \{50, 51, ...100\}$

PEF^{L}_{CVG} : Minimum price ($\underline{p}$) election factor by yield coverage level in APH

PEF^{U}_{CVG} : Maximum price ($\overline{p}$) election factor by yield coverage level in APH

Equation (B.11) requires that the sum of the binary values for yield coverage level across crop insurance programs should be less than or equal one so that no more than one yield coverage level and one crop insurance program is selected for each crop. Equation (B.12) represents that one of the price election factors between 95% and 100% should be chosen for each yield coverage level in CRC. Equation (B.13) shows the lower and upper bound of price election factor by yield coverage level in APH. Equation (B.14) represents the non-negativity of acreage allocation, the binary conditions of yield coverage level and the price election factor, and the set of price election factors available, respectively.

APPENDIX C

C.1. Comparative Static Results of the External Equity Financing with Crop Insurance

(C.1) $$\frac{\partial b^*}{\partial \delta} = \left[\frac{1+2\alpha_p\sigma^2}{1+2(\alpha_a+\alpha_p)\sigma^2}\right]\frac{1}{(1-\delta)^2} - \frac{1}{(1-\delta)^2}$$

$$= \frac{1}{(1-\delta)^2}\{\left[\frac{1+2\alpha_p\sigma^2}{1+2(\alpha_a+\alpha_p)\sigma^2}\right]-1\} < 0$$

(C.2) $$\frac{\partial^2 b^*}{\partial \delta^2} = \frac{2}{(1-\delta)^3}\{\left[\frac{1+2\alpha_p\sigma^2}{1+2(\alpha_a+\alpha_p)\sigma^2}\right]-1\} < 0$$

(C.3) $$\frac{\partial b^*}{\partial \alpha_a} = \frac{1}{1-\delta}\left[\frac{-2\sigma^2(1+2\alpha_p\sigma^2)}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right] < 0$$

(C.4) $$\frac{\partial b^{*2}}{\partial \alpha_a^2} = \frac{1}{1-\delta}\left[\frac{8\sigma^4(1+2\alpha_p\sigma^2)[1+2(\alpha_a+\alpha_p)\sigma^2]}{[1+2(\alpha_a+\alpha_p)\sigma^2]^4}\right] > 0$$

(C.5) $$\frac{\partial b^*}{\partial \alpha_p} = \frac{1}{1-\delta}\left[\frac{2\sigma^2[1+2(\alpha_a+\alpha_p)\sigma^2]-2\sigma^2(1+2\alpha_p\sigma^2)}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right]$$

$$= \frac{1}{1-\delta}\left[\frac{4\alpha_a\sigma^4}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right] > 0$$

(C.6) $$\frac{\partial^2 b^*}{\partial \alpha_p^2} = \frac{1}{1-\delta}\left[\frac{-16\alpha_a\sigma^6[1+2(\alpha_a+\alpha_p)\sigma^2]}{[1+2(\alpha_a+\alpha_p)\sigma^2]^4}\right] < 0$$

(C.7) $$\frac{\partial b^*}{\partial \sigma^2} = \frac{1}{1-\delta}\left[\frac{2\alpha_p[1+2(\alpha_a+\alpha_p)\sigma^2]-(1+2\alpha_p\sigma^2)[2(\alpha_a+\alpha_p)}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right]$$

$$= \frac{1}{1-\delta}\left[\frac{-2\alpha_a}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right] < 0$$

(C.8) $$\frac{\partial e^*}{\partial \alpha_p} = 0.5\left[\frac{2\sigma^2[1+2(\alpha_a+\alpha_p)\sigma^2]-2\sigma^2(1+2\alpha_p\sigma^2)}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right]$$

$$= 0.5\left[\frac{4\alpha_a\sigma^4}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right] > 0$$

(C.9) $$\frac{\partial^2 e^*}{\partial \alpha_p^2} = 0.5\left[\frac{-16\alpha_a\sigma^6[1+2(\alpha_a+\alpha_p)\sigma^2]}{[1+2(\alpha_a+\alpha_p)\sigma^2]^4}\right] < 0$$

(C.10) $$\frac{\partial e^*}{\partial \alpha_a} = 0.5\left[\frac{-2\sigma^2(1+2\alpha_p\sigma^2)}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right] < 0$$

(C.11) $$\frac{\partial e^{*2}}{\partial \alpha_a^2} = 0.5\left[\frac{8\sigma^4(1+2\alpha_p\sigma^2)[1+2(\alpha_a+\alpha_p)\sigma^2]}{[1+2(\alpha_a+\alpha_p)\sigma^2]^4}\right] > 0$$

(C.12) $$\frac{\partial e^*}{\partial \sigma^2} = 0.5\left[\frac{2\alpha_p[1+2(\alpha_a+\alpha_p)\sigma^2]-(1+2\alpha_p\sigma^2)[2(\alpha_a+\alpha_p)}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right]$$

$$= 0.5\left[\frac{-2\alpha_a}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right] < 0$$

(C.13) $$\frac{\partial w^*}{\partial \alpha_p} = \frac{1}{1-\delta}\{-\mu\left[\frac{2\sigma^2[1+2(\alpha_a+\alpha_p)\sigma^2]-2\sigma^2(1+2\alpha_p\sigma^2)}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right]$$

$$-0.5(1-2\alpha_a\sigma^2)\left(\frac{1+2\alpha_p\sigma^2}{1+2(\alpha_a+\alpha_p)\sigma^2}\right)\left[\frac{2\sigma^2[1+2(\alpha_a+\alpha_p)\sigma^2]-2\sigma^2(1+2\alpha_p\sigma^2)}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right]\}$$

$$= \frac{1}{1-\delta}\{-\mu\left[\frac{4\alpha_a\sigma^4}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right]$$

$$-0.5(1-2\alpha_a\sigma^2)\left(\frac{1+2\alpha_p\sigma^2}{1+2(\alpha_a+\alpha_p)\sigma^2}\right)\left[\frac{4\alpha_a\sigma^4}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right]\}$$

$$= \frac{1}{1-\delta}\{\left[\frac{4\alpha_a\sigma^4}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right][-\mu - 0.5(1-2\alpha_a\sigma^2)\left(\frac{1+2\alpha_p\sigma^2}{1+2(\alpha_a+\alpha_p)\sigma^2}\right)]\} < 0$$

(C.14) $$\frac{\partial w^*}{\partial \sigma^2} = \frac{1}{1-\delta}\{-\mu\left[\frac{2\alpha_p[1+2(\alpha_a+\alpha_p)\sigma^2] - (1+2\alpha_p\sigma^2)[2(\alpha_a+\alpha_p)}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right]$$

$$-0.5(1-2\alpha_a\sigma^2)\left[\frac{2\alpha_p[1+2(\alpha_a+\alpha_p)\sigma^2] - (1+2\alpha_p\sigma^2)[2(\alpha_a+\alpha_p)}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right]$$

$$+0.5\alpha_a\left(\frac{1+2\alpha_p\sigma^2}{1+2(\alpha_a+\alpha_p)\sigma^2}\right)^2\}$$

$$= \{\mu\left[\frac{2\alpha_a}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right] + 0.5(1-2\alpha_a\sigma^2)\left[\frac{2\alpha_a}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right]$$

$$+0.5\alpha_a\left(\frac{1+2\alpha_p\sigma^2}{1+2(\alpha_a+\alpha_p)\sigma^2}\right)^2\}$$

$$= \{\left[\frac{2\alpha_a}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right](\mu + 0.5(1-2\alpha_a\sigma^2)$$

$$+0.5\alpha_a\left(\frac{1+2\alpha_p\sigma^2}{1+2(\alpha_a+\alpha_p)\sigma^2}\right)^2\} > 0$$

(C.15) $$\frac{\partial w^*}{\partial \alpha_a} = \frac{1}{1-\delta}\{\mu\left[\frac{2\sigma^2(1+2\alpha_p\sigma^2)}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right]$$

$$+0.5(1-2\alpha_a\sigma^2)\left(\frac{1+2\alpha_p\sigma^2}{1+2(\alpha_a+\alpha_p)\sigma^2}\right)\left[\frac{2\sigma^2(1+2\alpha_p\sigma^2)}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right]$$

$$+0.5\sigma^2\left(\frac{1+2\alpha_p\sigma^2}{1+2(\alpha_a+\alpha_p)\sigma^2}\right)^2\}$$

$$= \frac{1}{1-\delta}\{\left[\frac{2\sigma^2(1+2\alpha_p\sigma^2)}{[1+2(\alpha_a+\alpha_p)\sigma^2]^2}\right][\mu+0.5(1-2\alpha_a\sigma^2)\left(\frac{1+2\alpha_p\sigma^2}{1+2(\alpha_a+\alpha_p)\sigma^2}\right)]$$

$$+0.5\sigma^2\left(\frac{1+2\alpha_p\sigma^2}{1+2(\alpha_a+\alpha_p)\sigma^2}\right)^2\} > 0$$

(C.16) $$\frac{\partial w^*}{\partial \delta} = \frac{1}{(1-\delta)^2}\{\bar{U} - \left(\frac{\left(1+2\alpha_p\sigma^2\right)}{\left(1+2(\alpha_a+\alpha_p)\sigma^2\right)}\right)\mu$$

$$-0.25\left(\frac{\left(1+2\alpha_p\sigma^2\right)}{\left(1+2(\alpha_a+\alpha_p)\sigma^2\right)}\right)^2\left(1-2\alpha_a\sigma^2\right)\} > 0$$

(C.17) $$\frac{\partial^2 w^*}{\partial \delta^2} = \frac{2}{(1-\delta)^3}\{\bar{U} - \left(\frac{\left(1+2\alpha_p\sigma^2\right)}{\left(1+2(\alpha_a+\alpha_p)\sigma^2\right)}\right)\mu$$

$$-0.25\left(\frac{\left(1+2\alpha_p\sigma^2\right)}{\left(1+2(\alpha_a+\alpha_p)\sigma^2\right)}\right)^2\left(1-2\alpha_a\sigma^2\right)\} > 0$$

(C.18) $$\frac{\partial w^*}{\partial \bar{U}} = \frac{1}{(1-\delta)} > 0$$

(C.19) $$\frac{\partial w^*}{\partial \mu} = \frac{-1}{(1-\delta)}\left(\frac{\left(1+2\alpha_p\sigma^2\right)}{\left(1+2(\alpha_a+\alpha_p)\sigma^2\right)}\right) < 0$$

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