DYNAMIC OPTIMIZATION OF CONSUMPTION SMOOTHING, INSURANCE,

AND DEBT UNDER LIQUIDITY CONSTRAINT

By

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Under the direction of Jeffrey D. Mullen

ABSTRACT

The dynamic optimization process of consumption, insurance, and debt and its relationship with farm precautionary wealth are simulated by a stochastic dynamic model. Both finite and infinite optimization horizon are considered to examine the effect of retirement plans on optimal strategy paths and the resulting net wealth path. A risk averse cotton farmer in Mitchell, Georgia, is supposed to maximize the expected utility defined over life-cycle consumption. Irrigation, insurance, and credit are considered explicitly as three strategies to cope with risk associated with income shocks. Three types of insurance products, a traditional farm-yield based Multi-peril Crop Insurance (MPCI), an area-yield based Group Risk Plan (GRP), and a precipitation based Weather Derivative (WD), are compared to investigate the impact of basis risk on the optimization process. Effects of liquidity constraint, premium loading, market risk, risk aversion level, impatience level, and interest rate on the optimal process are examined through sensitivity analysis.

The results show that the choice variables and state variable wealth evolve over time to reach a steady-state distribution, which provide insight about the behavior of most farmers in the economy. The result concerning marginal propensity to consume (MPC) seems to support Friedman (1957)'s PIH theory and provides intuition that poor farmers use a larger proportion of transitory income for consumption than rich farmers. The result concerning insurance confirms Gollier (2003)'s conclusion, that wealthier farmers tend to reduce insurance purchase.

A variety of sensitivity analysis shows that the general shape of the consumption function $c(w)$ (increasing and concave) is unchanged under alternative scenarios. Under stricter liquidity constraint, MPC is higher, indicating that the farmer's consumption level is more influenced by transitory shock to their income than that in benchmark case. More impatient/poor farmers are shown to have higher intention to invest in insurance for precautionary purposes, even if the insurance is expensive. Changes in interest rate and in farmers' credit limit are shown to have great impact on consumption, insurance, and debt, which would be valuable for government agencies interested in monetary policy transmission. Basis risk leads farmers to accumulate desired precautionary wealth and to reduce desired insurance holdings.

INDEX WORDS: Risk Management, MPCI, GRP, WD, Consumption Smoothing, Liquidity Constraint, Dynamic Optimization

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CHAPTER 1

INTRODUCTION AND PROBLEM STATEMENT

1.1 IMPORTANCE OF AGRICULTURAL RISK MANAGEMENT AND MOTIVATION OF THE STUDY

Agriculture has usually been characterized by a high degree of risk, including market risk, production risk, and financial risks confronted by producers (Velandia *et al.* 2009). Production risk is typically assumed to originate from uncertainties and variations in weather conditions like drought and freeze, soil quality, pests, diseases, etc. Market risk is usually involves with uncertainties in output prices and production costs. While market risk typically refers to input/output price variation resulting from the market supply and demand shifts, production risk includes variability of crop yield due to spatial and temporal weather, such as extreme rainfall and temperature events and natural disasters (USDA, Briefing Rooms 2009).

Risk management means to maintain a certain level of income and to avoid or reduce loss when a bad state happens (Olofsson 2010). Generally people have two options to deal with disease, danger, etc.: preventing beforehand or treating afterwards. For risk, the principle is the same. Olofsson (2010) classifies risk management options into two classes. One class is to "reduce the actual exposure to risk" (avoid risk); examples are building stronger wind shelters, using pesticide, applying supplemental irrigation, etc. Another class is to "cope with the effect of risk" (accept, mitigate, and transfer the effect of risk) (Olofsson 2010); for example, farmers can buy insurance and get indemnity payment if the production is below a contracted level; for market risk, futures/forward contracting is used to hedge against price variation. Farmers can also build up reserves, like deposit or other types of accumulated assets, or use credit (borrowing and savings) to mitigate consequences of unanticipated income shocks .

In reality, farmers choose a combination of options to provide the best protection against various risks (Velandia *et al.* 2009). However, most previous studies only analyzed a single risk management instrument; very few studies investigated the simultaneous adoption of these instruments and the potential interaction among them. In these few studies, Coble *et al*. (2000) investigated the interaction between new types of crop insurance and futures/options contracts. However, the authors used a static utility model which is defined over end-of-season wealth (W). Lin *et al*. (2009) analyzed on-farm risk management including both irrigation and weather derivative contracts; although they analyzed the dynamic aspect of crop production strategy, they did not analyze the dynamic aspect of weather derivative contract; in addition, the authors used expected utility function which is a function of net profit for a single year instead of consumption level for the whole life-time, and thus only produced discontinuous ex-post dynamic crop production strategy for a given optimization period.

Effective risk management should be forward-looking and should be able to change continuously over time. As farming enterprises and systems are dynamic and change over time, which introduce different and new patterns of risk, new ways of risk management techniques are needed to be updated immediately in order to cope with those new risks and to establish the link between a loss and the cause of that loss (Olofsson 2010). Some papers on hedging and supply-response model used dynamic optimization (e.g., Chambers and Lopez. (1984), Karp (1987), Martinez and Zering (1992), Meyer and Meyer (2005)); however, most previous studies on insurance used static optimization model (e.g., Hofflander *et al*. (1971), Doherty (1975), Shavell (1979), Andersen and Danthine (1981), Saha *et al*. (1994), Lin *et al*. (2009)).

This dissertation tries to extend Lin *et al.*'s (2009) study and to fill in the gap of the literature by using a stochastic dynamic model corresponding to life-time planning of consumption, insurance, and credit decisions. Both finite and infinite optimization horizon are considered to examine the effect of retirement plan on optimal strategies path and the resulting net wealth path. Life-time consumption, rather than one-year net profit, is now an important determinant of farmer's decision making. Irrigation, insurance, and credit (deposit/debt) are considered explicitly in this paper as three strategies to cope with risk associated with income shocks.

Agricultural insurance has gained increased attention since last century as a risk management tool, by covering losses from adverse weather and other risky events beyond the control of farmers, as well as by pooling and spreading risk across economy and through time. However, as pointed out by Arrow (1963), insurance has a variety of significant empirical problems. Major problems include moral hazard, high transaction cost (high premium loadings), adverse selection, insurability, systemic risk (e.g., Doherty (1975), Chambers (1989), Barnett and Skees (1994), Coble *et al*.

(1996), Liang and Coble (2009), Miranda and Glauber (1997)). It is easy to understand why insurance industry are faced with large transaction costs: because of moral hazard, adverse selection, and catastrophic risk problems, insurance companies must develop expensive technologies for auditing and monitoring individual risks and for loss adjustment, whose costs are eventually passed onto the policy holder through a loading on the premium (Skees and Barnett 2006). These problems lead to high transaction cost of traditional insurance, and at the same time, calls for the emergence of innovations and new types of insurance products.

Classic crop insurance can be classified into two main types: indemnity-based and yield-based (Olofsson 2010). Indemnity-based insurance is based on a measure of the actual loss incurred by the policy holder, and is often caused by single perils such as fire, hail, windstorm, frost, etc. Yield-based insurance is also called "Multi-Peril Crop Insurance"(MPCI), which covers against production loss caused by multiple possible perils that in junction affect production (Olofsson 2010). For both these classic crop insurance products, actual physical loss or damage is measured in-field, and the claim is specific to the field/farmer. This characteristic, along with fact that farmers are exposed to spatially correlated risks, lead to the problems of systemic risk and asymmetric information (Miranda 1991), and as a result, these two types of insurance schemes need substantial government support. Stoppa and Hess (2003) stated that in recent years policymakers often intend to design policy instruments that are more "market-oriented" and can induce farmers to use resources more efficiently and equitably, rather than to rely on free disaster aid. Under this policy orientation, a number of studies were conducted to develop innovative and sophisticated insurance programs, like Group Risk Plan which is based on area-yield, Weather Derivatives which is based on measured weather index at a given weather station, Group Risk Income Plan which is based on area-income, and to analyze their efficiency and impact on production, input use, and producers' profit and welfare (Stoppa and Hess 2003).

Innovative insurance products include crop area yield index insurance, weather index insurance, livestock mortality index insurance, etc. For these new insurances, the indemnity is calculated based on a public and transparent index designed to resemble farmers' loss (Miranda 1991). Miranda (1991) is one of the first authors to call for area-yield crop insurance. A lot of studies contended that area-yield crop insurance and/or other index insurance can provide more effective and better loss-coverage compared with traditional insurance, without most of the problems like adverse selection and moral hazard which are inherent in traditional indemnity-based and yield-based insurance, although they raise the issue of basis risk (e.g., Miranda (1991), Edwards *et al.* (2000), Chan and Black (2004), Skees and Barnett (2006)).

Farmers' reliance on credit as a risk management strategy protecting against income variation, on the other hand, introduces other sources of risk in terms of financial institution's lending decision to farmers. It is difficult to develop procedures for measuring a farmer's credit risk and determining the cost and availability of the supply of credit because of the complexity of credit determinants. One determinant is the micro-effect of the farmer-lender relationship that reflects the lender's concept of farmers' credit worthiness, which is usually evaluated based on the evidence farmers provide to assure that credit risk is below the allowing threshold. For example, financial institutions are unwilling to lend money to farmers whose probability of default (PD) is higher than their established threshold (Deng 2005). Other factors affecting the supply of available credit might include banks' own financial situation, bank regulations, macro-conditions related to monetary/fiscal policies (e.g., reserve requirement ratio), interest rate (related to inflation), and aggregate economic performance (affecting credit demand). These factors influence, but are not influenced by farmers' risk management, as farmers can only monitor them as part of their financial environment. It is thus difficult to control these factors, which introduced added uncertainty to farmers.

The risk associated with cost and availability of credit and the resulting liquidity constraint on farmers, thus is an added element of farmers' risk that would possibly affect farmers' risk management decisions but has not been accounted for in most previous studies. Most previous risk management studies assumed a complete and perfect credit market, in which farmers can borrow against their future income at the risk-free rate of interest (Nyambane 2005). This assumption, however, has been tested and rejected in most of the current studies on consumer theory.

Permanent Income Hypothesis (PIH) has been stated and tested in a lot of previous studies (e.g., Friedman (1957), Hall (1978), Flavin (1981), Campbell and Gregory (1990)), and several studies rejected the permanent income hypothesis by empirically estimating the coefficient of transitory income in consumption function (the sensitivity of consumption to transitory income), and stated that the failure of the assumption of perfect credit market (the existence of liquidity constraints) may be the reason for the estimated excess sensitivity (e.g., Zeldes (1989), Flavin (1985), Evans and Karras (1998)). Although there is a debate on whether the high Marginal Propensity to Consume (MPC) should be attributed to liquidity constraint, it is an acknowledged fact that borrowing constraint is a reality, which is demonstrated by the practices of banks which use various tools to determine the credit score and credit limit for a specific borrower.

If liquidity constraints exist, farmers who buy insurance might be viewed by banks as having lower credit default risk and thus have higher credit limit and higher debt. On the other hand, under the same liquidity constraint, farmers who borrow more money might have lower net wealth and thus may not be able to buy insurance (or need to spend more on insurance because of higher precautionary motive). However, the existing literature on this subject is very limited. Among these few studies, Gollier (2003) argued that with liquidity constraint, farmers with larger wealth would have low or no demand for insurance, and that only poor people who are currently liquidity constrained or who are faced with catastrophic risk would have demand for insurance. Nyambane (2005) contended that liquidity constraints leads to an insurance level lower than full insurance and provided different result concerning the relationship between insurance and liquidity constraint compared with the result of Gollier (2003). While these studies made great contributions in this field, Nyambane (2005) only compared the insurance choices with and without liquidity constraint, but didn't examine the effect of different levels of liquidity constraint (the severity of liquidity constraint) on insurance choices. Moreover, these studies did not explicitly analyze the other way around - the impact of insurance on debt and consumption smoothing, nor did they analyze the time path of consumption, insurance, or debt decision.

The real-world multi-instruments risk management practice, the dynamic aspect of risk management, the added risk from credit market, are all motivations of this study, an attempt to explore the dynamic perspectives of management of risks involved in agricultural production, price variation, and imperfect credit market. Three types of insurance products, an individual farm-yield based Muti-peril Crop Insurance (MPCI), a county-yield based Group Risk Plan (GRP), and a precipitation based Weather Derivative (WD), are compared to examine the role of basis risk in farmer's dynamic decision making as well as the impact of innovations in insurance and finance on farmers' decision making. The effect of liquidity constraint, premium loading, market risk, farmers' risk aversion, impatience level, interest rate, and basis risk are examined through sensitivity analysis, to provide a better understanding of how these parameters influence the dynamic optimization process, as well as how a variety of potential policy interventions influence farmers' behavior.

1.2 RESERACH OBJECTIVES

The main objective of this dissertation is to apply and update a dynamic life cycle model for the analysis of risk management and consumption smoothing. The special objective is to identify and examine the impact of potential policies and interventions which are intended to help farmers cope with risk or to transmit credit shock and monetary policy to farmers. To accomplish this task, the following particular tasks are pursued:

1. To apply and update a dynamic stochastic model which portrays the optimal life-cycle decisions for a farmer subject to a liquidity constraint. This would be of interest to policymakers, deposit/debt financial institutions, or insurance company who want to know what is farmers' demand for consumption, credit, and insurance and in what time frame.

2. To examine the relationship between optimal choices and the state variable wealth. This would have implications for policy/insurance designs targeted at different farmers (wealthy or poor).

3. To investigate whether there is a steady state for the optimization process and if so, what are the farmers’ decisions and the total amount and component of the precautionary wealth portfolio. This information would be especially critical for policymakers who want to understand the behavior of most farmers in the economy.

4. To conduct sensitivity analysis under various alternative assumptions on the financial institutions (level of liquidity constraint, premium loading, interest rate), the market (i.e., output price), and farmers (i.e., time preference, risk aversion level). This would have valuable policy implications for policymakers to understand the impact of government interventions on different types of farmers.

It is important to conduct pilot test prior to the implementation of new agricultural financial services, like new insurance or agricultural banks/funds programs (Skees and Barnett 2006). This information would be valuable in determining the technical design, size, scope, and rating of the new services. To accomplish these goals, a Bellman's Equation of dynamic optimization is used to simulate results under different scenarios, which breaks the dynamic decision problem into smaller sub-problems. As our problem is a stochastic decision that affected by a random element (the uncertainty of future income in our study), a closed-form solution is impossible or difficult to get (Seater 1993). For this reason, numeric stochastic dynamic programming (DP) is used to approximate the solution to the model.

1.3 ORGANIZATION

The dissertation is composed of six chapters. Chapter 2 reviewes the literatures on risk management, including hedging, APH-based insurance and indexes insurance products, the problems inherent in traditional insurance products, the dynamic models in related studies, the permanent income hypothesis, the test and impact of liquidity constraint, precautionary saving, and consumption smoothing in agricultural context. Chapter 3 provides a conceptual framework on the theory of dynamic optimization of consumption smoothing and insurance under liquidity constraint, with a brief description of experimental design on different types of insurance products. Chapter 4 provides a more elaborated description of numeric dynamic stochastic model of consumption, insurance, savings/borrowing, and precautionary wealth portfolio decisions, and presents the results of dynamic choices paths, the relationship of the choices and precautionary wealth, and the impact of retirement plan (which may induce higher precautionary saving motif) on the results. Several simulations on liquidity constraint, premium loading, market price, risk aversion level, impatience level, interest rate, and basis risk are reported in Chapter 5. Chapter 6 summarizes the main findings, along with policy implications and suggestions.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The literature pertinent to the present study is summarized in this chapter. It provides a review of agricultural insurance, consumption smoothing, and credit in general. The review on risk management shows the applications of different risk management instruments, the inherent problems in traditional APH-based insurance products, an increasing knowledge of and interest in index insurance and its application, the comparison of traditional Multi-peril Crop Insurance (MPCI) and index insurance (GRP and Weather derivative insurance), and the dynamic method in risk management literature.

The review on consumption smoothing, liquidity constraint, and credit/savings reviewed the empirical tests of Permanent Income Hypothesis (PIH) (Friedman 1957), which are mostly the tests of whether the observed consumption is sensitive to transitory income; the possible reason for the rejection of the hypothesis, which most studies found to be liquidity constraint; the role and interactions of consumption smoothing, wealth, savings, and credit in farmers' risk management.

Consequently, the interaction among insurance (MPCI, GRP, and WD), consumption, debt/deposit, and precautionary wealth under liquidity constraint, leads the spotlight shooting on optimal design of dynamic agricultural insurance and financial facilities that is the motivation of this study.

2.2 LITERATURE ON RISK MANAGEMENT

In reality, farmers use a variety of risk management tools to maintain income, to avoid risk, and to reduce the loss and damage of the risk from undesirable bad states. Examples are using credit (deposit or debt) to maintain income; applying irrigation and pesticide to avoid production risk; purchasing insurance to reduce the impact of production risk; hedging in future markets to reduce the impact of market risk.

However, most previous studies only analyzed a single risk management instrument; very few studies investigated the simultaneous adoption of various risk management instruments in farmers' portfolio and the potential interaction among them.

Among the studies on a single risk management instrument, Hofflander *et al.* (1971) examined the implications of using a wealth maximizing model to determine the optimal amount of property insurance to cover a structure or plant and to estimate the contribution of insurance to long run profitability. The wealth maximizing model, noted by the authors, is equivalent to maximize a utility function of the cumulative return on a firm's net worth over many decision periods. The author also conducted sensitivity analysis to examine the impact of taxes, expenses, and the firm's capital structure on the optimal insurance decision and on the long run profitability.

Doherty (1975) is one of the first studies that explored how the expected utility equation can be applied to the risk management (insurance) situation, and used the expected utility framework to examine how rational risk management decisions are influenced by the structure and level of insurance premium. He concluded that the relationship between insurance and loss prevention is highly dependent on the size, structure, and nature of the premium loading.

Shavell (1979) analyzed the relationship between agents' and principals' attitudes toward risk and the Pareto-optimal fee schedules. He studied the contractual arrangements related to the amount of fee that a principal should pay to his agent, and argued that the Pareto optimal fee arrangement must be able to allocate and share risk appropriately and to provide good incentives to influence the agent's activity. The author concluded that both the agents' attitudes toward risk and the principals' attitudes toward risk play an important role in determining the design of the Pareto-optimal fee schedules.

Mean-variance criteria have been used a lot in the risk management literature. Andersen and Danthine (1981) derived optimal decision rules based on the mean-variance criteria in hedging in futures markets to examine how price expectations and production possibilities affect the optimal futures and cash positions. They proved that a hedging ratio under a mean-variance criteria is analytically the same as the hedging ratio using variance minimizing method if spot position is fixed and determined beforehand and if the futures price series satisfies the condition $E(\Delta F) = 0$ (i.e., follows a martingale). The author suggested that as long as the market spot prices and the prices in the futures market used for hedging purposes are related (correlation is not equal to zero), there is an opportunity to hedge.

In the literature of hedging, Myers and Thompson (1989) argued that there is no appropriate simple regression approach to optimal hedging ratio except under special circumstances. The reason, as they stated, is that a simple regression only estimates a slope parameter that is equivalent to the ratio of the unconditional covariance (between the explanatory variable and the dependent variable) to the unconditional variance (of the explanatory variable); however, the optimal hedging rules should use conditional covariance and conditional variance as the rules should be based on the available information when decision is made. The authors thus developed a generalized approach for the estimation of optimal hedge ratios on the basis of the conditional covariance and variance that is conditioned on information available when decision is made. The authors then used the generalized approach to evaluate the appropriateness of conventional simple regression approaches in an empirical study of storage hedging of corn, soybeans, and wheat. Their results found that simple regression using the levels of price or revenue leads to errors in optimal hedge ratio estimation but the simple regression using changes in price or revenues provides reasonably accurate estimates.

Regarding the utility function used in the literature, a lot of authors proposed to use a decreasing absolute risk aversion utility. Epstein (1983) examined the utility indices with the property of decreasing absolute risk aversion (DARA) and established the characterization of decreasing absolute risk aversion utility indices. He stated that the necessary and sufficient condition for DARA utility index is that the index is the indirect function related to a concave and non-decreasing utility function of consumption for an infinite optimization horizon. Saha *et al*. (1994) developed a method using Expo-power Utility to study the risk aversion aspect of wheat farmers in

Kansas including both relative risk aversion and absolute risk aversion, which did not impose any restriction on the structure of risk aversion and permitted joint estimation of production technology, risk aversion level, and structure of risk preference. Their results rejected the null hypothesis which assumed neutrality of risk, in favor of the alternative hypothesis which assumed that the farmers in Kansas exhibited decreasing absolute risk aversion with respect to wealth and increasing relative risk aversion (DARA-IRRA).

Among the few authors who investigated the interaction between different risk management instruments, Coble *et al*. (2000) examined the interaction between new types of crop insurance and futures/options contracts. The authors conducted numerical analysis which incorporated futures price, basis, and yield variability, and examined optimal futures and put ratios in the presence of four alternative insurance coverages. A positive relationship was found between yield insurance and hedging levels. Revenue insurance, on the other hand, was found to result in slightly lower hedging level than yield insurance did, but the relationship between hedging level and revenue insurance was still positive. However, the author assumed that the producer's objective function is the expected value of a utility function which is function of final wealth and assumed that the portfolio would be selected according to the expected utility criteria, and thus it was a static portfolio model under uncertainty.

In the literature on problems and innovations of insurance products, many authors recognized that insurance products have a variety of significant empirical problems (Arrow 1963). Major problems include moral hazard, adverse selection, high premium loadings, insurability, systemic risk, etc.

Arrow (1963) pointed out that moral hazard is one of the inherent problems of insurance. He stressed that insurance provides incentives for the individual to change their activity, which leads to moral hazard problem. He provided an example of moral hazard problem in medical care industry, with the phenomenon that the demand for medical care increases as a result of the widespread medical insurance.

Doherty (1975) followed the work of Arrow (1963), and examined the "moral hazard" argument, which as he stated, is related to the fact that insurance discourages expenditure on loss prevention: as people are insured to get payment when actual loss happens, they would not do necessary precautionary actions to prevent the loss from happening.

Chambers (1989) pointed out the persistence of adverse selection and moral hazard problems that impeded the development and application of crop insurance. He also pointed out the concept of insurability, and related insurability to the availability of rational individually-tailored insurance products, in other words, whether the insurance products can make both principals and agents better off compared with the situation without insurance. The author examined the effect of moral hazard on agricultural insurance indemnity schedules for constant absolute risk aversion farmers, and provides results showing that moral hazard may lead to lower deductibles.

Barnett and Skees (1994) analyzed two critical research issues related to MPCI: price elasticity of MPCI and the impact of changes in insurance premium on the total expected insurance indemnities and total expected insurance revenue. They confirmed that price elasticities of demand would be different for insurance buyers with different expected insurance indemnity, and presented a variety of recent empirical estimates of the MPCI price elasticity from some other studies.

They also contended that: as insurance premium increases, total expected indemnities received by farmers should decrease because of the decrease in total insured acres; however, total premium (loaded) revenue received by insurers should increase due to the overall inelastic demand. They also stated that while it is possible that the increase in insurance premium may cause adverse selection, it is impossible for it to cause increase in the loss ratio if the overall demand is inelastic.

Coble *et al*. (1996) used a random-effect, binomial PROBIT model with data of a panel of wheat farms in Kansas to examine the impact of adverse selection on MPCI demand. They classified adverse selection into two types: spatial and inter-temporal, and focused on the inter-temporal aspect of adverse selection. They developed a model that includes weather variables and the first and second moments of both the revenue from crop selling and the indemnity from insurance.

The estimated predictive power of weather variable was assumed to represent the inter-temporal aspect of adverse selection. The estimated price elasticity of insurance demand is -.65, confirming that insurance demand is inelastic. The results also indicated that while the first and second moments of return to crop selling and the first and second moments of return to insurance were significant, the weather variables were not significant. The author thus concluded that the data did not support the hypothesis of inter-temporal adverse selection.

Miranda and Glauber (1997) stated that "without affordable reinsurance, private crop insurance markets are doomed to fail because systemic weather effects induce high correlation among farm-level yields, defeating insurers' efforts to pool risks across farms." The authors used an empirical model to study the U.S. crop insurance market, and found that if there was no systemic risk, yields were stochastically independent across farms, and the portfolios of crop insurance companies would only have 1/50 to 1/20 risk compared with the current situation. They proposed to use area yield reinsurance contracts which would, as they stated, enabled crop insurance companies to mostly mitigate the systemic risk of crop loss.

Liang and Coble (2009) employed a trans-log cost function analysis method to investigate the existence of moral hazard in cotton buy-up insurance for Mississippi cotton production. Their results found that per acre agricultural input cost is statistically significant in predicting farmers' cotton buy-up insurance decision; and they concluded that moral hazard can affect agricultural input usage, and whether the effect is decreasing or increasing is ambiguous, and depends on specific production condition in a given year.

As all APH-based agricultural insurance schemes are plagued by these problems, they need substantial government support in order to survive, which does not solve the problems. A significant number of studies were conducted to develop innovative and sophisticated insurance programs to offer more effective loss coverage and to alleviate the problems rooted in traditional insurance products.

Miranda (1991) is one of the first authors who proposed to develop area-yield crop insurance, whose premium rates and indemnities are calculated on the basis the average yield of some surrounding area (e.g., a county) instead of on the farmer's individual yield. The author suggested that area-yield crop insurance would offer better loss coverage than traditional individually tailored insurance, by solving most of problems like information asymmetry, systematic risk, adverse selection, and moral hazard that impeded the development of traditional federal agricultural insurance program.

Edwards *et al*. (2000) summarized and compared the important characteristics of the different categories of crop insurance. While Multiple Peril Crop Insurance (MPCI) and Catastrophic Insurance (CAT) insurance products are based on actual farm-level yield, Crop Revenue Coverage (CRC) and Revenue Assurance (RA) insures against individual revenue risk and indemnities are defined over the actual farm yield and futures price at harvest, and Group Risk Plan (GRP) insures against county level production risk and indemnity is based on county yield. The authors stated that most of the insurance products can be customized and offered to farmers with different needs, by selecting different price and yield coverage levels, selecting add-on features, etc.

Chaffin (2009) compared the cumulative probability distributions of net yields with and without insurance to analyze the effects of county and farm trigger insurance policies on risk mitigation and transfer and also analyzed the factors that contributes to basis risk. The author used case studies to track the correlation between farm yields and county yields, in order to examine the relationship of the farm-county yield correlation and basis risk in risk transfer performance. The results indicated that the farm location and spatial diversification result in variations in the farm-county yield correlations, which lead to basis risk, and the basis risk is directly related to the county trigger insurance's risk transfer performance compared with no insurance and with farm trigger insurance.

Skees and Barnett (2006) studied how to enhance microfinance and microcredit with Index-based Risk-Transfer Products (IPRTPs), which is composed of a variety of index-based financial risk management instruments (options, bonds, derivatives, insurance products, etc.) designed to transfer correlated risks between parties; thus far, the major pilot programs include: Group Risk Income Protection (GRIP) and Group Risk Plan (GRP) which are offered by the U. S. Federal Crop Insurance Program; catastrophe insurance (CAT) and options which are used mostly by casualty and property insurers; and weather derivatives based on objectively measured weather index like cumulative rainfall and heating degree day (HDD) (Skees and Barnett 2006).

Skees and Barnett (2006) noted that while most of the current rainfall based IBRTPs are over-the-counter products, standardized temperature (like HDD) based IBRTPs are traded in exchange markets for mostly energy sectors in some major cities; most IBRTPs based on weather indexes are customized and offered to the end users with different needs and sold by reinsurers. The authors stated that in developing countries where traditional insurance and financial institutions are plagued by asymmetric information, systematic risk, and high transaction costs, the use of index insurance contracts offers great opportunities for microfinance entities (MFEs), as IBRTPs transfer systemic risk into global markets, eliminate the potential problems like adverse selection and moral hazard, and have lower transaction costs because of lower cost in monitoring and loss adjusting procedure. The authors also summarized the largest challenges of IBRTPs: finding low-cost delivery mechanisms and the basis risk inherent in IBRTPs.

Mount (2002) analyzed the feasibility and impact of weather derivative contract in energy section. Specifically, the author combined a forward contact and a collar option, and investigated the advantages of this risk management portfolio in protecting against the risk involved in purchasing electricity. The author found that making peaking power expensive strengthens the effectiveness of price signal, and that the portfolio of risk management instruments increases the correlation between weather derivative indemnity and high spot markets prices, and thus offers advantage over single weather derivative tool.

Brix *et al*. (2002) addressed the data and technical issues of pricing weather derivatives based on temperature indices as risk management instruments. They started by considering dynamics of the historical weather data and described how to forecast weather, including how to estimate and remove the trends. They then proceeded to analyze the application of the statistical methods for modeling weather indexes (daily temperatures), including both non-parametric distribution and parametric time-series modeling, and in particular they showed that traditional ARMA time-series models are not adequate for modeling daily temperatures. The authors then derived a modification of the Black and Scholes formula which is the main formula of the no-arbitrage model of pricing financial derivatives in a liquid market. The authors expected that a liquid weather derivative market would emerge and develop in the future, and thus anticipated that no-arbitrage pricing will in some cases replace actuarial methods; however, for most weather derivative contracts that currently are not yet liquid enough to justify no-arbitrage pricing, the authors stated that the most reasonable valuation approach will continue to be the actuarial methods.

Richards and Sanders (2004) examined the usefulness of temperature-based weather derivative product in protecting against production risks for nectarine growers in California. The authors developed an insurance pricing model that considers the weather derivative with the underlying index of cumulative cooling degree days (CDD) as one of traditional financial assets, and allowed for the properties of time-varying volatility, mean reversion, and discrete jump diffusion instead of continuous diffusion processes.

They adapted and applied a variety of statistical tests to identify the proper stochastic process of the underlying CDD index and then defined the price of weather derivative based on an equilibrium pricing model using the parameters of the stochastic process through a Monte Carlo simulation method. They found that under alternative stochastic process assumptions regarding the underlying CDD index, the obtained weather derivative prices are significantly different, indicating that mis-specifying the stochastic process of the weather index underlying the weather derivatives contract can lead to mis-pricing of weather derivatives insurance. However, their study concerned only the weather derivatives for a single region, without the consideration of basis risk associated with adjacent weather stations.

While these studies made important contributions to the innovative risk management literature, all the above cited studies used static models to define decision makers' objective function. While Brix *et al.* (2002) and Richards and Sanders (2004) considered the dynamic aspect of the underlying indices (e.g., temperature), they didn't analyze the dynamic decision process of the weather derivative parameters (e.g., farmers may choose different limit parameters and thus different priced weather derivatives for different time period, under their dynamic optimization decision scheme). The following section summarizes studies using dynamic models of decision process, of which most are not focused on insurance, but can shed some light on our study on dynamic risk management.

In the literature related to dynamic models, Chavas and Holt (1990) pointed out the importance of linking empirical supply response and economic theory in a dynamic framework, and that risk and risk behavior are important in agricultural production decisions. They thus tried to develop an acreage supply response model to estimate a system of risk-response acreage equations for U.S. corn and soybeans producers. Their results suggested that risk and wealth variables have great impact on the crop acreage decisions.

Chambers and Lopez (1984) applied a general dynamic continuous time model with infinite horizon to the analysis of general supply response model. The authors discussed certain properties of "a general autonomous control model" and emphasized the potential empirical applications of the model to agricultural economics, resource economics, and related fields.

Karp (1987) analyzed the joint hedging/production problem - how futures and forward markets influence the production decision, with special emphasis on two aspects of the problem: dynamics and production uncertainty. The author stated that, if the initial decision is affected by the anticipation of future revision, which implies that the current price is not an unbiased estimator of future price in every period, then the dynamic model is an improvement over the static model.

Uncertain production was the second aspect the author emphasized: "If production were certain, the farmer could sell the entire crop forward to obtain a known present value of revenue". However, if production is stochastic, the producer needs to decide whether to over-hedge or under-hedge using another strategy. Thus, the author developed and solved a dynamic hedging model with stochastic production, and analyzed the resulting distribution of revenue numerically. The results confirmed the hypothesis that optimal future hedges would be chosen dynamically based on the most current information, which "enables the analyst to select the risk aversion parameter that results in the preferred distribution of revenue".

Sargent (1987) presents a variety of dynamic equilibrium models that were developed to simulate the time path of economic aggregates and to predict the impact of alternative government policies on these aggregates. The author described dynamic numeric programming technique, optimal dynamic growth model, and dynamic arbitrage pricing models, etc., and provided applications of these dynamic models to real world prediction of economic indexes like interest rates, stock prices, and option prices.

Martinez and Zering (1992) emphasized the potential empirical applications of dynamic model to the optimal hedging problem faced by corn producers in North Carolina. The authors assumed that the actual farm-level yield, yield basis at harvest in futures market, and futures prices in futures market are all unknown, and by estimating their values and their variance and covariance, they managed to calculate the optimal dynamic hedging ratio. They provided different conclusion compared with Karp (1987)'s, and concluded that if producers update their hedge position infrequently during the crop growing season, the commissions and gains from the dynamic hedging would only be slightly larger than that from a fixed hedge position.

Myers and Hanson (1996) solved a discrete-time dynamic hedging problem with basis risk using expected utility maximization criteria. The author stated that the estimated hedging ratios are valid for any increasing and strictly concave utility function. They also stated that as no particular parametric form was imposed for the utility function, and no specific distribution was assumed for cash and futures prices, and thus the dynamic hedging ratios can be estimated similarly as that in estimating static hedge ratios.

Farr and Luengo-Prado (2001) proposed two methods to solve a nonlinear expected utility defined over dynamic consumption, including both consumption of durables and consumption of nondurables. One method is called the "Euler Equation

Iteration" and the other is the "Finite-State Approximation". The authors stated that while the Euler Equation Iteration is a fast and precise method for inter-temporal consumption models which can apply the Euler Equation Iteration framework and be solved rigorously; for some multidimensional problems with geometric structure that cannot apply the nonlinear Euler equations, it is possible for a Finite-State approximation method to approximate the Euler Equation Iteration solution with relatively good precision.

Meyer and Meyer (2005) examined the disparity in the empirical estimates of relative risk aversion coefficients, and investigated the relationship between these estimates. In the study, the authors compared the risk aversion based on utility function defined over consumption, and the risk aversion based on value function defined over wealth, and stated that the relationship is influenced by the relationship between the objective functions, or the outcome variables. The authors proposed to use a time separable utility function to adjust a various of reported relative risk aversion levels and to eliminate the problem related to incomparability of estimated relative risk aversion measures.

While these studies were not directly related to our study, they offer us the concept and methodology of dynamic modeling and shed light on our study of dynamic optimization of consumption, insurance, credit, and precautionary wealth.

2.3 LITERATURE ON CONSUMPTION SMOOTHING

Permanent Income Hypothesis (PIH) has been stated and tested in a large number of previous studies. In Chapter III of Friedman’s (1957) book, Theory of the Consumption Function, the author proposed to treat consumer's measured income for some time period (e.g., a year) as the sum of a permanent income component and transitory income component. The permanent component reflects the effect of factors which determines household's wealth - nonhuman wealth (property, capital value, money, etc.) and human wealth (training, ability, personality, occupation, location, etc.) The transitory component reflects other factors, like accidental or chance occurrences, cyclical economic fluctuations, etc.

Friedman (1957) stated that it is unnecessary to pre-describe the meaning of permanent income, which should best be determined the data and with the intention to interpret the data.

Friedman (1957) formally stated the permanent income hypothesis as four hypotheses: 1. The ratio of permanent consumption to permanent income depends on the ratio between nonhuman wealth (property) and income, the level of impatience and prudence (demand for current consumption versus wealth accumulation), and the risk-free interest rate, but does not depend on the amount of permanent income. 2. Consumer's measured income consists of permanent income and a transitory income. 3. Consumer's measured consumption is consist of permanent consumption and transitory consumption. 4. Correlation coefficients between transitory income and permanent income, between transitory consumption and permanent consumption, and between transitory consumption and transitory income are all zero. Friedman (1957) noted that the fourth assumption, especially the assumption that the correlation coefficient between the transitory consumption and transitory income is zero, is a very strong assumption. It implies, as Friedman (1957) noted, that “consumption is determined by rather long-term considerations, so that any transitory change in income lead primarily to additions to assets or to the use of previously accumulated balances rather than to corresponding changes in consumption.” It is also primarily because of this assumption that a lot of subsequent authors questioned and tested this hypothesis.

Hall (1978) tested the PIH with time-series postwar data. He stated that the hypothesis implies a strong stochastic property that while consumption lagged one period should have a non-zero coefficient and thus have predictive value in the regression of current consumption, the lagged wealth, lagged actual income, and consumption lagged more than one period should not. Hall (1978) provided an explanation related to macroeconomic theory, that is, as previous consumption incorporates all information about the well-being of consumers at that time, then other factors should have no additional predictive power. Hall (1978) stated that the life-cycle PIH does not imply that current measured income has no explanatory value.

To test the hypothesis, Hall (1978) regressed consumption on previous first quarter's consumption, and previous four quarters stock prices. As the reliable quarterly data on property values (wealth) were not available, Hall (1978) used stock prices instead, and stated that "tests of the random-walk hypothesis do not require a comprehensive wealth variable, so a test based on stock prices is appropriate, even though the resulting equation does not describe the structural relation between wealth and consumption." The results found that changes in previous first quarter's consumption and changes in previous first quarter's stock price are statistically significant in predicting changes in consumption, thus rejected the pure life cycle-permanent income hypothesis.

The author explained the result by recognizing a lag between the corresponding consumption changes and permanent income change, because "some part of consumption takes time to adjust to a change in permanent income." As previous first quarter's stock price is related with permanent income in *t*-1, and permanent income in *t*-1 is related to consumption in *t* (because of the lag), then previous first quarter's stock price should have predictive value in the prediction of the consumption in period t, and thus the data are compatible with this modification of the hypothesis which "recognizes a brief lag between changes in permanent income and the corresponding changes in consumption".

Hall (1978) contended that the discovery that stock prices have predictive power in predicting consumption function actually supports the random-walk hypothesis as stock prices themselves follows a random walk distribution with trend. In particular, the author suggested that no factors except current consumption have predictive value for the prediction of future consumption, and that if the life-cycle PIH is correct then consumption would obey an AR(1) process.

The policy implications from Hall (1978) is that, as present consumption has incorporated all information related to households' welfare, including information about future changes in policy, future consumption would only be affected by "unexpected" changes in policy which would have effect on permanent income. It should be noted that Hall (1978) did not imply that policies affecting income have no effect on consumption; actually he argued that as long as the policy is unexpected (new information about policy instruments) and can affect permanent income, it could have an impact on consumption and the impact would be permanent." The author thus concluded that "the policy analyst must answer the difficult question of the effect of a given policy on permanent income in order to predict its effect on consumption." (Hall 1978).

Flavin (1981) tested the PIH by analyzing the effect of current income on the prediction of future income and the consumption adjustment to the changing expectations about permanent income. The author used an autoregressive-moving average (ARMA) time-series analysis and a structural econometric model to quantify the changes in permanent income and consumption induced by an innovation in the current income process. Their empirical results rejected the permanent income hypothesis statistically, as the estimated coefficient on current income for the prediction of consumption is greater than what the permanent income hypothesis implies, even after taking into consideration the fact that current income plays a role of signaling permanent income changes, thus suggesting that there is "excess sensitivity of consumption to current income".

Hall and Mishkin (1982) investigated the role of both transitory income and permanent income in predicting future consumption of food with data from the Panel Study of Income Dynamics (PSID) on about 2000 households' consumption and income. The authors revealed that while permanent income plays a larger role in consumption prediction than transitory movements of income, the coefficient on transitory income is also statistically significant and positive, indicating that consumption still responds positively to transitory income.

The authors also found that although the observed covariation of income and consumption failed to support the pure Permanent Income Hypothesis for around 20 percent of households, the majority of the data was compatible with the hypothesis, thus supporting the general PIH. The authors confirmed Hall's (1978) statement that unexpected policy which can affect permanent income could have a larger impact on consumption than temporary policies (e.g., temporary income tax policies), even if they are of the same magnitude.

Mankiw (1982) expanded Hall's (1978) framework to post-war U.S. Data and showed that consumption of durable goods should best be characterized as ARMA(1,1) process instead of AR(1) process. The author also found that the data rejected the expanded model which includes both durable goods and non-durable goods, as it was revealed that their ability of forecasting expenditure is the same. The results thus are contrary to the theory that lagged information has no predictive power in forecasting consumption of non-durable goods and only has predictive power in forecasting consumption of durable goods.

Hayashi (1982) restated and tested the permanent income hypothesis with rational expectations using an instrumental variables technique on the post-war U.S. aggregate time-series data. Hayashi (1982) revealed that the PIH was decisively rejected on the time-series consumption from the National Income and Product Accounts. However, the results accepted the permanent income hypothesis on a consumption series which included service flows from durables, which were different from the one used in National Income and Product Accounts, and were calculated as the product of the amount of durable consumption and the sum of the risk-free rate of interest and the depreciation rate of the durable goods.

Campbell and Mankiw (1990) used aggregate postwar U.S. data and nested the PIH in a model with higher generality, in which we can change the real interest rate and the utility function has the property that the consumption of non-durables and the consumption of other goods (e.g., government expenditures, consumption of durables, and labor supply) are inseparable, for the purpose of explaining the disparate results regarding the soundness of PIH. In the model consumers are classified into two types, one type decides their consumption based on current income instead of permanent income (spends current income on consumption), and the other type decides their consumption based on permanent income instead of current income (spends permanent income on consumption).

By estimating the percentage of income that goes to consumers who spend current income on consumption through an instrumental variables (IV) approach, the authors can determine whether the data support the PIH. The estimated percentage of income which goes to consumers who spend their current income on consumption was significant and was equal to 0.5, implying that the PIH was rejected by their results. They conducted another test by regressing consumption on its own lags for years from 1953 to 1985, and found that some coefficients were estimated to be statistically different from 0 at the .l% significance level. They thus confirmed that their results rejected the permanent income hypothesis, with the implication that it is possible to predict changes in consumption because consumption does not follow the random walk process as shown in their results.

Carroll (2001) argued that a lot of empirical studies that found evidence to reject the permanent income hypothesis in the 1970s and 1980s actually misinterpreted Friedman’s (1957) work, and should be regarded as supporting both his original description and the updated version of the model under uncertainty. The author cited the Hall and Mishkin (1982) paper as an example of the misinterpretation of Friedman's (1957) PIH. Hall and Mishkin (1982) estimated the marginal property to consume to be about 0.2. Instead of treating this as evidence supporting Friedman's PIH, Hall and Mishkin (1982) used a threshold of 0.05, and argued that as this estimate was much greater than 0.05, PIH was rejected by more than 15% to 20% of consumers.

Carroll (2001) stated that a lot of professions misinterpreted Friedman's concept of the PIH as the certainty equivalent or perfect foresight models (which predict the MPC to be 0.05 or less). In fact, as Carroll (2001) noted, the MPC out of transitory income was actually asserted by Friedman to be about 0.33 rather than 0 implied by the PIH, and the main point of Friedman's papers is that the MPC for a typical consumer should be much smaller than 1 in contrast to the "Keynesian" model in which consumption simply corresponds current income (consumption is approximately equal to current income as stated by Carroll (2001)).

Moreover, Carroll (2001) argued that Friedman (1963) had already pointed out the problem of liquidity constraint, or more specifically "capital market imperfections", which states that there is uninsurable future income uncertainty and that it is difficult to borrow under this income uncertainty, and that Friedman (1963) had pointed out that it is because of this reason that current consumption was only slightly affected by distant future labor income.

Pozzi and Malengier (2007) investigated the soundness of imposing certainty equivalence assumption to consumption function, by looking at how the assumption affect the estimated coefficient of transitory income in consumption prediction (the sensitivity of consumption with respect to transitory income) with a panel data on consumption and income in 17 OECD countries from 1981 to 2003.

They derived a nonlinear consumption function which encompasses two types of individuals: one type is rule-of-thumb consumers whose consumption is only determined by their current income (spend their current income on consumption), while the other type is forward looking optimizing and prudent consumers with a precautionary motive to save, who possibly would have higher expected growth rate of consumption and higher MPC out of current income (lower MPC out of wealth) than that implied by certainty equivalence.

They used a Generalized Method of Moments (GMM) method on untransformed consumption function, instead of the method of transforming consumption using growth rates, quasi-differences, or first-difference, to estimate the sensitivity of consumption with respect to transitory income without information loss. A Lagrange Multiplier hypothesis test, which imposed a restriction that the expected consumption growth rate is equivalent to that under certainty equivalence, was used to test for the certainty equivalence assumption.

Their estimated sensitivity of consumption with respect to transitory income was 0.369, implying that the percentage of the first type of consumers (the rule-of-thumb consumers) is approximately 36.9%. The growth rate of consumption is estimated to be 1.024, higher than that implied under certainty equivalent assumption for all different risk aversion levels, implying that the certainty equivalence hypothesis is rejected, and thus they concluded that it would result in a serious mis-estimation of the percentage of rule-of-thumb consumers (consumption only depends on current income) if certainty equivalence is inappropriately imposed to the model. Their results concerning sensitivity of consumption with respect to transitory income actually can be regarded as consistent with the PIH since the estimated MPC was 0.369 in this study, similar to the estimated value in Friedman (1957)'s model 0.33.

In the literature related to liquidity constraint, Flavin (1985) reviewed the previous empirical studies on the Permanent Income Hypothesis and summarized that almost all of the tests had rejected the hypothesis. The author classified the null hypothesis in empirical literature into three hypotheses that includes: 1) rational expectations, 2) permanent income determines consumption, and 3) perfect capital markets, where agents can borrow or lend against expected future income freely at the same interest rate. The author mainly focused on the third part and attempted to determine the relationship between perfect capital market assumptions and the estimated sensitivity of consumption with respect to current income.

The study examined a simple "Keynesian" model of consumption behaviour, which assumed, as stated by Flavin (1985), that the behavioral marginal propensity to consume (MPC) was different from zero, and regarded this hypothesis as a specific alternative to PIH. The author used unemployment rate to approximate the percentage of the population who were faced with liquidity constraints, and used a generalized version of the econometric model to conduct a specification test of the "Keynesian" consumption function.

The estimated function showed that the estimated coefficient on unemployment rate was statistically significant in predicting MPC out of transitory income and the coefficient was sufficiently large, indicating that the estimated MPC was dramatically affected by the unemployment rate, and thus the author suggested that liquidity constraint was a significant factor that led to the observed "excessive" sensitivity of consumption with respect to transitory income (even after taking into consideration the fact that current income plays a role of signalling permanent income according to Flavin (1981)).

While the author made an important contribution in recognizing the importance of liquidity constraint in consumption theory, the author seemed to misinterprete PIH and considered it as implying marginal propensity to consume (MPC) to be zero. In fact, the results only correctly rejected the hypothesis that MPC is zero, and attributed the non-zerio MPC to liquidity constraint, but actually did not reject the PIH, according to the arguments of Carroll (2001).

Zeldes (1989) also investigated consumption and liquidity constraints with data from the Panel Study of Income Dynamics (PSID) on time-series/cross-sectional households' consumption and income. The author used a model which assumed a constant relative risk aversion property of the utility function and took into consideration the uncertainty of stochastic income. The author classified households as subject to liquidity constraint if the borrowing against future labor income was not allowed, which was assumed to be embodied by the fact that their current net wealth was lower than their 2 months' value of permanent income.

The hypothesis that individuals' consumption decisions depended on the sequence of borrowing constraints was then tested. A numerical technique was used to give an approximation to the solution. Their results supported the hypothesis that liquidity constraint affected the consumption for a large share of the population. The impact of interest rate was also analyzed with the conclusion that in periods of low interest rates household tended to have high growth of consumption. Their results also showed that future liquidity constraints, which bind only in certain future states, could effect consumption similarly as the current binding constraints.

Rosenzweig and Wolpin (1993) studied the interaction among the accumulation of durable production assets, consumption smoothing, and liquidity constraints. With household data on bullocks and profits, they estimated a dynamic structural economic model with finite-horizon. They used the estimated structural parameters to assess the effects of policies that related to providing assured sources of income to farmers on the life-cycle accumulation of bullocks, farm profits, and welfare.

Chah *et al*. (1995) developed and tested a new model to investigate the optimization process and the stochastic implications of the dynamic consumption (including both non-durables and durables) under liquidity constraints. They used an "error correction term from the long-run cointegrating relationship between durables and nondurables" to represent the existence of current binding liquidity constraints. That is, if the hypothesis of binding liquidity constraints is true, then the error correction term would have non-zero coefficient in the prediction of consumption of non-durable goods and services. They used aggregate data to test the stochastic implications empirically, and their results supported the hypothesis that the presence of current binding liquidity constraints, instead of rule-of-thumb consumption behaviour (responds simply to current income), is the largest reason for the fact that consumption is sensitive to transitory income.

Evans and Karras (1998) investigated the relationship - substitutes or complements - between different types of consumption with data from sixty-six economies. Their results showed that while military expenditure and private consumption could be regarded as complements, nonmilitary expenditure and private consumption were more like substitutes. Evans and Karras (1998) also studied the relationship between liquidity constraints and consumer saving and consumption behavior. The results showed that the stricter the liquidity constraints, the smaller saving rates and the more volatile the transitory income.

Gross and Souleles (2000) investigated how the dynamic optimal consumption and debt change with the changes in liquidity constraint and in interest rates using a database of credit report information on several hundred thousand credit card accounts. They found that the total debt increases significantly with an exogenous increase in households' credit limits (lower liquidity constraint), especially for liquidity constrained individuals whose debt was near their limit; even for people not subject to binding liquidity constraint, they were found to significantly increase total debt.

Comparing these results, the authors found that after increasing households' credit limits, the optimal debt would keep relatively constant and be stabilized at some level when the level of remaining credit capacity was roughly the same as that before the increase in the credit limit.

Gross and Souleles (2000) also used the model to explain the fact that a lot of individuals use credit cards for consumption and at the same time hold other low yielding assets. As for the effect of account-specific interest rates, Gross and Souleles (2000) found that "debt is particularly sensitive to large declines in interest rates, which can explain the widespread use of teaser rates." Their results also showed that the elasticity of debt with respect to interest rate was estimated to be approximately

-1.3, a large proportion of which was reflected by net decrease in total debt, and some of which was embodied by switching balances among credit cards. The high elasticity implied that total debt burden was significantly sensitive to the variations of interest rates.

Carroll (2001) questioned the previous studies that tested whether the high marginal propensity to consume was due to liquidity constraint. He argued that the necessary condition for the high marginal propensity to consume is "impatience" and a precautionary saving motive, rather than liquidity constraint. According to Carroll (2001), same behavior can be generated by the precautionary saving motive as that by a liquidity constraint, as the precautionary demand for saving would act like a self-imposed constraint from borrowing, which would in turn reduce consumption and debt, just in the same way as the effect of liquidity constraint on consumption and debt. Thus, average behavior, as the author suggested, should be determined mainly by the degree of impatience, not by liquidity constraints.

The author argued that "most of the existing empirical studies that supposedly test for constraints should probably be reinterpreted as evidence on the average degree of impatience", and suggested researchers in this area change their focus from detecting constraints to measuring the average degree of impatience.

Carroll (2001) stated that in many cases, there is no need to differentiate liquidity constraints from precautionary motive to save. However, in cases where it is needed to distinguish them, for example, when analyzing the effect of credit supply related policies on consumption, it is difficult to distinguish them using Euler equations. Carroll (2001) contended that a potential method to distinguish the two factors is to look at the net holding of wealth (instead of growth of consumption). Thus, in our study, we analyze wealth holding to distinguish the impact of the precautionary motive from the impact of the liquidity constraint. However, as our model include both saving and insurance as precautionary motive, rather than treat wealth holding as precautionary saving, we treat wealth as composed of two parts, precautionary saving and insurance purchase, and treat the remaining part of wealth after subtracting insurance premium as precautionary saving.

Nyambane (2005) examined the effect of liquidity constraints on insurance by two methods: a mathematical proof and a numerical programming using ASDP algorithm. The author supported the hypothesis that a binding liquidity constraint would have the effect of reducing optimal coverage to a point below the full coverage level; specifically, in a perfect credit market, if the insurance is fair, then farmers would choose maximum allowable coverage, and if the insurance is positively loaded, then farmers would reduce coverage below the maximum allowable coverage.

In an imperfect credit market, farmers would reduce coverage below the maximum allowable coverage, whether the insurance is fair or loaded. However, the author did not analyze the impact of "severity" of liquidity constraint, nor did he specify explicitly the other way - whether/how the insurance and the severity of liquidity constraint would have an impact on consumption smoothing and credit. The time paths of the decision variables were not analyzed either.

2.3.3 PRECAUTIONARY SAVING, CONSUMPTION SMOOTHING, AND WEALTH ACCUMULATION

Leland (1968) described the precautionary demand for saving as "extra saving" induced by the uncertainty about future random income. Leland showed that it is not enough to ensure the precautionary motive for saving with only the assumption of risk aversion. Leland thus introduced assumptions on certain risk properties of utility functions to ensure the positive precautionary saving induced by uncertainty. Specifically, Leland (1968) stated that it is necessary for a proper utility function to have a characteristic that its third derivative is positive (which is also called "prudence" property).

Rosenzweig and Stark (1989) studied marriage, migration, and consumption smoothing using longitudinal data for the consumption of South Indian villagers. The authors sought to explain the mobility patterns of migration induced by moves of women for marriage through consumption smoothing theory, and pointed out that in the South Indian village where there are high spatially covariant risks and information costs, the migration caused by marriage of daughters can be viewed implicitly as interhousehold contracts for the sake of reducing variability of household food consumption and facilitating consumption smoothing.

The authors then analyzed the empirical longitudinal data on consumption patterns, income, and marital arrangements in South Indian households, and the results were found to confirm the hypothesis, that the marriage induced migration resulted in a significant reduction in the volatility of consumption. Rosenzweig and

Stark (1989) also found that villagers whose profits were more volatile are more inclined to get involved in long-distance migration induced by marriage. They thus concluded that their model based on consumption smoothing theory has advantages over the standard models that focused on static income gains and search costs.

Deaton (1991) considered the saving behavior for consumers who were not permitted to borrow (fully liquidity constrained). Unlike most of the previous studies that attributed the sensitivity of consumption to liquidity constraint, Deaton (1991) recognized the importance of impatience and precautionary demand for saving in the presence of uncertainty in determining households' consumption and saving behaviour, and stated that when labor income is i.i.d. over time, and consumers have high discount rate (being relatively impatient), the interaction between the liquidity constraints and the precautionary saving motive leads to a high demand for assets holding, as assets perform as a buffer stock that protects consumers against a sharp drop in consumption when bad states prevail.

The author then presented his results for a liquidity constrained representative agent under different income process scenarios: if labor income process is stationary but positively autocorrelated, saving and consumption would be contracyclical over the business cycle; that is, "assets are still used to buffer consumption, but do so less effectively and at a greater cost in terms of foregone consumption"; if income process follows a random walk, the behaviour would be consuming all their income and there is no saving. The author summarized that aggregate U.S. saving behavior can not be generated by an agent who is subject to a binding liquidity constraint even if she/he receives aggregate labor income. If his/her actual income follows a random walk, there would be no saving; and if incomes are positively autocorrelated, then saving would be contracyclical over the business cycle. None of these scenarios generates the aggregate saving behavior.

Deaton (1991) pointed out, although a lot of households are not subject to liquidity constraint and thus not behaving as presented before, the microeconomic model of saving with liquidity constraints in this paper can explain a significant number of important facts in the reality that cannot be explained by traditional life-cycle models.

Paxson (1992) examined the relationship between the saving behavior of Thai farm households and their transitory income due to rainfall variations. Specifically, Paxson (1992) estimated marginal propensities to save for consumption smoothing in the face of unexpected income shocks, using three cross-sections and time-series of regional rainfall, income, and expenditure data for Thai rice farmers. Rather than measuring permanent income directly and treating transitory income as a residual,

Paxson (1992) decomposed income into transitory and nontransitory (i.e., permanent) components through explicit estimate of transitory income. Time-series regional rainfall and cross-sectional household income was used to estimate transitory shocks to income due to rainfall variation. He found that the marginal propensities to savings were high, and thus confirms that savings were used to smooth consumption and to mitigate the impact of income fluctuation, and that "farm households save a significantly higher fraction of transitory income than nontransitory income."

Besley (1995) reviewed the literature related to nonmarket institutions in low-income countries with the duties of helping individuals cope with risk and providing individuals with credit, and analyzed the related issues by using the methodology and insights from mechanism design theory, contract theory, and information economics.

Besley (1995) stated that savings only has limited effect on mitigating the risk of fluctuating income, and thus proposed other arrangements for risk sharing, such as inter-temporal trading contract between individuals for risk and credit transferring and sharing.

He then provided specific examples and described them in detail, such as group lending with joint liability, which acts like a risk-sharing contract; credit cooperatives, where a group of households borrow funds from a bank or from the government and then distribute them among the group members in the form of debts; credit associations and rotating savings, where a group of individuals allocates a pot of funds to one group member and then rotates among members, either by lot or bidding. While these mechanics are proposed and offered in low income countries, they provided insights regarding developing innovative financial institutions in low-income counties in developed countries.

Lopez *et al*. (2000) examined how effective the alternative fiscal instruments were in raising national savings and affecting private consumption, using a large panel data on time-series and cross-sectional households' savings and consumptions in industrial and developing countries (41 countries from 1975 to 1992). They firstly reviewed the related literature and pointed out that most previous studies rejected the Ricardian Equivalence hypothesis, which stated that in a society composed of rational forward-looking consumers, national savings and private consumptions are only affected by the amount of permanent government expenditure, but not affected by how to finance the government spending (e.g., in the form of debt, inflation, or taxation). They attributed the reason of rejection to "binding borrowing constraints", which affected "a large share of consumers in both developing and industrial economies."

They used a nonlinear instrumental-variable panel method to estimate a consumption model for private households in which two categories of agents exist: agents with finite horizons which induce them to assign higher weight to present in the utility function than to future, and agents with full liquidity constraints which make them unable to optimize inter-temporally and thus induce them to consume all their disposable income (myopic).

The authors also took into account the public consumption (government spending) that can influence consumption of private households through the channel of budget constraint. They found that the results rejected the full Ricardian Equivalence in all the samples, and stated that the rejection is mainly because of the existence of constrained individuals rather than because of the finite horizons. In addition, they found that industrial and developing countries had significant differences in their households' consumption behavior --- the share of the constrained (Keynesian) consumers was considerably smaller in industrial countries than in developing countries, and the share of households who internalized the government budget constraint rather than only looked at future taxes is larger in industrial countries than in developing countries.

Their findings related to fiscal policy disturbances included that, in order to raise national saving, the cuts in temporary government expenditures were more effective than the rise in temporary taxes, as the cuts in temporary government expenditures do not cause the offsetting effect (reducing private savings) for both constrained and unconstrained consumers. The difference between the discount rate (representing time preference) and the risk-free rate of interest is another important factor contributing to the effect on private consumption and national savings of fiscal policies.

In Chapter 15 of the book "The Economics of Risk and Time," Gollier (2001) examined how the level of current saving is affected by an expectation of future risk at a given level of wealth, and how the sensitivity of saving with respect to change in wealth - the marginal propensity to save - are affected by an expectation of future risk.

Later, Gollier (2003) examined the impact of precautionary saving on the demand for insurance with liquidity constraint was examined in a dynamic lifecycle model. In the model it was assumed that the insurable risk did not have serial correlation, and that farmers followed a time-varing insurance-credit strategy to accumulate buffer stock wealth. The control variable for the insurance decision was a deductible level, which as Gollier (2003) stated, was "governed by the willingness to limit the risk borne by risk-averse agents at an acceptable cost, given the deadweight loss of insurance loading." While it offered an insight of insurance design, it should be noted that in reality insurance companies employ other more complex designs of insurance products. The risk/uncertainty was modeled rather arbitrarily, by assuming a probability of 10% that the consumer would lose 75% of income.

Gollier (2003) concluded that compared with the results suggested by classical static insurance models, the dynamic model indicated that the demand for wealth accumulation leads to a substantial decrease in consumers' insurance purchase, and implied that insurance may not be demanded for rich consumers holding high level of wealth; and that only consumers who have binding current liquidity constrained, or who are in the face of catastrophic risk, may need insurance. The author thus stated that this model partly explained the reason why in such an economy the insurance sector provided a low level of added value which leads to the low demand for insurance.

Lamb (2003) analyzed the effect of off-farm labor on consumption smoothing and on the use of fertilizer by developing a two-period dynamic model. Their analysis showed that the deepening of the off-farm labor market (higher share of nonagricultural work and lower unemployment rate) increased the fertilizer demand and the level of consumption smoothing, controlling for exogenous weather risk.

The results suggested that on-farm production and off-farm labor markets could be regarded as complementary in an environment with crop production risk and financial risk, as promoting the depth of the off-farm labour market would also increase farmers' on-farm input use and thus bolster on-farm production. Therefore, policies with the effect of deepening off-farm labor market may simultaneously be useful in increasing farmer's productivity and increasing their welfare in low-income areas.

Ravi (2006) examines the savings decision of a household when faced with an income shock. In particular, the author analyzed how an idiosyncratic income shock affects the saving behaviour and asset portfolio held by a household. He provided results showing that income variability contributes to poverty of rural households by leading them to reduce stocks of productive assets and to increase liquid assets.

The author further classified the income shock into two categories: income shock related to health, and income shock related to weather, and classified the households into two categories: nuclear and joint families. The results revealed that there are important differences in savings and asset portfolio behavior between these two household categories and two income shock categories. Specifically, when faced with income shocks related to health, nuclear households would reduce their stock of productive illiquid assets, while joint families would reduce liquid assets.

A more important result indicated it was more likely for the income shocks related to health to contribute to the poverty of rural households than the income shocks related to weather, as income shocks related to health would induce consumers to accumulate liquid assets and to reduce more productive illiquid assets. Therefore, Ravi (2006) proposed that policy interventions in health infrastructure might be more effective in poverty reduction than policy intervention in weather infrastructure.

CHAPTER 3

CONCEPTUAL FRAMEWORK

3.1 INTRODUCTION

This chapter provides a conceptual framework which addresses essential issues involved in solving the dynamic risk management problem in the recently developed forward looking stochastic models. A dynamic stochastic model is developed to derive the optimal choice paths of consumption smoothing, insurance, and debt and their relationship with precautionary wealth for an impatient and risk-averse farmer.

The following sections in this chapter describes the detailed conceptual framework of the Bellman's Equation of dynamic optimization, specific mathematical programming techniques used, the optimization criterion under the risk management framework, and the experimental design for different types of insurance products under the dynamic framework.

3.2. BELLMAN'S EQUATION OF DYNAMIC OPTIMIZATION

The discrete time, discrete state dynamic Markov decision model can be characterized as follows: consider a farmer who seeks an optimal policy which predescribes a sequence of optimal actions (dynamic choices) that should be taken at any given time and state, with objective of maximizing the life-time expected utility which is the expectation of the sum of current utility and a series of future utilities discounted by a time preference factor over a time horizon (Gomez-Soto 2007):

$$max(EU) = E_0 \sum_t \beta^t U(C_t) \tag{3.1}$$

where E_0 is expectation operator; β is the time preference factor (discount factor) which is negatively related to farmers' discount rate; U (.) represents a utility function depending on consumption; and C_t is the consumption at time period t.

This dynamic Markov decision model can be solved and analyzed using the Bellman's stochastic dynamic programming (DP) model developed by the American mathematician Bellman in the 1950s. The basis method is essentially developed on the basis of the Principle of Optimality articulated by Bellman (1957): "An optimal policy has the property that whatever the initial state and initial decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision" (Miranda 2010).

According to Bellman's Principle of Optimality, the optimal policy (a sequence of optimal choices) that maximizes the value function for the whole time period has the property that after *s* periods, the remaining optimal policy for the original problem is still optimal for the remainder of the value function after *s* periods. Therefore, the optimal policy is time-consistent and would not depart from the original plan when time advances (Violante 2000). Bellman's Principle of Optimality thus enables analysts to break a dynamic optimization problem into simpler sub-problems (Miranda 2010). In other words, the dynamic problem can be solved backward by recursively solving Bellman's equations to find "time consistent" policy functions. Violante (2000) noted that the time-consistency property of optimal policy does not apply to all settings, as it depends on the recursive nature of the dynamic problem.

The life-time expected utility function thus can be transformed into a Bellman's equation, which in essence describes a situation where a rational, dynamic, and forward-looking optimizing agent needs to make a decision to optimally balance between an immediate reward and expected future rewards (Miranda 2010):

$$V_t(s_t) = max_{x_t}[f_t(s_t,x_t) + \beta E_t V_{t+1}(s_{t+1})] \tag{3.2}$$

subject to:

$$s_{t+1} = g_t(s_t,x_t,\varepsilon_{t+1}) \tag{3.3}$$

In Equation (3.2), $V_t(s_t)$ is the objective function, which represents the value function contingent on the state at *t*; $f_t(s_t,x_t)$ is the immediate return function at *t*, which could be a function of the state vector, s_t, and the control vector, x_t at *t* ($f_t(s_t,x_t)$ can also be a function of just control vector x_t).

Equation (3.3) is the equation of motion (transition equation) describing how the state vector evolves through time. ε_{t+1} is random shock which represents uncertainty involved in the transition path of the controlled state variable.

3.3. DYNAMCI MODEL OF CONSUMPTION SMOOTHING AND INSURANCE UNDER LIQUIDITY CONSTRAINT

For the specific problem in our study, Bellman's equation illustrates how a rational, dynamic, and forward-looking optimization farmer chooses an optimal policy that describes the action (consumption, insurance, and debt) that should be taken, contingent on time and state (Gomez-Soto 2007). The optimal policy prescribes three dynamic choices: (i) consumption decisions, which is directly related to immediate reward in each sub-period; (ii) insurance decisions, which is for risk management and precautionary purpose and influences the expected future reward, and is regarded as a proportion of farmers' precautionary wealth; (iii) credit decisions, which include beginning-of-season debt decisions for the finance of consumption, insurance, and production for the whole year, as well as end-of-season deposit (precautionary saving) decisions for precautionary purpose for the future. Both consumption and insurance decisions indirectly relate to the decision that how much debt should be used. As precautionary saving (deposit) is just the remaining part of precautionary wealth after subtracting insurance, and as insurance is only a small fraction of precautionary wealth, deposit is not very different from precautionary wealth, and thus the time path of deposit will not included in our results.

The Bellman's equation for the problem faced by a farmer is formalized below, based on the methodology of Gollier (2003), Nyambane (2005) and Gomez-Soto (2007):

$$V_t(w_t, P_{output} y_t) = max_{x_t}[U_t + \beta E_t V_{t+1}(w_{t+1}, P_{output} y_{t+1})] \qquad (3.4)$$

Subject to:

$$w_{t+1} = (1+r)(w_t\text{-}cost_t\text{-}c_t\text{-}p_t) + P_{output} y_t^f + indemnity_t \qquad (3.5)$$

where w_{t+1} is a vector of state variable wealth; U_t is the immediate reward (utility) in period t; r is market interest rate; production costs is noted as $cost_t$, and is assumed as a known fixed amount; c_t is consumption; p_t is insurance premium; $P_{output} y_t^f$ is another vector of state variable, which is realized individual farm revenue (labor income, or more properly noncapital income); Indemnity is noted as $indemnity_t$ which is the possible indemnity the farmer may receive from the insurance company (0 or positive). w_{t+1} is end-of-season wealth, or cash-at-hand for precautionary motive, and is composed of precautionary saving and insurance purchase. As deposit and debt are using the same interest rate, we treat $(w_{t+1}\text{-}p_{t+1})$ as end-of-season deposit (precautionary saving) for the future, and treat $[-(w_{t+1}\text{-}cost_{t+1}\text{-}c_{t+1}\text{-}p_{t+1})]$ as beginning-of-next-season net debt to finance consumption, insurance, and production for the whole year. They are treated separately to better understand the optimization process.

The problems related to durable goods investment are not considered in our model. Carroll (2001) argued that even in the existence of durable goods, the behavior of buffer stock saving still emerges as long as consumers are sufficiently impatient. Therefore, this study does not take into consideration durable goods like vehicle, housing, and farming equipment.

The realized individual farm revenue (labor income, or noncapital income) is interpreted in this study as composed of permanent non-capital income and a transitory shock, according to Friedman (1957). Friedman (1957) stated that it is unnecessary to prescribe the meaning of permanent income, which should best be determined by the data, with the intention to interpret the data. Carroll (2001) pointed out that for each non-self employed household in the Survey of Consumer Finances, the permanent income was the measured income which satisfies the two conditions: 1) be equal to or greater than $5000; and (2) be reported as "about normal."

Labor income introduces uncertainty into the future path because it is uncertain when the decisions are made. The uncertainty considered here is explicitly uncertainty rated to revenue changes, as opposed to the rate-of-return uncertainty in Samuelson

(1969) and Merton (1969)'s studies, who showed that in the presence of rate-of return uncertainty, consumption behavior is not very different from the perfect-foresight model.

Equation (3.5) is a transition function, which governs how the state variables evolve along the optimization horizon: the stock of precautionary wealth is equal to the sum of farmer's revenue from crop production and possible indemnity payment from insurance, after repaying the money borrowed for consumption, insurance purchase, and production for the whole year and its interest rate for this period. Thus, the interest rate in this sense is another source of the credit risk (in addition to liquidity constraint), which influences the amount of net wealth accumulated the following period.

Assume an imperfect credit market, a liquidity constraint is imposed:

$$w_t - cost_t - c_t - p_t >= minnet \tag{3.6}$$

where *minnet* is the minimum net wealth permitted (can be negative), representing the credit limit imposed on a farmer at all periods. For example, -1500 \$/acre means that the amount of money farmers can borrow cannot exceed 1500 \$/acre at any time. Under liquidity constraint, debt cannot exceed a given amount.

Also subject to transversality condition:

$$\lim_{t \to \infty} \beta^t w_t = 0 \tag{3.7}$$

which rules out the perpetual debt; that is, people cannot just borrow the funding today to repay yesterday's debt for an infinite period; they must eventually pay back all the debt (Nyambane 2005). We further assume that the farmer's debt cannot exceed minimum possible revenue from the next period of production. This in effect rules out perpetual borrowing.

In our study, the immediate reward function is the farmer's utility derived from consumption. Empirical studies have demonstrated that farmers in many areas exhibit the property of decreasing absolute risk aversion (DARA) (e.g., Epstein (1983), Mahul (2002), Saha *et al*. (1994), Gomez-Limon (2002)), and stated its necessary condition, i.e., $R_a'(\mathrm{c}) = \frac{-\mathrm{u}''\mathrm{u}' + \mathrm{u}''^2}{\mathrm{u}'^2} < 0$. Given $\mathrm{u}' > 0$, $\mathrm{u}'' < 0$, the necessary condition of DARA would be the convexity of marginal utility, that is: $\mathrm{u}''' > 0$ (Mahul 2002). The utility function used in this study satisfies these conditions. The widely used representation of utility with the characteristics of constant relative risk aversion (CRRA) is parameterized as (Lin *et al*. 2009):

$$U_t = \frac{c_t^{1-\gamma}}{1-\gamma} < 0 \tag{3.8}$$

where γ represents the relative risk aversion coefficient. Instead of using net return as its argument, the utility function is defined over consumption c_t.

The optimization process is: at the beginning-of-season for a year, farmers would decide the magnitude of consumption, c_t, for the whole year, the parameter of insurance he would purchase (which determines the insurance price p_t), and the amount of money he would like to borrow, $[-(w_t - cost_t\text{-}c_t\text{-}p_t)]$. Debt is determined right after the two other control variables are decided. At the end-of-season for a year t, farm yield, y_t^f, is realized; the farmer gets paid by the amount of $indemnity_t$ (0 or positive) from the insurance company which is based on the difference between farm yield and contracted yield level; precautionary wealth (cash-on-hand, w_{t+1}) is accumulated, which is the total net wealth the farmer hold on hand (accumulated total wealth as opposed to marginal increase in wealth), and is composed of two types of assets: one deposit with a financial institution and another one with insurance.

A variety of sensitivity analysis will be conducted to investigate the effects of the variations in parameters on the total amount and composition of the precautionary wealth portfolio composed of insurance with insurance companies and deposits with financial institutions. For example, the analysis on the liquidity constraint, on the transaction costs incurred by the insurance purchase, which is captured in the insurance premium loading, on the price of output, on farmer's relative risk aversion, impatience (discount rate), on the effective interest rate on the debt/deposits (assumed to be same for debt and deposit), etc.

The model has two state variables, net wealth, w_t ($/acre), which can be negative or positive (negative means in debt), and realized revenue (county level or farm level), which introduces random shock to the model; two control variables, coverage, cov_t, which stands for the percentage of the expected yield covered by the insurance, or limit parameter in WD case, λ, which directly affect insurance payment $indemnity_t$ and insurance price p_t in the model, and consumption c_t, which is the total consumption for a given year. Debt, $[-(w_t - cost_t\text{-}c_t\text{-}p_t)]$, is a mixed state and choice variable which is determined (after determining the two control variables) to finance consumption, insurance, and production for the whole year.

Compared with static models, our dynamic Bellman's model induces a rational, risk averse, and forward-looking farmer to accumulate precautionary wealth, either as precautionary savings (deposit) with financial institutions, or as insurance holdings with insurance companies, to protect consumption from a sharp drop when bad states prevail.

3.4 EXPERIMENTAL DESIGN

To investigate how the farmer's optimal choices vary with the nature of the insurance indemnity and pricing schedule, the model is solved under three alternative designs of insurance products, namely farm-level yield based Multi-peril Crop Insurance (MPCI), county-level yield based Group Risk Plan (GRP), and precipitation based weather Derivative (WD). Under the GRP scheme, indemnity is calculated on the basis of the difference between actual county yield (kg/acre) and the yield insured by the farmer (which is equivalent to the product of the chosen coverage and the expected county yield in our study), instead of on the individual farm loss. Under the WD scheme, indemnity is paid on the basis of the difference between regional rainfall and the rainfall index insured by the farmer during the insured period.

MPCI DESIGN

For the MPCI design, it should be noted that in practice, a variety of individual farm yield insurance products are offered and tailored with adding on features to satisfy farmers' different needs, and thus we are unable to examine all of the possible designs.

The MPCI design in this section is a general and simple scheme which maintains the key features of the MPCI contracts. Based on the studies of Edwards (2000), Deng (2005), and Nyambane (2005), the strike of the MPCI product is assumed to be the expected farm yield, the indemnification index (insurance payout trigger) is realized farm yield, and the indemnity is calculated according to the difference between the share of the expected farm yield covered by the insurance and the realized individual farm yield. Based on the Edwards (2000) and Deng (2005) studies, the premium is given by:

$$p_t = \frac{1+\alpha}{1+r} P_{output} E\, max\,(0, cov_t * strike_t - y_t^f) \tag{3.9}$$

where α is a loading parameter ($\alpha > 0$ means a loaded premium insurance, while $\alpha < 0$ means a subsidized insurance).

Based on Nyambane's (2005) study, the transition equation represents the relationship between state variable and control variables and describes the evolution of the state vector through time:

$$\begin{aligned} w_{t+1} &= (1+r)\,(w_t - cost_t - c_t - p_t) + P_{output} y_t^f \\ &\quad + P_{output}\, max\,(0, strike_t * cov_t - y_t^f) \end{aligned} \tag{3.10}$$

GRP DESIGN

For the GRP design, the strike of the contract is the expected county-level yield (kg/acre), the indemnification index (insurance payout trigger) is realized county-level yield, and the indemnity is calculated according to the shortfall of the realized county yield compared with the part of the expected county yield that are covered by the insurance (Edwards 2000). Based on Deng (2005), the premium is given by:

$$p_t = \frac{1+\alpha}{1+r} P_{output} E\, max\,(0, cov_t * strike_t - y_t^c) \tag{3.11}$$

where y_t^c is the realized county level yield for a given year. Based on Nyambane (2005)'s study, the transition function is:

$$\begin{aligned} w_{t+1} &= (1+r)\,(w_t\text{-}cos\,t_t\text{-}c_t\text{-}p_t) + P_{output} y_t^f \\ &\quad + P_{output}\, max\,(0, strike_t * cov_t - y_t^c) \end{aligned} \tag{3.12}$$

WD DESIGN

Weather derivatives can be designed as swap, call, and put contracts with weather indexes as the underlying derivatives, which include precipitation, temperature, snowfall, etc. For example, weather derivatives based on heating degree day (HDD) are traded in the market and the major sellers/buyers are energy sectors with the objectives to reduce the risk related to extreme temperatures and/or make trading profits (Zeng 2000). Weather derivatives have very flexible designs which make it possible to develop innovative products to satisfy farmers' different changing needs.

The weather derivative contract envisaged here is focused on hedging against lower-than-average-rainfall, and thus functions much like a put option on the precipitation. Specifically, it triggers an indemnity payment based on the shortfall of realized rainfall compared with a certain contracted strike rainfall amount for a specified time period. Based on Brix (2002), Richards (2004), and Lin *et al.* (2009), the indemnity payment schedule is given by:

$$indemnity_t = m \times \begin{cases} 0, & if\ \mathrm{i_t} > i_t^*; \\ \dfrac{i_t^* - i_t}{i_t^* - \lambda_t i_t^*}, & \text{if } \lambda_t i_t^* < i_t \le i_t^*; \\ 1, & \text{if } i_t \le \lambda_t i_t^*. \end{cases} \tag{3.13}$$

where i_t^* is the strike, which is the contracted rainfall amount; i_t is the rainfall index which is measured at some weather station specified in the weather derivative contract for the insured period; the *indemnity* at time *t* is paid if i_t falls below i_t^*; *m* is the maximum indemnity, which specifies the maximum payment a farmer can get from the weather derivative contract, and in our model the highest possible irrigation cost is used to approximate the maximum liability; $\lambda_t i_t^*$ is the limit parameter which decides the threshold of rainfall when maximum indemnity is paid, i.e., *m* is paid if i_t falls below $\lambda_t i_t^*$.

The particular properties of the underlying weather index pose challenges of pricing weather derivatives.

First, because the precipitation underlying the weather derivative is not publicly traded, it is impossible to use no-arbitrage option pricing (e.g., Black-Scholes formula) to define the price of weather derivatives. As there is no market price for the underlying precipitation, this kind of weather derivative can only be traded over-the-counter, which limits the use of the traditional derivative pricing models to price weather derivatives.

Second, the traditional actuarial approach for insurance products is also difficult to be applied to weather derivative pricing, because of statistical difficulty, as the distribution of precipitation underlying the weather derivative has high variance which makes it difficult to estimate and to draw robust statistical inferences (Zeng 2000).

Third, because the economic exposure to weather risk and thus the economic loss caused by precipitation shortfall are different among farmers, reliably estimating the level and volatility of economic gain from weather derivatives for different farms to calculate fair premium is problematic (Zeng 2000).

The pricing approach with the Kernel smoothing method and DSSAT crop simulation model is proposed here to alleviate these problems. The Kernel smoothing method does not rely on data belonging to any particular distribution, nor does it assume the structure of a model. The DSSAT crop simulation model provides a more reliable way of linking the relationship between precipitation and yield than the traditional regression model, and thus provides a better way of estimating the economic gain from purchasing precipitation based weather derivatives and thus facilitate the weather derivative pricing.

To derive the probability density function $h(i)$ of i_t, a non-parametric Kernel smoothing method is used. The formal definition, as noted by Deng *et al.* (2007), is that: for index realization of i_t, $t = 1, 2, ..., T$, its kernel density function can be expressed as:

$$h(i) = \frac{1}{T\Delta}\sum_{t=1}^{T} K\left(\frac{i - i_t}{\Delta}\right) \tag{3.14}$$

where *K(.)* represents the kernel function; Δ represents the degree of smoothness and is called bandwidth (Deng *et al.* 2007).

Based on Deng *et al.* (2007), the pricing scheme on the precipitation based weather derivative contract depends on i_t^*, λ_t, *m*, and the probability distribution of i_t, and can be specified as follows:

$$p_t = \frac{1+\alpha}{1+r} \int indemnity_t h\ (i)\ d_i \tag{3.15}$$

The transition function is:

$$\begin{aligned} w_{t+1} &= (1+r)\,(w_t\text{-}cost_t\text{-}c_t\text{-}p_t) + P_{output} y_t^f \\ &\quad + indemnity_t \end{aligned} \tag{3.16}$$

The control variables, namely the consumption c_t and the limit parameter λ_t are selected so as to maximize the Bellman's Equation in the last section.

CHAPTER 4

NUMERICAL STOCHASTIC DYNAMIC PROGRAMMING

4.1 INTRODUCTION

As the future per-period revenue (labor income) is uncertain when agents make the decisions (i.e., per-period revenue is chosen randomly from a 31-year historical yield), it is impossible or difficult to derive a closed-form solution to the problem of dynamic optimization of consumption, insurance, and credit (Seater 1993), although it can be mathematically proved that optimal consumption is strictly increasing with respect to wealth (Carroll 2001).

Numerical techniques have been regarded as one of the quickest methods to approximate the solution to a model with relatively good precision. (Farr and Luengo-Prado 2001). Bellman's equation is solved by the collocation method in our study, which approximates the Bellman equation by combining and solving *n* basis functions (Miranda and Fackler 2001), and a stochastic dynamic Monte-Carlo simulation is used to examine how the system evolves over a 30-year horizon starting from a given initial condition.

This section presents and describes the state variables, control variables, model parameters, and how the MATLAB DDPSOLVE algorithm can be applied to solve the stochastic dynamic Monte-Carlo simulation model. A numeric solution of the optimal paths of consumption, insurance, debt, and precautionary wealth is provided for the benchmark case. The relationship between choice variables and precautionary wealth, and the steady state statistics for the choice and state variables are provided and analyzed. Both infinite and finite horizon optimization results are presented to investigate the effects of a retirement plan on the dynamics of consumption, insurance, credit, and precautionary wealth.

4.2 INCOME UNCERTAINTY, PRODUCTION COST, AND PRECAUTIONARY WEALTH

One of the two state variables in the model is realized revenue, $P_{output} y_t^f$, which introduces random shock to the model. Due to limited farm-level yield data, the Decision Support System for Agro-technology Transfer (DSSAT) crop simulation model is used to determine optimal irrigation strategy and to simulate farm level yield data for 31-year (from 1976 to 2006) cotton production in Mitchell, Georgia. DSSAT is a computer simulation model developed by a small group of modelers and system scientists, which combines the models (programmed in FORTAN), databases (dBASE or .dbf format), and an application program (in BASIC) into computer software and provides users with easy access to simulate, analyze, and display outcomes of alternative crop production management strategies under a specific environment specified by the user (irrigation, fertilizer, weather station, soil type, etc.) (Soler 2009).

The DSSAT model evaluates the soil water balance of a crop on a daily basis, and the limit to which water can be applied is an input for the model which is usually calculated as the difference between saturated upper limit and lower limit (SUL-LL)

(Soler 2009). Irrigation schedules in our study are rule-based scheduling, that is, the rules (e.g., irrigate at 40% means the threshold of irrigation is 40% of soil water capacity (SUL-LL) and when irrigation is needed, it will refill soil water to field capacity) determine the timing of irrigation and the amounts to be applied. Outputs from the crop simulation model are later incorporated into an economic model to determine the optimal irrigation scheduling and the farm level yield for 31-year production. For simplicity, we assume the optimal irrigation strategy is not time-variant; that is, the economic model that determines the optimal irrigation strategy is the expected utility function of one-year revenue, not the dynamic Bellman's Equation. Therefore, the main attention is paid to dynamic financial risk management (insurance and credit), rather than to dynamic production management (irrigation).

A production cost *cost* = \$592.45/acre is calculated, which include variable costs and fixed costs. As fertilizer application is fixed for a given crop, fertilizer cost is classified as a fixed cost. All costs except irrigation data are obtained from The University of Georgia/Extension Agricultural and Applied Economics office. Irrigation cost is assumed to consist of two parts: pumping cost and application cost. In this study, application cost is set to be \$12 per application, and assumed to be constant. Pumping cost is assumed to be \$30 acre-foot. After optimal irrigation is determined, *cost* is calculated and assumed to be fixed.

A price of crop product P_{output} = \$0.59/lb is obtained from the average of each year's output price data from the USDA National Agricultural Statistic Service (NASS) multiplied by CPI (Consumer Price Index) to adjust for inflation, and is assumed as constant through the optimization period. In the benchmark simulation, uncertainty comes only from production (yield) variation to shorten the time of optimization process. Price (market) risk will be analyzed in the section chapter through sensitivity analysis.

Another set of yield data is county level yield data for the same time period, which is also from NASS. In the optimization process, realized yield (farm level or county level) for each year is chosen randomly from these two sets of data, which leads to income uncertainty and as a result, the decision process is a stochastic process, which in turn makes it difficult if not impossible to derive an explicit solution for the optimization process (Seater 1993).

Wealth in the model is another state variable, which is accumulated according to the transition equation due to precautionary purpose. We assume wealth is composed of two parts, one part is insurance, and the remaining part is deposit, both of them are risk free in MPCI insurance design, but in GRP and WD insurance designs, the insurance products are not risk free because of basis risk. Remember that in our model, the interest rate for deposit and debt are the same, and that the farmer determines the amount of debt (negative means deposit) to finance consumption, insurance, and production for the whole year, and determines the amount of precautionary saving (negative means still in debt) for the future. Thus w_{t+1} is end-of-season precautionary wealth and is composed of precautionary saving and insurance purchase. As the same interest rates are applied to deposit and debt, we treat

$(w_{t+1}\text{-}p_{t+1})$ as end-of-season precautionary saving/deposit for precautionary purposes, and treat $[-(w_{t+1}\text{-}cost_{t+1}\text{-}c_{t+1}\text{-}p_{t+1})]$ as net debt to finance consumption, insurance, and production for the next year. To understand the decision process more clearly, we treat net debt (to finance consumption, insurance, and production for the whole year) and deposit (precautionary saving for the future) as separate, and interpret end-of-season saving/deposit as precautionary saving.

As we want to analyze optimal decision rules for a wide range of farmers (with different wealth levels), we follow the work of Nyambane (2005), and specify a wealth space in the range of [-500, 2000] in 100 increments to represent all farmers with a wide range of wealth levels, as opposed to actual wealth data for a decision maker. Thus, the state wealth is a vector, with each wealth level corresponding to its own optimal choice set and its own value function. Note that the unit of each wealth level is $/acre, and thus this provides a very wide range of wealth levels.

4.3 CONSUMPTION AND INSURANCE PARAMETERS

Consumption and insurance parameters are the control variables in the numerical model. To find the optimal consumption path over the optimization horizon, we follow the work of Nyambane (2005) and specify a consumption space in the range of [0, 2000] in steps of 100, and then use the numeric simulation method to choose the optimal one for each sub-period. Note that the unit of each consumption level is also $/acre.

In the MPCI and GPR designs, similar to the concept of searching for optimal consumption, we specify a *coverage* space in the range of [0, 0.9] in steps of 0.01. Thus, the upper limit imposed is 0.9, which is consistent with the actual practice of crop insurance in practice and helps mitigate the problems of moral hazard (Nyambane 2005). The guaranteed yield level, *strike*, is set to be a fixed level and is calculated as the estimation of the long-run expected yield (expected farm-level yield for MPCI; expected county-level yield for GPR design).

In the WD design, similar to the concept of searching for optimal consumption, we specify a space of limit parameter λ in the range of [0.01, 0.90] in steps of 0.01. *Strike* is designed to be the expected precipitation during the growing season. *Maximum liability* is set to be the irrigation cost corresponding to the 85% (maximum level available) irrigation threshold strategy, as the irrigation cost in years with the worst weather is regarded as a good estimate to approximate the value at risk (VaR) for crop production (Lin *et al.* 2009), and thus can be used as the proxy for the maximum liability for crop production under weather risk.

4.4 INTEREST RATE, TIME PREFERENCE, AND OTHER PARAMETERS

The benchmark of the model assumes the following set of parameter values which were estimated in empirical studies or are often used in the literature.

A per sub-period risk free interest rate on deposits/debt is set to be r = 0.0469 in the benchmark case, which is the annual return on a 30-year Treasury Constant Maturities (FRB 2010).

A discount factor of β = 0.8989 is assumed, which indicates the farmer's measure of time preference, with a higher β meaning valuing future more and thus being more patient. The relationship between β and discount rate ψ given by: $\beta = \frac{1}{1+\psi}$; thus, the higher the ψ, the more impatient the farmer. The discount rate is different from the risk free interest rate; in fact, it is often interpreted as the risk of cash-flows, and is calculated as the sum of the risk free rate of interest, r (the time value of money), and a risk premium which reflects the compensation the farmer demanded for the risk of not receiving the future cash flow of the investment in farming (Nyambane 2005). A discount rate of 11.25% is used in this study by adding a risk premium of 6.56% to the annual risk free interest rate of 4.69% (FRB 2010). The risk premium is assumed according to the time-series estimates of the crop farmers' risk premium by Hanson and Myers (1995), who suggested that agricultural risk has increased significantly over time. Thus, in this paper a higher risk premium is used than the estimates in Hanson and Myers (1995), representing higher risk in agriculture in recent years.

For the insurance premium loading factor, α, in the benchmark case α is set to 0 to reflect a fair premium without loading, and then α is set to 40% and -40% in the sensitivity analysis to represent scenarios in which there is a 40% loading as well as 40% subsidy , respectively.

The relative risk aversion parameter is set to 2 in the benchmark case based on previous studies (e.g., Gourinchas and Parker (2002)) and then the sensitivity analysis is set to 4 to investigate how an increase in relative risk aversion affects the optimal choices and their relationship with precautionary wealth. A liquidity constraint of *minnet* = -$1500/acre is assumed in the benchmark case, representing that farmers cannot borrow more than $1500/acre per period.

Table 4.1 summarized the set of parameter values for the benchmark case.

Table 4.1: Benchmark Parameters

$p_{output} = 0.59$	$minnet = -1500$
$r = 0.0469$	$\beta = 0.8989$
$cost = 592.45$	$\alpha = 0$
$\gamma = 2$	$max_{liability} = 291.8$

4.5 MODEL IMPLEMENTATION USING MATLAB DDPSOLVE ALGORITHM

The stochastic model generates multiple paths emerging from the realization of random shocks, as opposed to a single path generated by deterministic models (Gomez-Soto 2007). The stochastic dynamic model is solved by applying the "ddpsolve" algorithm included in the CompEcon Toolbox. The simulation is conducted over a 30-year horizon, starting from an initial state. A finite (with retirement plan) and infinite (without retirement plan) version of the stochastic dynamic model is computed and compared.

The solution to the model under each set of parameter values can be classified into two sets of results. One set is the dynamic path analysis of optimal choices (i.e., the optimal consumption, insurance coverage, and debt), and the state variable - net wealth. Note that the optimal paths of the choice variables are contingent on the path of the state variable. Thus, the other set is the relationship analysis between optimal choices and state variable, that is, the relationships between consumption and wealth, between insurance and wealth, and between debt and wealth, which shows how the choices change with respect to different wealth level, and can also reflect different behaviour for different farmers with different initial wealth.

The simulations of infinite horizon with initial wealth level of -$500/acre is presented first. For an infinite horizon problem, the value functions would not depend on time *t*, and the dynamic programming (DP) problem which is conditional on the initial state is also time invariant as we always have infinite sub-periods left in the future (Violante 2000).

In our model, farm income is chosen randomly from the income during 1976 and 2006 with probability 1/31, which introduces uncertainty and stochastic characteristics into our model. The analysis is more complicated because labor income is random distributed as opposed to a deterministic one. In the infinite horizon, given the optimal choice variables, the time-series of state variable (wealth) would be a Markov chain with infinite horizon and with a stationary transition matrix *g*. The *ij*'th element of the transition matrix *g* indicates the probability of migrating from state *i* at some time *t* to state *j* at the following time *t+1*, given the current state and the optimal choices that are chosen (Miranda 2010). The CompEcon Toolbox provides a utility *getindex* which helps solve the discrete Markov decision by calculating an index attached to the following period's state (*inext* = *getindex*(*nextwealth*, *wealth*)), and thus facilitate the calculation of transition matrices with *ij'th* element being the probability *g(j, i, inext)* (Miranda 2010).

After we got the transition probability matrix *g* of the controlled state process (*wealth*), we are able to conduct a Monte Carlo simulation to simulate many representative state paths (Miranda 2010). To start, we pick an initial state, w_0=-$500/acre, that is, initial wealth level is -$500/acre (meaning that the farmer is in debt of $500/acre at the initial state), and then use a Monte Carlo simulation to simulate the next state of wealth level based on the transition matrix, and this process goes on to infinity. For example, having the state $S_t = i$, we can simulate S_{t+1} by randomly picking a new state *j* with probability *g(j, i, inext)* (Miranda 2010). In this way, the dynamic evolution of the controlled state over time can be specified. The Monte Carlo simulation also helps to generate multiple paths, each of which emerges from the realization of random shocks, as opposed to a single path in a deterministic model; thus, the steady state is a distribution rather than a point (Gomez-Soto 2007).

The infinite horizon simulation implemented with the stochastic dynamic model provides the following results.

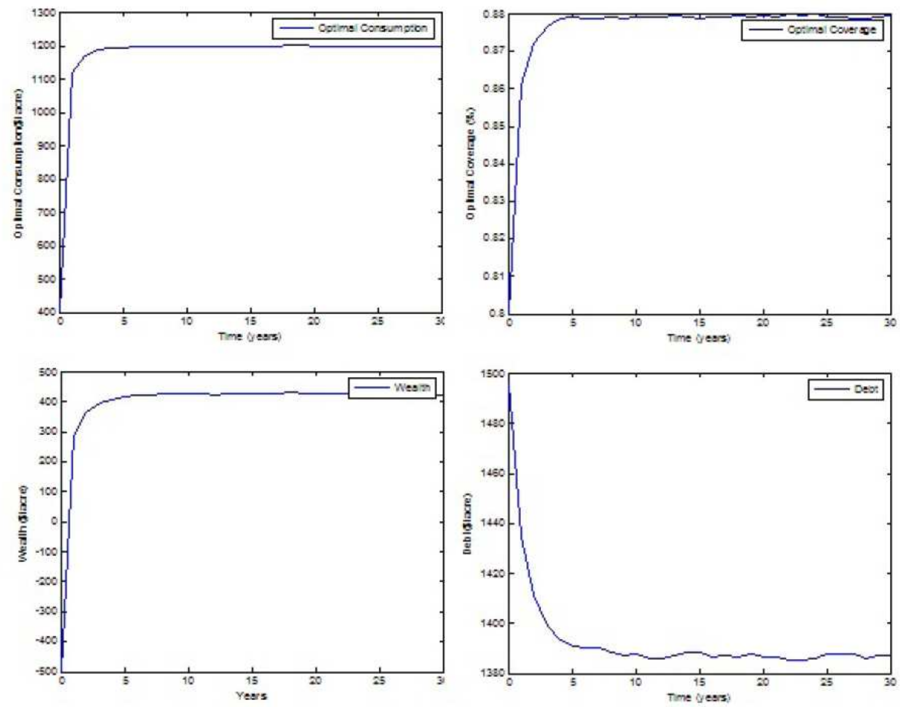

Figure 4.1: Time Path of Consumption, Coverage, Wealth, and Debt for a MPCI Fair Premium Insurance Purchaser

Figure 4.1 shows the 30-year time path optimization process of consumption, coverage, wealth, and debt for a cotton farmer in Mitchell, Georgia, starting from the initial state *w* = -\$500/acre. It can be seen that under the values assumed for the model, these distributions evolve over time and then keep sufficiently close to the steady-state distribution after 5 to 10 years from the initial state. Thus, the steady-state distribution emerges quickly over time, implying that if all farmers have the same or similar levels of the parameter values assumed for the model, the statistics derived from the steady state distribution would represent the majority of the behavior for the economy.

Specifically, optimal consumption increases from \$400/acre to \$1100/acre within 5 years and then remains at its relatively steady state value, which is around \$1200/acre, for the next 25 years. Optimal insurance coverage increases from 80% to

86% within 5 years and then remains at its relatively steady state value, which is around 88%, for the next 25 years. Wealth increases from the initial level of -$500/acre to $300/acre and then to $420/acre within 5 years and remains relatively constant at $420/acre for the next 25 years. These three effects (increasing wealth, increasing consumption, and increasing insurance premium) offset each other, and the resulting debt value decreases from around $1500/acre, the maximum allowable debt level, to around $1385/acre within 5 years and then is relatively constant for the next 25 years.

The above results are simulated with initial wealth equal to -$500/acre. When we change the initial wealth to other values (with other parameters being unchanged), we get the same steady-state distributions. For the same set of parameter values assumed in Table 4.1, the distribution of optimal consumption and insurance coverage reach their steady-state value within a five year time span. The distribution of wealth and debt also get closer to their steady state over time and after the first five years they remain relatively constant. The optimal debt converge to around $1385/acre, and the controlled state variable wealth is stabilized at around $420/acre.

This result indicates that with the parameters in this model, no matter how much initial net wealth farmers hold, their choices will always be stabilized to a relatively constant steady state after 10 years from initial state. In other words, if the set of parameter values used in the model is correct for most of the farmers in the economy, most farmers' behavior could be predicted and would be almost identical after sufficient time, so the levels and the related ratios of the steady-state distribution for consumption, coverage, wealth, and debt would approximate the typical behavior in the economy fairly well.

Table 4.2 presents a number of statistics and the related ratios of average consumption, insurance, debt, and precautionary wealth behavior based on the stochastic Monte Carlo simulation generated steady-state distribution under the benchmark parametric assumptions.

Table 4.2: Steady-State Statistics For Benchmark Model

	BENCHMARK
Consumption (CON)	1200
Coverage (COV)	0.88
Debt (D)	1385
Expected Revenue (Y)	1860.1
Net Wealth (W)	420
Insurance Premium (P)	16.5
Deposit (DEP)	403.5
Ratios	
W / Y	22.6%
D/Y	74.5%
CON / Y	64.5%
P / W	3.9%
DEP/W	96.1%

Table 4.2 shows that wealth is stabilized at around $420/acre, or equal to around 22.6% (wealth ratio is around .226) of the expected production revenue (permanent income). As the time unit of an optimization sub-period is a year, the steady state wealth represents about three months' worth of permanent non-capital income, meaning that farmers hold approximately three months' of permanent income for precautionary purpose. We use expected production revenue to represent permanent income (based on Friedman’s (1957) theory) that interprets observed income as the sum of the permanent income component and a transitory random component.

This result confirms the contention of Carroll (2001), who stated that there is a target level of the buffer stock of precautionary wealth (cash-on-hand) which balances farmers' impatience (related to β) and prudence (related to γ) levels and provides a criteria for farmers' decisions, that is, if their precautionary wealth is below the target (optimal level), prudence will dominate impatience and farmers would have a higher precautionary saving motive and would try to increase wealth toward the target (optimal level); while if their precautionary wealth exceeds the optimal level, impatience will dominate prudence, and farmers would consume more and cause net wealth to go back to the target level (Carroll 2001). This result is also related to Friedman's (1957) PIH theory, as noted by Carroll (2001), which views wealth as "emergency reserve" against uncertainty. In Carroll's (2001) paper, the wealth ratio was estimated to be around 0.4; while in our model, the optimal wealth ratio is simulated as 0.226 for the benchmark case. Note that in our benchmark case a high level of impatience is assumed, which leads to a lower target level of wealth. By checking our results against other literature, we can see our results are consistent with the theoretically predicted results, confirming that our stochastic life-cycle model and dynamic programming technique is correct.

Debt is stabilized at around $1385/acre as shown in Table 4.2, which is around 74.5% of the expected production revenue, meaning farmers use more than 74.5% (including interest) of permanent income to repay previous loans; consumption is stabilized at $1200/acre, which is around 64.5% of permanent income, meaning that farmers consume around 64.5% of permanent income for immediate reward; insurance premium is stabilized at $16.5/acre, which is around 3.9% of net wealth, meaning that farmers allocate 3.9% of net wealth to buy insurance for precautionary purpose, while the remaining net wealth (96.1%) is allocated to precautionary savings.

Our result is consistent with the result by Carroll (2001), who generated converged consumption function and revealed that impatience is the necessary condition for converged consumption. Modigliani (1966) noted that certainty equivalent models cannot yield general results about consumption behavior because different levels of optimal consumption are derived at different times. Thus, our results are different from the results of the certainty equivalent model, and can represent the typical behavior of the majority of farmers in the economy, under the same set of parameter values.

As the optimal choices along the time path are contingent on the state variable along the time path, the relationships between the choice variables and the state variable are presented below (specifically, the relationship between consumption and wealth, the relationship between insurance coverage and wealth, and the relationship between debt and wealth). Figure 4.2, 4.3 and 4.4 plot the optimal choice variables (consumption, coverage, and resulting debt) against the state variable wealth.

Figure 4.2 shows that optimal consumption always increases as wealth increases. This result can be derived by formal mathematical proof (Carroll 2001). Furthermore, some other important properties can be derived from the consumption curve $c(w)$:

1. The consumption curve is upward sloping and concave, and thus its slope is smaller at high level of net wealth (cash-on-hand) than at low levels. According to Keynes (1935) and Carroll (2001), the share of transitory income that is spent on

consumption is higher for poor people than for rich people, and this view is confirmed in our result, as MPC for poor farmers is higher than MPC for rich farmers.

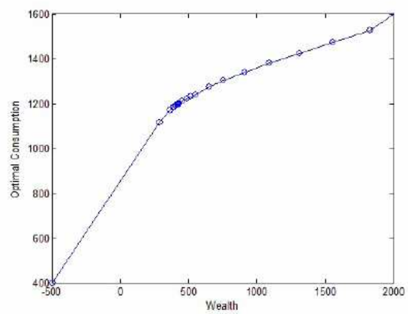

Figure 4.2: Relationship of Optimal Consumption and Wealth for a MPCI Fair Premium Insurance Purchaser

2. MPC out of transitory shock to their income is around 0.8 for poor farmers (net wealth level in the range of -\$500/acre to \$500/acre), and is around 0.266 for wealthy (normal) farmer (net wealth level in the range of \$500/acre to \$200/acre). In Friedman's (1957) conception of the PIH theory, MPCs are much less than 1, and the average MPC is about 0.33 for typical consumer. Our result seems to support Friedman's (1957) PIH theory, as his estimated MPC is in the range of our simulated MPC for poor and wealthy farmers, and our simulated MPC for both poor and wealthy farmers is much less than 1, and dramatically larger than the 0.05 implied by the perfect foresight model. In the perfect foresight model, it is assumed that uncertainty does not exist (Carroll 2001). Carroll (2001) argued that consumers who are younger than 65, representing the majority of the consumers, would have MPC of less than 0.05 in a perfect foresight model, in which no uncertainty is assumed and thus consumers would spread the change in wealth evenly over their entire life (at least 20 years for most consumers), assuming that an average age of death is around 85.

Our result also differs from the certainty equivalent solution, in which optimal consumption level should be a fixed percentage of lifetime wealth -- the sum of consumers' initial wealth and the discounted series of expected lifetime income (Zeldes 1989), with MPC less than 0.05 (Carroll 2001). Zeldes (1989) noted that the certainty equivalent model assumes a quadratic utility form with the implication of increasing risk aversion and of a linear marginal utility, and thus there is no precautionary motive and consumption growth rate would only depend on the risk premium demanded by consumers (the difference between discount rate and the risk-free rate of interest *r*). Carroll (2001) pointed out that MPC in certainty equivalent model is also less than 0.05.

Figure 4.3 shows that when initial wealth increases from the lowest level (-\$500/acre, meaning farmer is heavily in debt), coverage increases slightly from 80% to 88%, until wealth reaches the steady state \$420/acre. When initial wealth increases from steady state to \$2000/acre, optimal insurance coverage decreases from 88% to 0% as initial wealth increases.

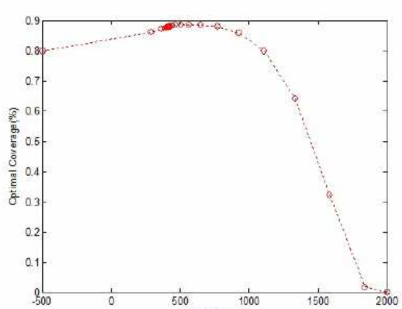

Figure 4.3: Relationship of Optimal Coverage and Wealth for a MPCI Fair Premium Insurance Purchaser

A possible interpretation of decreasing coverage with respect to wealth for most farmers (within the main range of wealth) is that the utility function of this research has the attribute of decreasing absolute risk aversion (DARA) (Epstein 1983). Since absolute risk aversion decreases in response to wealth increase, demand for insurance decreases, and thus insurance coverage decreases (Gollier 2003).

Figure 4.4 indicates that there is strictly negative relationship between wealth and debt. The interpretation of this result is straightforward: while debt is the beginning-of-season debt borrowed to finance consumption, insurance, and production for the whole year, wealth is end-of-season cash-at-hand each year, after repaying all the debt and its interest rate. Thus, a farmer will have a larger net wealth if the previous debt is small, and in the same way, the optimal debt should decrease as the farmer accumulates wealth, as the farmer doesn't need to borrow as much money to finance his consumption, production cost, and insurance purchase if he has accumulated enough wealth.

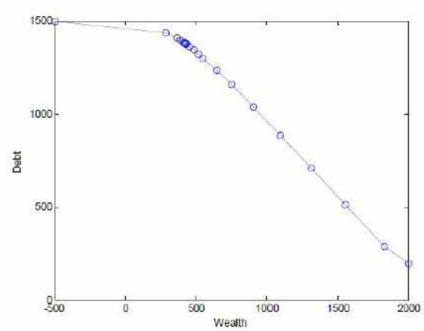

Figure 4.4: Relationship of Debt and Wealth for a MPCI Fair Premium Insurance Purchaser

The solution to the finite version with retirement plan comes next. For the finite horizon optimization, the terminal value V_{T+1} (which is a vector of values for all possible states variables) must be specified so that the Markov chain of the discrete time-series of controlled state variable (wealth) can be specified and derived. We assume at the terminal period, farmers must accumulate $2000/acre net wealth, and thus assign highest value for state *w* = $2000/acre. After the terminal value function is determined, the finite horizon Markov decision is solved by moving backwards from the terminal period and recursively applying the Bellman's equation.

Figure 4.5 shows the time path of consumption, coverage, wealth, and debt in a finite 30-year horizon for a farmer with a retirement plan of accumulating $2000/acre in the end. With a retirement plan, Figure 4.5 depicted that the distribution of optimal consumption evolves over time and gets fairly close to the steady state value within 5 to 10 years, which is not very different from the without retirement plan case. However, in the last period of time (about the last 10 years), the farmer gradually increases consumption from $1200/acre to $1600/acre. The optimal coverage path follows a similar pattern in the first 20 years compared with Figure 4.1; however, after 20 years, coverage drops dramatically from 0.88 to 0. Wealth and debt paths show that in the last period of time (about the last 10 years), the farmer begins to save substantial amounts and restrains from borrowing to finance consumption, insurance, and production for the whole year.

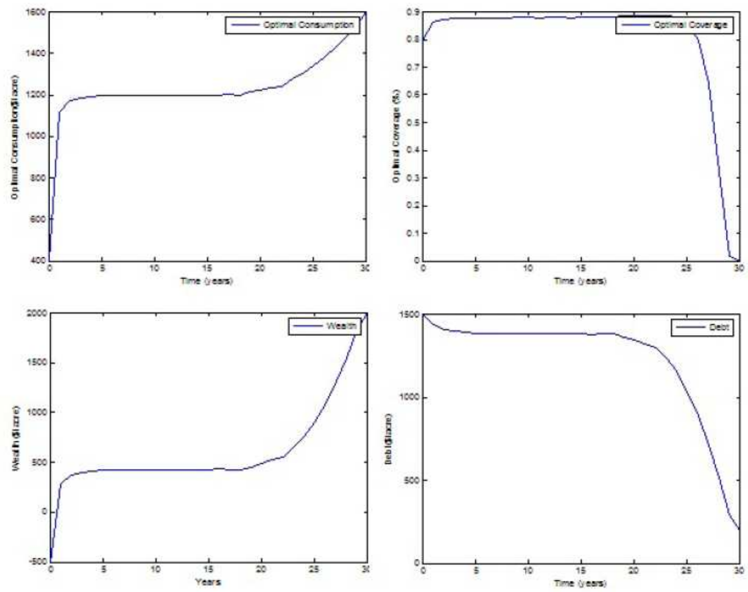

Figure 4.5: Time Path of Consumption, Coverage, Wealth, and Debt in a Finite Horizon with Retirement Plan

The reason for the increasing consumption in the last 10 years is that the relationship between wealth and consumption is always positive, whether the farmer has a retirement plan or not. Therefore, as the farmer accumulates wealth, the consumption level also increases, but with much lower increasing rates than that at the low level of net wealth (as shown in Figure 4.2, the MPC is much lower at the high level of net wealth). The intuition of decreasing coverage with retirement looming is that, as the farmer accumulates wealth for a retirement plan, he is less risk averse because of the DARA nature of utility function (as noted before), and thus decreases the demand for insurance.

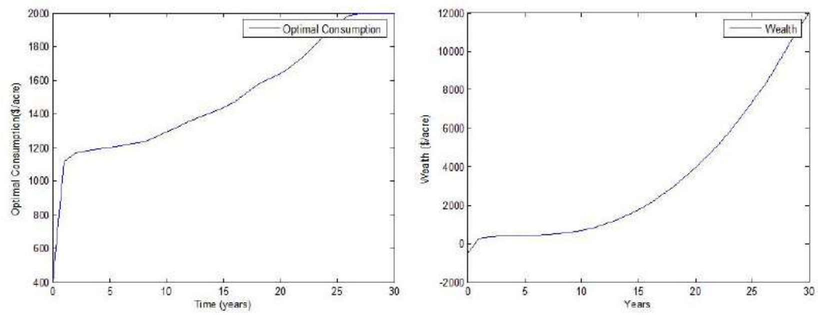

Figure 4.6: Time Path of Consumption, Coverage, Wealth, and Debt in a Finite Horizon with Retirement Plan of Accumulating $12,000/acre Wealth

When farmers have retirement plan of accumulating a higher level of wealth ($12,000/acre), we expect the behaviors to diverge sooner from the steady state distribution. Figure 4.6 confirms this expectation. The graph shows that the distribution of wealth gets fairly close to the steady state value within 2 to 5 years, which is not very different from the without retirement plan case. Consumption level at steady state seems to be lower than in benchmark case. However, farmers begin to accumulate wealth only after 10 years from initial state; and the consumption level also increases accordingly with the increase in wealth level. This result implies that a retirement plan with a higher target wealth level would induce farmers to sacrifice current consumption and diverge from steady state wealth level sooner in order to accumulate a higher level of wealth for retirement.

Table 4.3: Effects of Retirement Plan on Farmers' Value Function and Certainty Equivalent Consumption at Initial State

Retirement Plan ($/acre)	Value Function	Certainty Equivalent Consumption ($/acre)
2000	-0.010083	980.997
3000	-0.050575	195.575
5000	-0.050864	194.465
8000	-0.051088	193.611
12000	-0.051459	192.214

Table 4.3 summarized the effect of different retirement plans (with different target wealth levels) on farmers' value function and Certainty Equivalent

Consumption at the initial state. Certainty Equivalent Consumption is calculated on the analogy of Certainty Equivalent Revenue (CER) in static models. For a specified utility function in a static model, CER is the level of return that if received with certainty, would generate a level of utility equal to the expected utility of the risky investment. Similarly, Certainty Equivalent Consumption here means a risk adjusted consumption (the level of consumption without uncertainty) that can generate a level of value function equal to the expected value function of the dynamic stochastic consumption. Table 4.3 shows that the higher level of target wealth level of a retirement plan, the lower value function and the lower certainty equivalent consumption level.

CHAPTER 5

SIMULATIONS

5.1 INTRODUCTION

Several simulations are conducted in this chapter to examine the effects of variations in the values of parameters on the dynamic stochastic process. We paid special attention to the changes in the relationship between the intertemporal actions (consumption, insurance, and debt) and states variable (precautionary wealth), and changes in the steady state statistics, corresponding to different simulation scenarios. Changes in the time path of the intertemporal actions and states variable is only included for some simulations, when there are noticeable differences from the benchmark case.

The *ceteris paribus* criterion is used to conduct the simulation analysis, according to which, the effect of each simulation is explored once at a time compared to the benchmark scenario. This approach enables us to correctly identify the cause of change in each simulation scenario. Nine simulations are conducted separately to investigate the effect of financial parameters (liquidity constraint, interest rate, insurance premium loading, and basis risk), market risk parameter (lower price and random price), people factors (time preferences, risk aversion level), and production factors (crop types and rotation), on the farmer's optimal choices on consumption, insurance, and debt, as well as on the controlled state variable (wealth) which is composed of precautionary savings and insurance. The proportions of precautionary savings and insurance in the wealth portfolio will also be analyzed in different simulation scenarios. Specifically, the following simulation scenarios are conducted:

1. Variations in the credit constraint imposed by the financial lending institution, *minnet*, to examine how the severity of liquidity constraint would affect the relationship between dynamic choices and wealth, as well as the steady-state statistics.

2. Variations in the insurance premium loading parameter, α, to investigate how the decisions would be affected by the premium loading and by a premium subsidy.

3. Variations in output price, to examine what potential impact a decrease in output price would have on optimal dynamic choices and steady-state statistics.

4. Variations in the degree of risk aversion (or prudence), γ, to investigate which type of farmers are more inclined to purchase insurance, to use deposit or debt, and to accumulate precautionary wealth.

5. Changes in time preference factor (or patience level), β, with a higher β corresponding to more patient farmers (and richer farmers in most cases), to investigate what type of farmers are more inclined to purchase insurance, to using deposit/debt, and to accumulating precautionary wealth, and in what time frame.

6. Changes in the effective interest rate, r, to investigate the impact of adjustment of interest rate on farmers' optimal dynamic choices including insurance purchase, deposit/debt, and precautionary wealth, and the steady-state statistics.

7. Changes in basis risk, which is captured in three alternative insurance experimental designs, to examine the variations in farmers' optimal dynamic choices

as a result of basis risk, as well as the impact of various innovative insurance products on farmers' risk management.

8. Random price, to examine what potential impact an increase in market risk would have on optimal dynamic choices and steady-state statistics.

9. Variations in crop type and rotation, to examine the impact of production strategy on optimal choices.

Special attention is paid to the first, second, and sixth simulations, as changes in consumption and insurance choices produced by a change in credit constraint, insurance premium loading, and interest rate are related to policy interventions and have valuable empirical significance. In addition, the simulations allow us to draw expected consumption, insurance, and debt paths, and the resulting precautionary wealth path, which are critical for designing optimal financial facilities (e.g., debt/deposit facilities, insurance, etc.) and for analyzing the effect of financial facilities on consumption smoothing and precautionary wealth, which are directly related to the farmers' welfare as well as societal welfare. Gomez-Soto (2007) stated that both households' welfare and societal welfare will improve as a result of increasing precautionary wealth without additional cost, as the level of wealth and distribution of income (as embodied, e.g., by Gini coefficients) are related to societal welfare, and larger wealth is presumed to imply greater societal welfare. The composition of a precautionary wealth portfolio (the portion of precautionary wealth as insurance holding), is also an important factor influencing social welfare, as insurance plays a significant role in risk sharing for the larger population.

5.2 SIMULATION 1: VARIATIONS IN LIQUIDITY CONSTRAINT

This section shows the simulation result for a farmer subject to a stricter liquidity constraint and full liquidity constraint. With stricter liquidity constraint (cannot borrow money more than \$500/acre, and the starting point of simulation is \$500/acre as opposed to -\$500/acre in the benchmark scenario, in order to satisfy the stricter liquidity constraint at the starting period), the relationship between optimal consumption and wealth depicted in Figure 5.1 shows that the steady-state consumption is around \$1250/acre, which is similar to the steady-state level in the benchmark scenario. However, the corresponding wealth level at the steady-state is around \$1500/acre, much higher than in the benchmark scenario (\$420/acre). Comparing Figure 5.1 with Figure 4.2, it is not difficult to discern that, at the same wealth level, the farmer will choose a lower consumption level when faced with stricter liquidity constraint. For example, at wealth level w = \$500/acre, optimal consumption level is \$1250/acre in the benchmark case, but only \$400/acre in the stricter liquidity constraint case.

This result indicates that, with stricter liquidity constraint, farmers will reduce current consumption in order to accumulate precautionary wealth for future consumption. In other words, farmers sacrifice their current consumption to insure a future higher consumption and wealth level.

A more important result is a higher MPC (the slope of consumption curve) in the stricter liquidity simulation scenario than that in the benchmark scenario: MPC is around 0.8 for farmers with net wealth in the range of \$500/acre and \$1500/acre, and is around 0.6 for farmers with net wealth in the range of $1500/acre and $2000/acre, as opposed to MPC of 0.267 in the range of $500/acre and $2000/acre in the benchmark case.

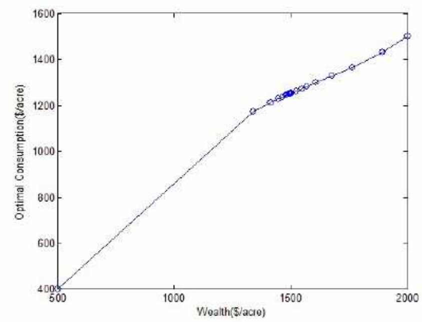

Figure 5.1: Relationship Between Optimal Consumption and Wealth under Stricter Liquidity Constraint

This result confirms the classical consumption smoothing theory, that liquidity constraint might be the situation that leads to the high sensitivity of consumption to transitory shocks to income. When complete credit markets exist, credit is supplied to individuals whose income is subject to transitory shocks, and thus consumption can be smoothed through borrowing and savings. However, in an incomplete credit market where liquidity constraint exists, some farmers face credit constraints which limit their liquidity and in turn affect their consumption smoothing ability (Chah *et al*. 1995). Our results show that with higher liquidity constraints, MPC is higher than that in the benchmark case. In other words, under stricter liquidity constraint, consumption is more influenced by transitory income (random shocks to net wealth) than that in the benchmark case. However, MPC is still much less than one, which still supports Friedman’s (1957) PIH theory.

Figure 5.2 shows the relationship between coverage and wealth level with stricter liquidity constraint. Comparing with Figure 4.3, it is not difficult to see that most farmers adopt less insurance coverage. At steady-state, coverage is 28%, in contrast to the coverage level of 88% depicted in Figure 4.3. Insurance coverage is lower for most farmers (with net wealth in the range of \$500/acre and \$1800/acre) compared with the benchmark case; however, for very wealthy farmers (with net wealth in the range of \$1800/acre and \$2000/acre), coverage is higher than that in the benchmark case.

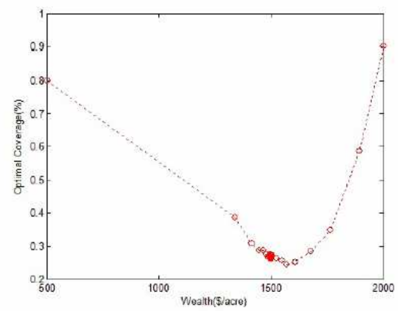

Figure 5.2: Relationship Between Optimal Insurance Coverage and Wealth under Stricter Liquidity Constraint

This result indicates that, for most farmers (within the main range of net wealth), a stricter liquidity constraint will not only reduce current consumption, but also reduce demand for insurance, because it constraint the farmer's budget to finance consumption and insurance purchasing. Moreover, Gollier (2001) showed that under a dynamic framework with the same DARA utility function for the immediate reward as in this study, a binding liquidity constraint has the future impact of constraining farmers' ability to spread risks over an optimization horizon and thus induces more risk aversion (in effect increases the relative risk aversion coefficient γ). Rothschild and Stiglitz (1971) showed that an increase in γ has two effects on farmers' precautionary behavior: one is to increase the precautionary motive to buy insurance; another is to increase the precautionary motive to save at the expense of insurance.

These two effects, along with the budget restraining effect of liquidity constraint, work together on most farmers (in the range of $500/acre and $1800/acre): the two effects of liquidity constraint (through the effect on γ *)* cancel each other, and the largest effect is that of restraining the budget, and this is why most farmers adopt less insurance coverage. However, for very wealthy farmers, the liquidity constraint is no longer binding, and thus there are only two effects of liquidity constraint (through its effect on risk aversion); it seems that the demand for insurance outweighs the demand for precautionary saving (the reason might be that the demand for precautionary saving comes very low when initial wealth increases to a very high level because of the DARA nature of utility), and thus insurance coverage is higher for very wealthy farmers compared with the benchmark case.

Figure 5.3 shows the relationship between debt and wealth. We can see the relationship is still strictly negative. However, under stricter liquidity constraint, optimal debt is smaller than that in the benchmark scenario for the same level of wealth. For example, at wealth level equal to $500/acre, debt level is $500/acre, as opposed to around $1400/acre in benchmark case; at wealth level equal to $1500/acre, debt level is around 350$/acre as opposed to $1380/acre in benchmark case; at wealth level equal to $2000/acre, debt level is around $110/acre as opposed to $200/acre in the benchmark case.

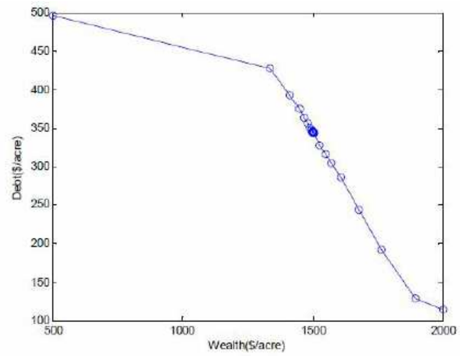

Figure 5.3: Relationship Between Debt and Wealth under Stricter Liquidity Constraint

Figure 5.4, 5.5, and 5.6 shows the relationship between optimal consumption and wealth, insurance coverage and wealth, debt and wealth level with full credit constraint, that is, the farmer is not allowed to borrow from financial institution (*minnet* = 0$/acre). In this case, the simulation is conducted assuming initial wealth level is equal to $1000/acre, rather than the -$500/acre in the benchmark case, as negative wealth level is not allowed in this scenario.

Figure 5.4 shows that the MPC (the slope of consumption curve) is higher in the full liquidity simulation scenario than that in the benchmark scenario or the stricter liquidity scenario: MPC is around 0.8 for all farmers in this case (with net wealth in the range of $1000/acre and $2000/acre, as opposed to 0.267 for farmers with net wealth in the range of $500/acre and $2000/acre in the benchmark case, and to 0.6 for farmers with net wealth in the range of $1500/acre and $2000/acre in the stricter liquidity case.

This result implies that under full credit constraint, the result concerning consumption behavior is also consistent with the results noted before. Liquidity constraint leads to higher MPC, and thus might be a reason that explains the high sensitivity level of consumption to transitory shocks to income; that is, consumption is more influenced by transitory income than that in benchmark case.

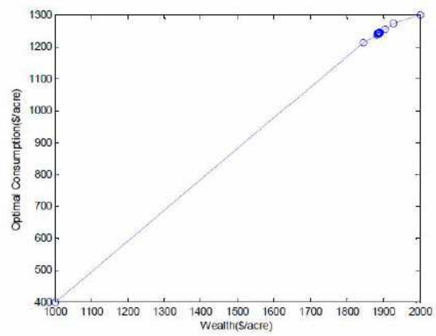

Figure 5.4: Relationship Between Optimal Consumption and Wealth under Full Liquidity Constraint

Figure 5.5 shows that the equilibrium insurance coverage level is 84.5%, with corresponding wealth level equal to \$1900/acre. The graph also shows a different relationship pattern between coverage and wealth. When initial wealth level increases from \$1000/acre to \$2000/acre, optimal coverage increases from 80% to 90% (all very high compared with the benchmark case).

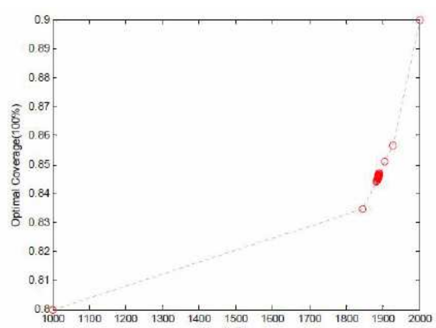

Figure 5.5: Relationship Between Optimal Insurance Coverage and Wealth under Full Liquidity Constraint

Figure 5.6 shows that the relationship between debt and wealth is still strictly negative under the full liquidity constraint scenario. However, debt is no longer positive in this case. As debt is not allowed, the optimal values for debt are all negative, meaning positive beginning-of-season deposit; that is, in addition to set aside money to finance consumption, insurance, and production for the whole year, farmers also set aside money for beginning-of-season deposit in order to guarantee the consumption and wealth level at steady state in the future. For farmers with net wealth level equal to \$1000/acre, they deposit \$4/acre; for farmers with net wealth level equal to \$1900/acre, they deposit \$42/acre; for farmers with net wealth level equal to \$2000/acre, they deposit \$90/acre.

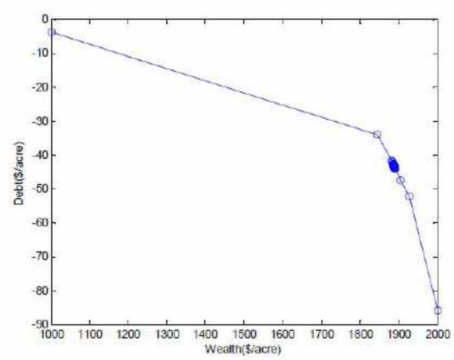

Figure 5.6: Relationship Between Debt and Wealth under Full Liquidity Constraint

By comparing Figure 5.2 and 4.3, it is possible to discern that the liquidity constraint has an impact of reducing optimal insurance coverage along the 30-year expected path. However, by comparing Figure 5.6 and Figure 5.2, we conclude that when full liquidity constraint is imposed (the farmer is not allowed to borrow), optimal coverage now converges to around 84.5%, higher than that in the second strict case. Therefore, no clear link can be established between increasing liquidity constraint and insurance coverage.

Table 5.1 compares a variety of statistics about farm risk management behavior under the benchmark, stricter liquidity constraint, and full liquidity constraint parametric assumption. Under stricter liquidity constraint, net wealth increases from \$420/acre to \$1500/acre, which is equal to increases from 22.6% of expected production revenue (which is assumed in the model to represent the permanent income and is fixed) to 80.6% of expected production revenue. This result indicates that stricter liquidity constraint induces higher intention to accumulate wealth. Debt decreases from \$1380/acre to \$350/acre, indicating that an exogenous decrease in liquidity constraint results in a significant decrease in debt immediately. This result implies that change in farmers' credit limit would be efficient in the monetary policy transmission. For example, when policy requires banks to strengthen liquidity constraint, the volume of debt would fall dramatically, (current) consumption would be reduced immediately to ensure higher future consumption (at steady-state), optimal insurance purchase would decrease to 0 (at steady-state), meaning insurance is no longer a good strategy for precautionary motive compared with precautionary saving, precautionary wealth would be accumulated much more, and the supply of deposits (precautionary saving) also increases dramatically. These results might be of interest for researchers working on monetary transmission mechanisms.

Table 5.1 also shows that when farmers are subject to full credit constraint, that is, not allowed to borrow any money from a financial institution (*minnet = 0*), the steady-state coverage level is 84.5%, higher than that in the second strict case. Therefore, different from Nyambane's (2005) result, our result suggests that there is no strictly negative relationship between liquidity constraint and insurance coverage. However, a clear relationship can be seen between increases in liquidity constraint, a higher level of net wealth, and a lower level of net debt (in the full credit constraint case, debt is not allowed, and the steady state value for debt is negative, meaning positive beginning-of-season deposit, and higher end-of-season precautionary saving (DEP).

In the extreme full credit constraint case, at the steady state, farmers set aside additional money for beginning-of-season deposit (net debt = -42) in order to ensure the consumption and wealth level at steady state. Expected end-of-season cash-at-hand each year accounts for 100.2% of the permanent income in the full credit constraint scenario as opposed to 22.6% in the benchmark (moderate liquidity constraint) scenario and 80.6% in the stricter constraint scenario. A full liquidity constraint limits farmers' ability to smooth consumption through lending facilities. As a result, farmers will choose higher insurance coverage for risk management. In other words, when there is no borrowing available to smooth consumption, farmer will resort to insurance for risk management.

Table 5.1: SIMULATION 1: Effects of Liquidity Constraint on Optimal Choice and Wealth Composition

	BENCHMARK	**SIMULATION 1: minnet**	
		Stricter Constraint	Full Constraint
	$minnet = -1500$	$minnet = -500$	$minnet = 0$
Consumption (CON)	1200	1230	1240
Coverage (COV)	0.88	0.28	0.848
Debt (D)	1385	350	-42
Expected Revenue (Y)	1860.1	1860.1	1860.1
Net Wealth (W)	420	1500	1900
Insurance Premium (P)	16.5	0	10
Deposit (DEP)	403.5	1500	1890
Ratios			
W / Y	22.6%	80.6%	100.2%
D / Y	74.5%	18.8%	-2.3%
CON / Y	64.5%	66.1%	66.7%
P / W	3.9%	0%	0.5%
DEP/W	96.1%	100%	99.5%

Figure 5.7 depicts the relationship between different levels of liquidity constraint and coverage levels at the steady state. Different from Nyambane (2005), our result suggests that there is no strictly negative relationship between liquidity constraint and insurance coverage. Specifically, insurance coverage first decrease with stricter liquidity constraint (mainly due to the effect of budget constraint), and then increase with stricter liquidity constraint. When liquidity constraint is so strict that farmers' ability to smooth consumption through borrowing is very limited, they have to resort to insurance for consumption smoothing and for risk management.

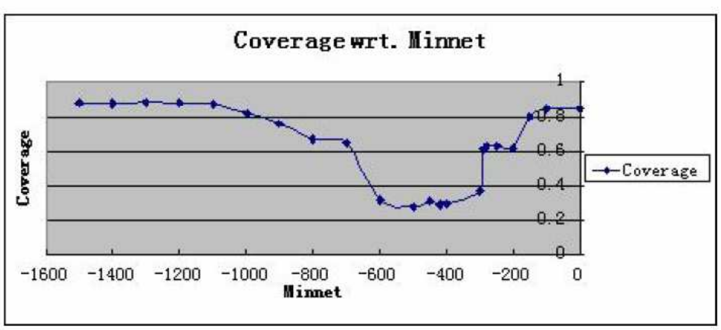

Figure 5.7: Relationship Between Coverage and Minnet for a Farmer under Liquidity Constraint

Some important policy implications regarding the simulation on liquidity constraint are:

First, a liquidity constraint has a large impact on optimal consumption and insurance choice, depending on the severity of constraint, and the initial wealth level. At the same wealth level, they will choose reduced current consumption and insurance coverage, in order to accumulate precautionary wealth for future consumption. A moderate liquidity constraint will not only constrain a farmer's current consumption, but also constrain a farmer's choice of insurance, because it constrains a farmer's budget to finance consumption and insurance purchasing. Moreover, under the dynamic framework with a DARA utility reward function, a liquidity constraint induces more risk aversion, which has two effects on insurance. For very wealthy farmers, it seems that the effect on insurance demand dominates the effect on the precautionary motive to save.

Second, at steady state, consumption level and net wealth is higher in the stricter credit constraint scenario than that in the benchmark scenario. In other words, farmers sacrifice their current consumption to insure future higher consumption and wealth level. In the extreme full credit constraint case, farmer set aside money as beginning-of-season deposit each year to ensure a sufficiently high level of consumption and wealth at steady state, and keep 100.2% of the per-period revenue as end-of-season precautionary wealth each year as opposed to 22.6% and 80.6% in the benchmark and stricter constraint scenario. This is because a higher risk averse level makes them more inclined to accumulate precautionary wealth, and thus decrease debt and decrease current consumption spending in order to maintain a higher level of consumption in the future (at the steady state).

Third, a full liquidity constraint limits a farmer's ability to smooth consumption through lending facilities. As a result, a farmer will choose higher insurance coverage for risk management. In other words, when there is no borrowing available to smooth consumption, farmers will resort to insurance for risk management.

5.3 SIMULATION 2: VARIATIONS IN PREMIUM LOADING

A second simulation is to investigate how the variation in the cost of insurance purchasing influences the dynamic optimization process and the relationship between choice variables and wealth. Two alternative scenarios are studied: a positive premium loading $\alpha = 0.4$, and a negative premium loading (premium subsidy) $\alpha=-0.4$.

In order to better understand the impacts of premium loading, I would go back and reexamine some important characteristics of the dynamic model. In order to cope with the risk related to income variation, farmers choose a portfolio composed of two risk management instruments. One instrument is insurance purchasing with possible transaction cost (implied by premium loading), and the other is a savings/borrowings with a financial institution, receiving/paying interest rate. For insurance purchase with full coverage, fixed output price, and without basis risk, the realized revenue plus indemnity (zero or positive) are guaranteed to be equal to or greater than the revenue specified in the contract (expected revenue), so there is no remaining downside risk. For savings/borrowings with a financial institution, no bankruptcy risk is assumed for the financial institution, so it is also risk-free. If we consider these two risk management instruments as supplements, then the price/cost of one instrument would be important in a farmer's decision of the proportion and allocation of this risk management portfolio.

Our results show that a positive premium loading $\alpha = 0.4$ will have little effect on consumption. The pattern of consumption function $c(w)$, as shown in Figure 5.8, is very similar to that in the benchmark scenario, with a slight lower value at the steady-state. Compared with Figure 5.8 and Figure 4.2, there are only slight differences in consumption patterns between the fair premium and loaded premium case. Specifically, the equilibrium consumption level decreases with premium loading, and the corresponding equilibrium wealth level also decreases from \$420/acre to \$400/acre.

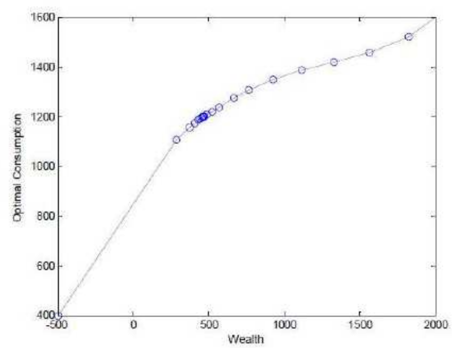

Figure 5.8: Relationship Between Optimal Consumption and Wealth for a Loaded Premium Insurance Purchaser

Figure 5.9 shows the optimal insurance coverage for fair, loaded (load parameter is 40%), and subsidized insurance (load parameter is -40%) products. Our results show that premium loading reduces coverage for most farmers (with net wealth in the range of \$500/acre and \$2000/acre). Only poor farmers in the range of

-$500/acre and $500/acre would take the same coverage compared with the benchmark scenario. This result shows that a loading in insurance premium would reduce a farmer's interest in purchasing insurance if the farmer is liquidity constrained within a dynamic framework.

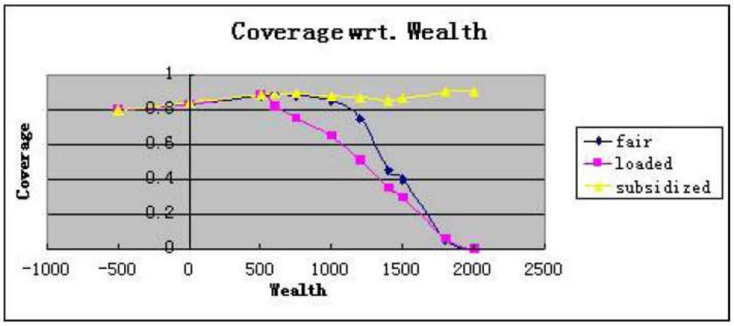

Figure 5.9: Relationship Between Coverage and Wealth in Fair, Loaded, and Subsidized Premium Scenarios

Moreover, Figure 5.9 provides additional insights concerning the optimal consumption and insurance choice for different farmers (with different initial net wealth) that could not be obtained from the static models. Figure 5.9 shows that when insurance is expensive, only poor farmers would be willing to keep the same insurance coverage and pay much more money to buy the more expensive insurance. Consistent with Nyambane’s (2005) results concerning increasing premium loading in complete credit markets (in our case credit is incomplete - farmers are liquidity constrained), wealthier farmers would substitute expensive insurance with precautionary saving, and reduce insurance coverage. According to Nyambane (2005), insurance and precautionary saving can be regarded as substitutes of risk management instruments to reduce the impact of yield risk on consumption (second option of risk management). Another explanation is, as poor farmers have higher MPC and higher marginal utility of consumption as stated in the last section, the possible loss if they do not insure enough, measured in terms of the possible decrease in consumption or utility, is higher than that for wealthy farmers. In addition, due to the decreasing absolute risk aversion (DARA) attribute of the utility function, poorer farmers with lower wealth levels would be more risk averse than richer farmers. Therefore, poorer farmers are more inclined to buy the same level of insurance as they do in the benchmark case than richer farmers although the insurance premium is unfair (loaded).

Figure 5.9 also depicted the coverage choice when insurance is subsidized. The steady-state coverage increases slightly from 88% to 89%. For most farmers (within the main range of net wealth), compared with the fair premium case, they choose to purchase higher insurance coverage. For very wealthy farmers with net wealth in the range of $1800/acre and $2000/acre, they choose the maximum allowable insurance coverage (90%).

These results imply that a negative premium loading increases farmers' interest in insurance and they would buy higher insurance coverage than they do with actuarially fair insurance. Nyambane (2005) proved that farmers would take full insurance coverage if there is no liquidity constraint, and that farmers would take less than the maximum allowable coverage if there is a liquidity constraint. Therefore, our result confirmed Nyambane's (2005) result and implied that the subsidy of insurance in effect reduces the impact of liquidity constraint and induces farmers to increase insurance coverage compared with the benchmark case, although for most farmers still less than the maximum allowable coverage will be taken. And for very wealthy farmers (initial wealth in the range of $1800/acre to $2000/acre), the maximum allowable insurance coverage (90%) is chosen under the subsidized insurance design.

Table 5.2: SIMULATION 2: Effects of Insurance Premium Loading on Optimal Choice and Wealth Composition

	BENCHMARK	**SIMULATION 2:** α	
		Loaded Premium	Subsidized Premium
	$\alpha = 0$	$\alpha = 0.4$	$\alpha = -0.4$
Consumption (CON)	1200	1190	1210
Coverage (COV)	0.88	0.87	0.89
Debt (D)	1385	1400	1375
Expected Revenue (Y)	1860.1	1860.1	1860.1
Net Wealth (W)	420	400	450
Insurance Premium (P)	16.5	22.5	11
Deposit (DEP)	403.5	377.5	439
Ratios			
W / Y	22.6%	21.5%	24.2%
D/Y	74.5%	75.3%	73.9%
CON / Y	64.5%	63.9%	65.1%
P / W	3.9%	5.6%	2.4%
DEP/W	96.1%	94.4%	97.6%

Table 5.2 compared the steady-state statistics for fair, loaded, and subsidized premium scenarios. Net wealth is slightly lower for the loaded premium case while slightly higher for subsidized premium case. Debt is slightly higher for loaded premium case, mainly because of higher insurance payments; while slightly lower for the subsidized premium case. These results imply that premium loading only has mild effect on farm risk management and precautionary wealth composition. These results are reasonable considering the inelastic property of insurance demand, based on the empirical estimation of agricultural insurance elasticity (-1 < elasticity < 0) (Barnett and Skees 1994), indicating that insurance demand is inelastic with respect to insurance price.

This result may imply that imposing higher premium loading would be beneficial to insurance companies, as the optimal insurance premium is $22.5/acre (meaning that farmers choose to spend $22.5/acre on insurance), higher than the benchmark case ($16.5/acre), in spite of the fact that optimal insurance coverage is lower. Subsidizing insurance, on the other hand, may not be very efficient in increasing farmers' welfare, as the increase in consumption and precautionary wealth is modest at best.

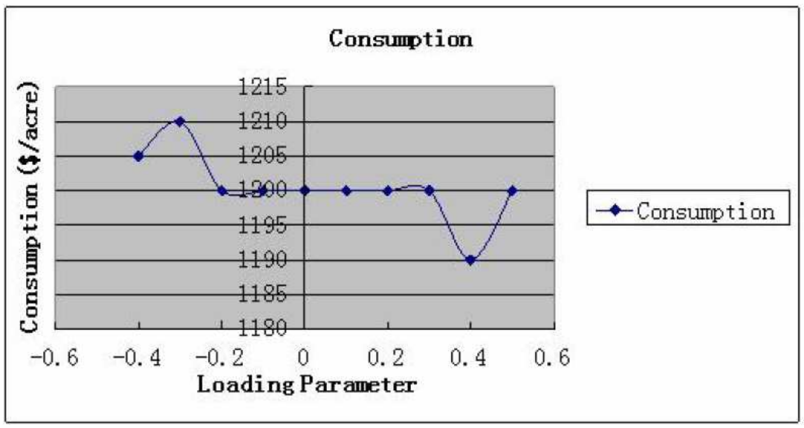

Figure 5.10: Relationship Between Consumption and Premium Loading for a Farmer under Liquidity Constraint

Figure 5.10 depicts the relationship between different levels of premium loading and consumption levels at the steady state. Compared to the benchmark case where premium loading factor is 0, when insurance is a little more expensive, farmers would feel that they need to save more to ensure higher consumption level in the future (at the steady state), so the steady state consumption level is a little bid higher. When premium loading is raised to 0.4, it affects farmers’ net wealth through budget effects. As a result, farmers’ consumption decreases at the steady state. When premium loading is raised to 0.5, however, farmers’ demand for insurance decreases (will be verified in the following graph), and as a result, premium loading will no longer affect farmers' wealth through budget effects, and farmers therefore increase consumption to the steady state level.

When insurance is subsidized (premium loading factor is negative), the reasoning is similar. A modestly subsidized insurance would make farmers feel that they don't need to save more and thus the steady state consumption decreases a little bid. When premium is more subsidized (premium loading factor is equal to -0.3), it in effect increases farmers' net wealth. As a result, farmers' consumption increases at the steady state. When premium is heavily subsidized (premium loading factor is equal to -0.4), however, farmers' demand for insurance increases to the maximum allowable level (90% coverage), and as a result, the expenditure on insurance increases, and thus farmers consumption level at the steady state is lower.

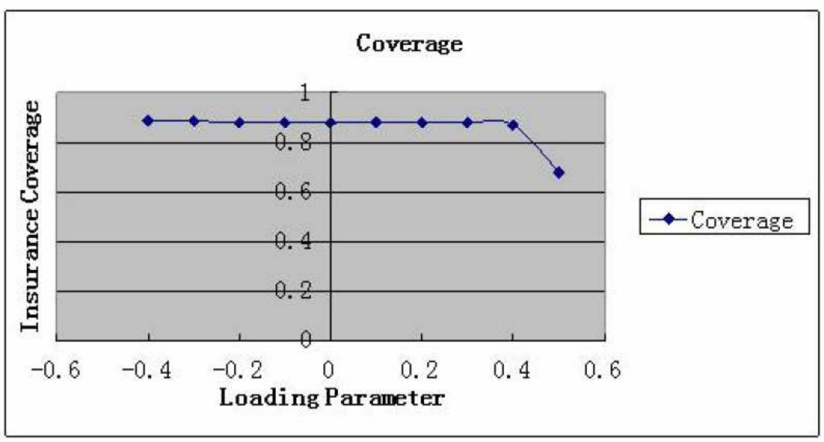

Figure 5.11: Relationship Between Coverage and Premium Loading for a Farmer under Liquidity Constraint

Figure 5.11 depicts the relationship between different levels of premium loading and insurance coverage levels at the steady state. We can see that insurance demand is very inelastic with respect to premium loading. When insurance premium loading factor is in the range of -0.4 and 0.4, insurance coverage is almost at the same level

(0.88, except for 0.9 for loading factor equal to -0.4). Only when insurance is heavily loaded (premium loading factor is equal to 0.5), insurance coverage decreases to 0.65.

Overall, these results have three implications. First, when liquidity constraint exists and insurance is actuarially unfair, loading an insurance premium would reduce a farmer's interest in insurance purchasing. Only when the insurance is subsidized and for the very wealthy farmer would one expect to purchase the maximum allowable insurance coverage as predicted in the static model for fair insurance products (Nyambane 2005). This result implies that when the insurance premium is subsidized, the liquidity constraint is somewhat relaxed, and for very wealthy farmers, the demand for precautionary saving is very low, which results in both increasing consumption and increasing insurance coverage.

Second, in the case of loaded premiums, the optimal insurance choice for a poorer farmer with lower initial wealth was to take the higher coverage than that for a wealthier farmer, because the poorer farmers have higher MPC, higher marginal utility, and higher absolute risk aversion level. As a result, a poorer farmer will have a higher intention to invest in insurance, even if it is expensive.

Third, the results imply that premium loading only has a mild effect on farm risk management and precautionary wealth composition. Imposing higher premium loading might be beneficial to insurance companies, as insurance demand is inelastic with respect to insurance price. Subsidizing insurance, on the other hand, may not be very efficient in increasing farmers' welfare, as the increase in consumption is modest at best.

5.4 SIMULATION 3: VARIATIOINS IN THE MARKET RISK

This simulation is to investigate the variation of the optimization process when the market risk increases, which is implemented by reducing crop price, since reducing output price will result in a higher probability of having a negative net profit, and thus cause higher market risks for farmers.

Figure 5.12 compares the time paths of optimal consumption in the benchmark case and in a riskier market environment. The result indicates that not only is consumption level lower in the riskier market, it is also more volatile. Under the high-risk scenario, farmers will have lower expected revenue (permanent income), and have to sacrifice more consumption at current state to keep a wealth level at future state for precautionary purposes (Gomez-Soto 2007). Thus, current consumption would decrease, with higher variability.

According to Gomez-Soto (2007), the opportunity cost (in terms of consumption foregone) of holding the same amount of precautionary wealth is higher when the farmer is faced with higher market risk, which in turn reduce farmers' ability to avoid sharp reductions in consumption. Farmers' lower consumption level, as well as their lower ability to smooth consumption when the bad states prevail reduces farmers' welfare (Gomez-Soto 2007).

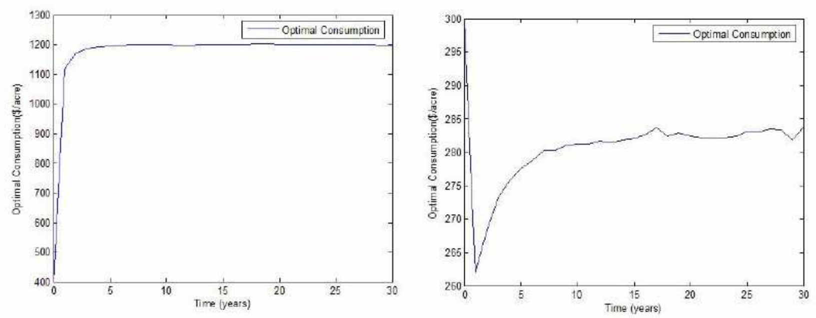

Figure 5.12: Time Path of Optimal Consumption in the Benchmark and the Riskier Market Environment

Table 5.3 shows the behavior of consumption, insurance, debt, and the composition of the wealth portfolio in the steady state. As output price is lower, the minimum revenue is lower, which results in lower minimum allowable net wealth (*minnet*) (-$900/acre). In order to analyze the effect of output price on optimal behavior in a *ceteris paribus* way, *minnet* in the benchmark case is also adjusted to be -$900/acre to be comparable with the simulation scenario.

When farmers are exposed to higher systemic market shocks, they will consume much less (29.6% of the expected per-period revenue (permanent income) as opposed to 66.23% in the benchmark base), borrow less money from financial institutions (31.7% of the expected per-period revenue as opposed to 37.36% in the benchmark case). Although the magnitude of steady state precautionary wealth is smaller, the wealth ratio (ratio of precautionary wealth to permanent income) is higher (65.55% of the permanent income as opposed to 60.75% in the benchmark case[1]).

An increase can also been seen for the share of precautionary saving in permanent income (64.40% as opposed to 60.64% in the benchmark case) and the share of insurance premium in permanent income (1.15% as opposed to 0.1075% in

[1] In Carroll's (2001) estimate, the wealth ratio is around 0.4.

the benchmark case), as these types of assets provide greater protection (risk-free assets).

Table 5.3: SIMULATION 3: Effects of Riskiness of Market on Optimal Choice and Wealth Composition

	BENCHMARK	**SIMULATION 3: P_{output}** Riskier Environment
	$P_{output} = 0.59$	$P_{output} = 0.3$
Consumption (CON)	1232	283
Coverage (COV)	0.77	0.89
Debt (D)	695	300
Expected Revenue (Y)	1860.1	945.8
Minimum Net Wealth (*minnet*)	-900	-900
Net Wealth (W)	1130	620
Insurance Premium (P)	2	10.87
Deposit (DEP)	1128	609.13
Ratios		
W / Y	60.75%	65.55%
D/Y	37.36%	31.7%
CON / Y	66.23%	29.6%
P/Y	0.1075%	1.15%
DEP/Y	60.64%	64.40%
P / W	0.1770%	1.75%
DEP / W	99.8230%	98.25%

The choice related to optimal debt (D) and deposit (DEP) shows that, when the market is riskier (output price is lower), farmers would tend to borrow less money (to finance consumption, insurance, and production for the whole year) and deposit more money (for precautionary saving purpose for the future) with financial institutions than they do in the benchmark case. A probable reason is that, according to Gomez-Soto (2007), the marginal valuation of keeping precautionary wealth is higher when there is higher market risk; thus, the farmer prefers to sacrifice some current consumption for the protection of future consumption rather than to resort to credit which would further deplete the stock of riskless wealth.

Figure 5.13, 5.14, and 5.15 depicts how the consumption, coverage, and wealth change with respect to changes in output price. It can be seen there is strictly positive relationship between consumption and output price, and between wealth and output price. Insurance coverage shows a decreasing-increasing curve. As wealth is positively related to output price, the coverage curve with respect to output price shows a similar pattern as the coverage curve with respect to wealth. Therefore, the curve is consistent with the relationship between coverage and wealth.

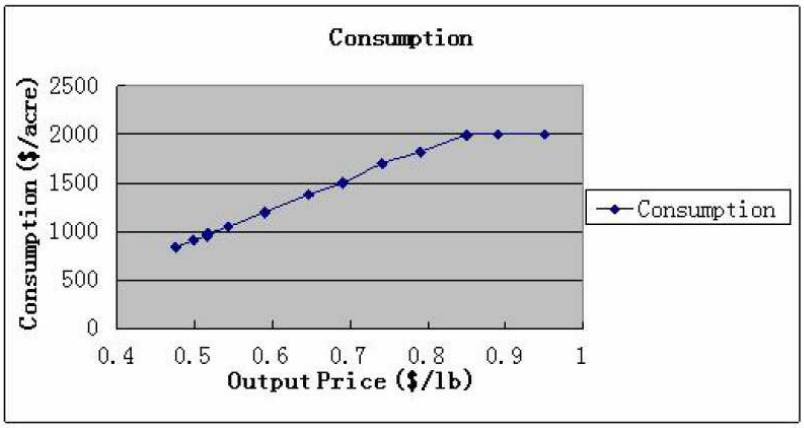

Figure 5.13: Relationship between Consumption and Output Price under Liquidity Constraint

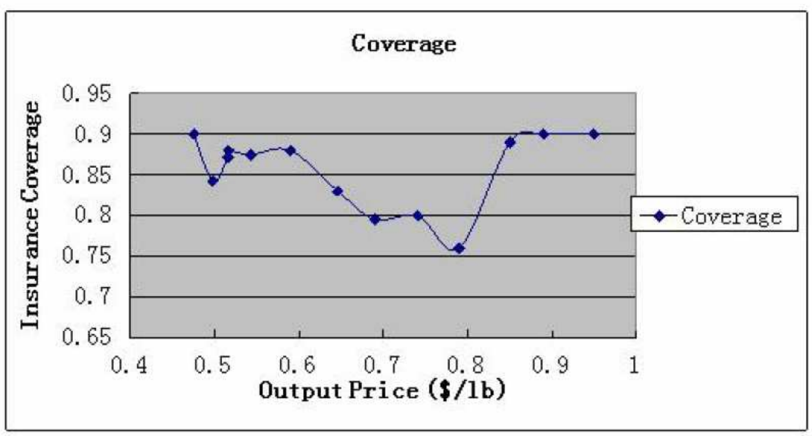

Figure 5.14: Relationship between Coverage and Output Price under Liquidity Constraint

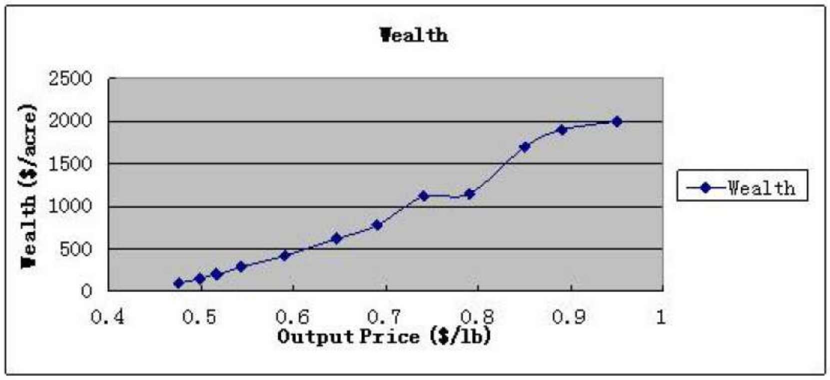

Figure 5.15: Relationship between Wealth and Output Price under Liquidity Constraint

This simulation can highlight some important policy implications. As pointed out by Gomez-Soto (2007), the level of financial deepening is especially low in poor agricultural areas where farmers are exposed to higher systemic market risk; specifically, a lower level of appropriate supply of financial and insurance facilities in remote and poor agricultural areas. This heterogeneity thus would also lead to different cost-benefits of the development of financial facilities, and thus call for different policy designs for different environments (Gomez-Soto 2007).

Our results indicate that the patterns of consumption and insurance behavior indeed vary much across different environments. Thus, different environments would call for different insurance and financial services. Particularly, when farmers are exposed to higher systemic market risk, precautionary saving ($489.13/acre as opposed to $403.5/acre in the benchmark case) and insurance (1.16% of the permanent income as opposed to 0.88% in the benchmark case) would become more critical in farmers' consumption smoothing and risk management strategies.

5.5 SIMULATION 4: VARIATIONS IN RELATIVE RISK AVERSION

This section analyzes the variations in the interaction between consumption, insurance, debt, and precautionary wealth when the farmers' relative risk aversion γ increases. In the benchmark scenario, the coefficient of relative risk aversion γ is set to be 2 following the empirical estimates of the farm-level risk aversion level in literature. For example, Gourinchas and Parker (2002) estimated the relative risk aversion coefficient by a consumption life-cycle model using Consumer Expenditure Survey data, and the coefficient is estimated to be 0.514 using Robust Weighting, while the coefficient is estimated to be 1.3969 using Optimal Weighting.

The relative risk aversion coefficient we use is higher than Gourinchas and Parker’s (2002) estimates, because generally speaking crop planting farmers are poorer than average households and thus are more likely to have higher relative risk aversion. Samuelson (1969) showed that "...any investor who faces a range of wealth in which the elasticity of his marginal utility schedule is large will have high risk tolerance and a high propensity to embrace variance," and that "...the scale of risk tolerance is highest for rich - but not ultra-rich – people." In other words, poor and very rich farmers would possibly have higher risk aversion level. Therefore, two coefficients of relative risk aversion, $\gamma = 2$ and $\gamma = 4$, are simulated in this section, as Gomez-Soto (2007) indicated that a maximum empirical value in the literature is equal to 4.0.

Figure 5.16 depicts consumption path lines starting from initial wealth w = \$2000/acre for the benchmark case and for the higher risk averse case. We can see current consumption decreases while future consumption increases comparing with the benchmark case. Current consumption drops from \$1600/acre for $\gamma = 2$ to \$1500/acre for $\gamma = 4$; while future equilibrium consumption doesn't change much. The result is consistent with Romer's (2001) proposition about risk aversion level, that people with a higher relative risk aversion level would be more inclined to accumulate wealth for precautionary purposes in order to protect against future income shocks. Thus, higher risk averse producers will have a higher propensity for precautionary saving, which in turn decreases current consumption to ensure future consumption.

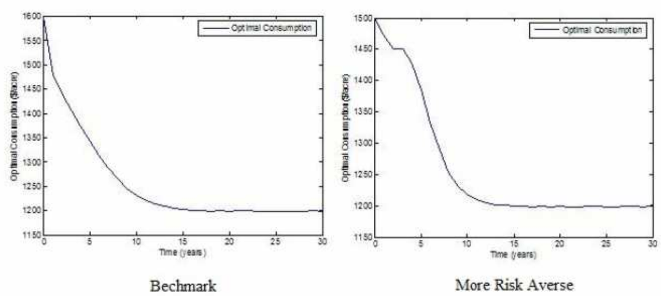

Figure 5.16: Time Path of Optimal Consumption for Benchmark Case vs. for More Risk Averse Case

As for the insurance coverage, optimal coverage depicted in Figure 5.17 increases for very wealthy farmers with wealth level in the range of \$1800/acre and \$2000/acre. For lower risk averse farmers, the optimal coverage for this range of high initial wealth level is very low, corresponding to 0 insurance premium, while for higher risk averse farmers, the optimal coverage for this range of initial wealth level is relatively high with positive insurance premiums. This result concerning the changes in insurance coverage due to changes in risk aversion level is very similar to an increase in the level of the liquidity constraint, and thus confirms that liquidity constraint has the effect of increasing farmers' risk aversion level.

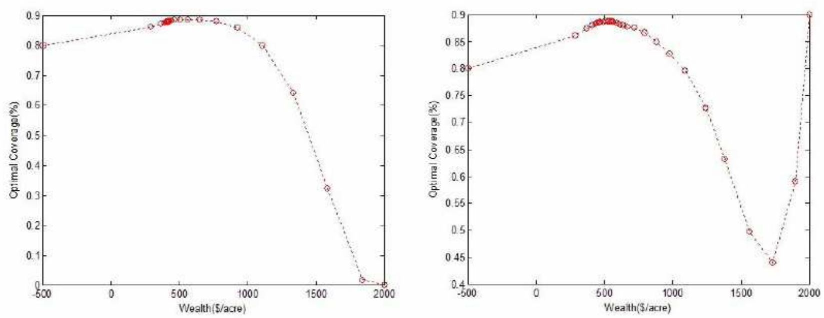

Figure 5.17: Relationship of Optimal Coverage and Wealth for Benchmark Case vs. for More Risk Averse Case

As noted before, increase in relative risk aversion would induce farmers to accumulate wealth for precautionary purpose. As for the portfolio of precautionary wealth, which consists of insurance and precautionary saving, the composition is ambiguous. For insurance, as noted by Nyambane (2005), the variation in relative risk aversion γ would have two effects on insurance: one is a positive impact on the precautionary demand for insurance, and the other one is a positive impact on the precautionary demand for accumulating wealth, which comes at the expense of insurance. The reason, as shown by Rothschild and Stiglitz (1971), is that the utility function used here has the property that the magnitude of the two effects depends on the same parameter, γ. It appears that in this specific study, for wealthier farmers, the demand for insurance outweighs the precautionary demand for accumulating wealth; as a result, when risk aversion level increases, they choose to insure more.

Table 5.4: SIMULATION 4: Effects of Risk Aversion on Optimal Choice and Wealth Composition

	BENCHMARK	**SIMULATION 4: γ** More Risk Averse
	$\gamma = 2$	$\gamma = 4$
Consumption (CON)	1200	1200
Coverage (COV)	0.88	0.878
Debt (D)	1385	1370
Expected Revenue (Y)	1860.1	1860.1
Net Wealth (W)	420	500
Insurance Premium (P)	16.5	16.1
Deposit (DEP)	403.5	483.9
Ratios		
W / Y	22.6%	26.9%
D/Y	74.5%	73.6%
CON / Y	64.5%	64.5%
P/Y	0.88%	0.865%
P / W	3.9%	3.2%
DEP / W	96.1%	96.8%

Table 5.4 summarized the results of the steady state statistics for a higher risk aversion level. As risk aversion increases, our results show that farmers would increase precautionary wealth from 22.6 percent of permanent income in the benchmark scenario to 26.9 percent of permanent income, which is accomplished by decreasing consumption at the previous periods before steady-state (not shown in the table) and by decreasing debt at steady-state from $1385/acre in the benchmark case to $1370/acre. A decrease in consumption and debt in the early periods when wealth level is low allows farmers to have higher end-of-season deposit each year and, therefore, to accumulate more precautionary wealth in the subsequent periods and have higher ability to smooth consumption when bad state prevails.

Figure 5.19, 5.20, and 5.21 depicts how farmers adjust their consumption, coverage, and wealth levels when they have higher risk aversion levels. The result shows that a higher risk aversion level will lead to higher demand for precautionary saving, and thus higher levels of consumption and wealth at steady state. Higher risk aversion level affects insurance coverage through two effects: one is a positive impact on the precautionary demand for insurance, and the other one is a positive impact on the precautionary demand for accumulating wealth, which comes at the expense of insurance. As wealth is positively related to risk aversion level, the coverage curve with respect to risk aversion should be consistent with the coverage curve with respect to wealth. Note that these graphs are all for steady state which corresponding to wealth level in the range of $400/acre and $500/acre. In this range of wealth level, coverage shows an increasing and decreasing trend with respect to wealth, as shown in last chapter.

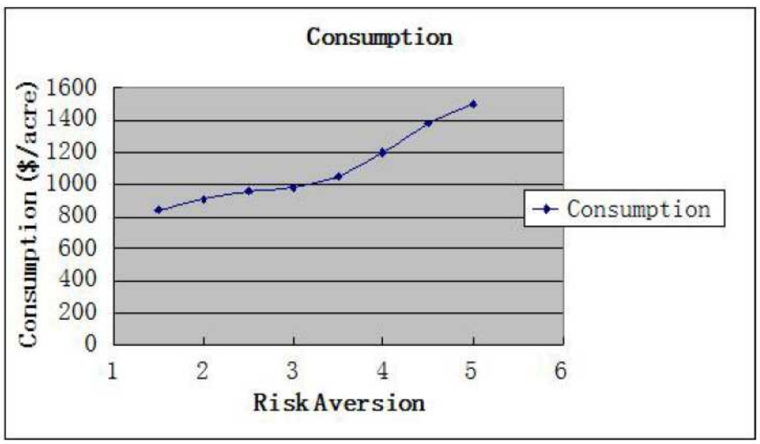

Figure 5.18: Relationship between Consumption and Risk Aversion under Liquidity Constraint

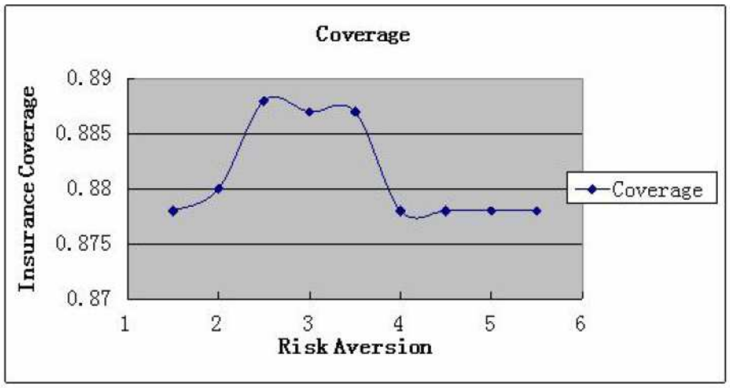

Figure 5.19: Relationship between Coverage and Risk Aversion under Liquidity Constraint

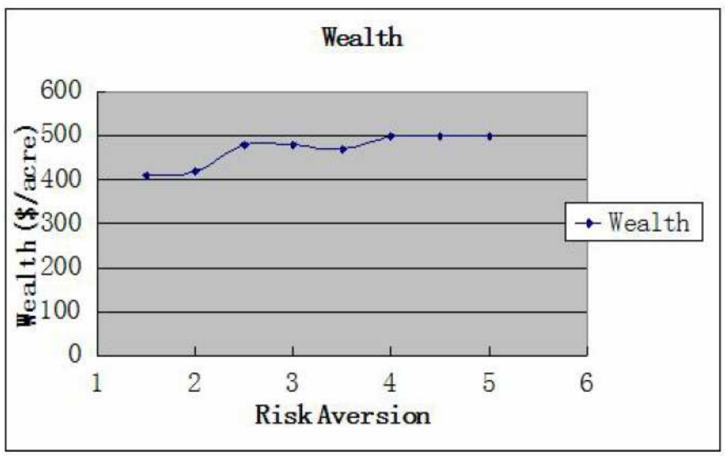

Figure 5.20: Relationship between Wealth and Risk Aversion under Liquidity Constraint

5.6 SIMULATION 5: VARIATIONS IN TIME PREFERENCE

The effect of changing farmers' measure of time preference parameter on optimization choices is investigated in this section. Gourinchas and Parker (2002) used a synthetic cohort technique and estimated the aggregate discount rate for U.S. households to be 4.188 percent using Robust Weighting (equivalent to discount factor β = 0.9598) and to be 4.507 percent using Optimal Weighting (equivalent to discount factor β = 0.9569), and also estimated the discount rate based on different levels of education and occupation, with 3.94 percent being the lowest for high school (equivalent to discount factor β = 0.962) and 5.93 percent being the highest for graduate school (equivalent to discount factor β=0.944). In our benchmark case, agreeing with the value used in Nyambane's (2005) study (11.25%), the discount rate of 11.24 percent (equivalent to discount factor β = 0.8989) is calculated, higher than the estimates in Gourinchas and Parker (2002), as generally poorer farmers are more impatient, and value current consumption and discount future consumption much more than the rich and patient farmers (Gomez-Soto 2007).

In the simulation scenario, the discount rate is 1%. Decreasing the discount rate to 1% is equivalent to increasing discount factor β to 0.99. In other words, farmers are relatively more patient in the simulation scenario.

Figure 5.21 shows that consumption line shows a much smoother increasing trend over time comparing with Figure 4.1, and the steady-state consumption level is around $1270/acre (higher than in the benchmark case) while coverage fluctuates between 87% and 65% and stabilizes at around 80% after 10 years (lower than in the benchmark case (88%)). It takes a longer time (10 years) for all control variables (consumption, insurance coverage, and debt) and state variables (wealth) to converge to the steady state, and all lines show much smoother increasing/decreasing trends.

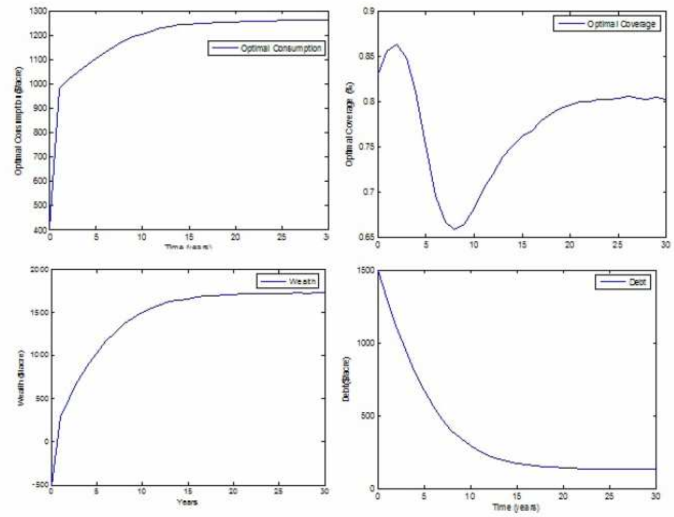

Figure 5.21: Time Path of Optimal Consumption, Coverage, Wealth, and Debt for a More Patient Farmer

These results are reasonable, as more patient farmers would be more inclined to accumulate wealth as they value future more than in the benchmark case, and as a consequence, reduce current consumption and increase future consumption, and indirectly reduce current insurance demand.

Table 5.5: SIMULATION 5: Effects of Time Preference on Optimal Choice and Wealth Composition

	BENCHMARK	**SIMULATION 5:** β
		More Patient
	$\beta = 0.8989$	$\beta = 0.99$
Consumption (CON)	1200	1250
Coverage (COV)	0.88	0.80
Debt (D)	1385	175
Expected Revenue (Y)	1860.1	1860.1
Net Wealth (W)	420	1750
Insurance Premium (P)	16.5	4
Deposit (DEP)	403.5	1746
Ratios		
W / Y	22.6%	94.1%
D/Y	74.5%	9.4%
CON / Y	64.5%	67.2%
P/Y	0.88%	0.865%
P / W	3.9%	0.26%
DEP / W	96.1%	99.74%

Table 5.5 compares the steady-state statistics for the benchmark case and more patient farmers. The results show that impatient farmers in the benchmark case keep a

very low level of wealth (22.6%) while more patient farmers keep a much higher level of precautionary wealth compared to the baseline, increasing from 22.6% to 94.1%. Debt decreases from 74.2% to 9.4%. A higher level of precautionary wealth enables farmers to better avoid sharp reductions in consumption and thus have a higher ability to smooth consumption (Gomez-Soto 2007), and as a result, consumption shows a smoother path (as shown in Figure 5.21). More patient farmers tend to have lower demand for insurance (coverage decreases from 88% to 80% at the steady state).

Figure 5.22, 5.23, and 5.24 depicts the relationship between consumption and patience level (β, as higher β means valuing future more and thus more patient), the relationship between coverage and patience level, and the relationship between wealth and patience level. Results indicate that more patient farmers would value future more and thus accumulate wealth for the future and consume more in the future (at the steady state). The result also confirms the contention stated previously, that more patient farmers tend to have lower demand for insurance.

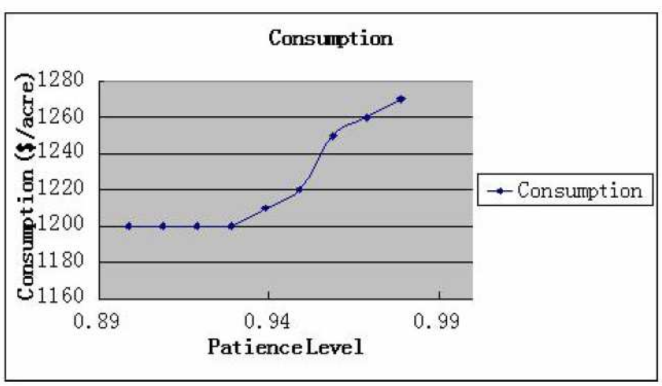

Figure 5.22: Relationship between Consumption and Patience Level under Liquidity Constraint

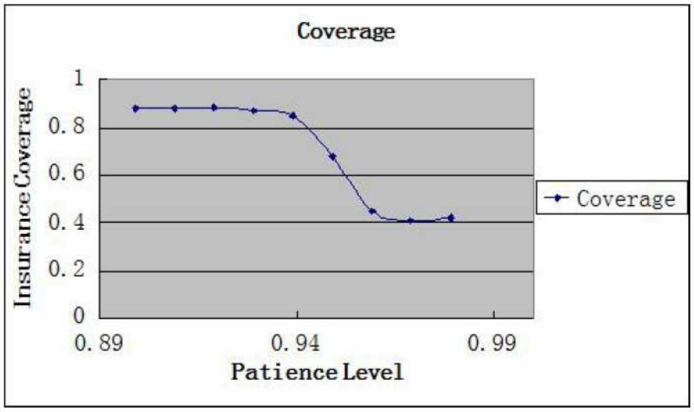

Figure 5.23: Relationship between Coverage and Patience Level under Liquidity Constraint

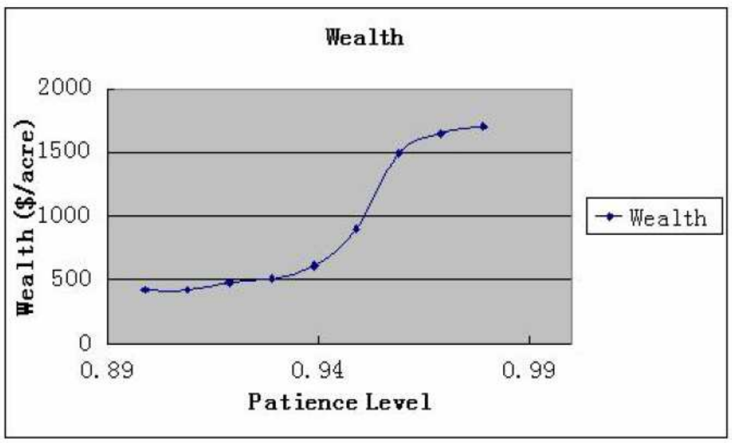

Figure 5.24: Relationship between Wealth and Patience Level under Liquidity Constraint

Gomez-Soto (2007) contended that impatience and poverty are intricately connected, thus providing deposit facilities for extremely poor and impatient villagers in developing countries may not effectively help them improve their risk profile. Our result confirms Gomez-Soto's (2007) contention, as impatient farmers in the benchmark case keep a very low level of precautionary wealth (22.6%), and the precautionary saving (DEP) is even lower (96.1% of precautionary wealth). With regard to policy making, other innovative risk management facilities may need to be provided to mitigate, transfer, and share the risk of income fluctuation (Gomez-Soto 2005). Our results indicate that impatient farmers have a higher tendency to invest in insurance for precautionary purposes. This result may be of interest to policymakers who want to help extremely poor and impatient farmers to manage their risk.

5.7 SIMULATION 6: VARIATIONS IN INTEREST RATE

This simulation examines the changes in optimal choices and their relationship with wealth when the risk-free rate of interest increases. The objective of this simulation is to examine the influence policy intervention may have on farmers' consumption smoothing, insurance, and debt decision through financial system channels. In the benchmark case, the risk-free interest rate r for deposit and debt is assumed to be 0.0469; and in the simulation scenario, a higher interest rate r =0.08 is assumed to be charged (for loan) or paid (for deposit) by a risk-free financial institution. It should be noted that the variations in interest rates can be made account-specific, that is, different interest rates can be applied to different farmers with different credit risks (e.g., expected probability of default).

Figure 5.25 shows the relationship between consumption and wealth in a higher interest rate scenario. The result shows that for most farmers (with initial wealth in the range of $500/acre and $2000/acre, MPC is lower than in the benchmark case. Specifically, for wealthy farmers (initial wealth = $2000/acre), optimal consumption is $1500/acre as opposed to $1600/acre in the benchmark case, as the result of higher precautionary demands for saving and accumulating wealth, which results in lower marginal propensity to consume (MPC is calculated to be approximately 0.21 as opposed to 0.2667).

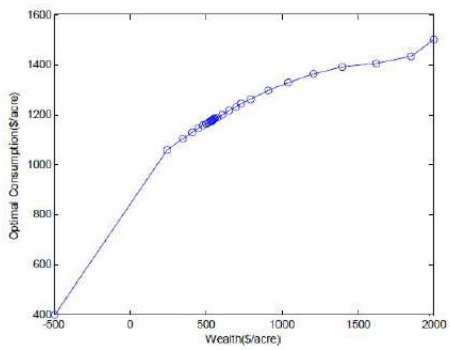

Figure 5.25: Relationship of Optimal Consumption and Wealth in a Higher Interest Rate Scenario

Figure 5.26 shows that, increasing the interest rate of the financial institution will, *ceteris paribus*, induce the farmer to reduce insurance purchase compared with the benchmark case. A possible reason is that between these two risk management instruments, a higher interest rate becomes more attractive, and thus they reduce insurance in order to deposit more in a financial institution. However, very wealthy farmers tend to increase insurance coverage. For example, for farmers with initial wealth equal to $2000/acre, the optimal insurance coverage is 80% as opposed to 0% in the benchmark scenario. The reason is probably that a very wealthy farmer already has sufficient deposit at financial institutions, and thus the extra money as the result of increasing interest rates enables them to buy more insurance without greatly affecting their consumption and deposit levels.

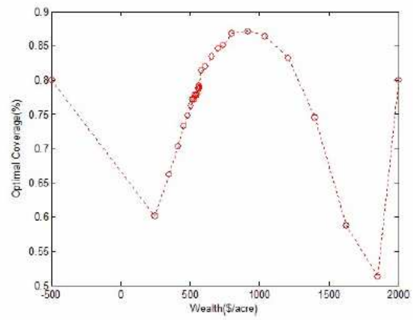

Figure 5.26: Relationship of Optimal Coverage and Wealth in a Higher Interest Rate Scenario

Table 5.6 summarizes the optimal choices and composition of wealth at the steady state. Table 5.6 indicates that increasing the interest rate of the financial institution will, *ceteris paribus*, induce farmers to reduce consumption (from \$1200/acre to \$1180/acre), and to hold a larger amount of net wealth, increasing from \$420/acre in the benchmark case to \$550/acre, or from 22.2% in the benchmark scenario to 29.6% of the expected production revenue, which is equivalent to around four months' permanent income as opposed to three months' permanent income in the benchmark case.

Table 5.6: SIMULATION 6: Effects of Interest Rate on Optimal Choice and Wealth Composition

	BENCHMARK	**SIMULATION 6:** r Higher Interest Rate
	$r = 0.0469$	$r = 0.08$
Consumption (CON)	1200	1180
Coverage (COV)	0.88	0.78
Debt (D)	1385	1200
Expected Revenue (Y)	1860.1	1860.1
Net Wealth (W)	420	550
Insurance Premium (P)	16.5	2.5
Deposit (DEP)	403.5	547.5
Ratios		
W / Y	22.6%	29.6%
D/Y	74.5%	64.5%
CON / Y	64.5%	63.4%
P/Y	0.88%	0.13%
P / W	3.9%	0.5%
DEP / W	96.1%	99.5%

The relative attractiveness of debts (to finance consumption, insurance, and production for the whole year) is reduced; now the ratio of debt to expected revenue is 64.5% compared with 74.5% in the benchmark case. Since deposits have become more attractive, farmers choose to attain more protection by accumulating precautionary savings. The composition of the wealth portfolio shows that, the percentage of insurance is lower (from 3.9% of net wealth to 0.5% of net wealth), implying that farmers would prefer saving to insurance for precautionary purpose.

Figure 5.27, 5.28, and 5.28 depicts the relationship between consumption and interest rate, the relationship between coverage and interest rate, and the relationship between wealth and interest rate. The results suggest that higher interest rate would induce farmers to reduce consumption, which is consistent with macro-economic theory. An increase in interest rate would also reduce insurance purchase indirectly, as farmers would prefer saving to insurance. An increase in saving would also have positive effect on wealth level at the steady state, and thus wealth level is positively related to interest rate.

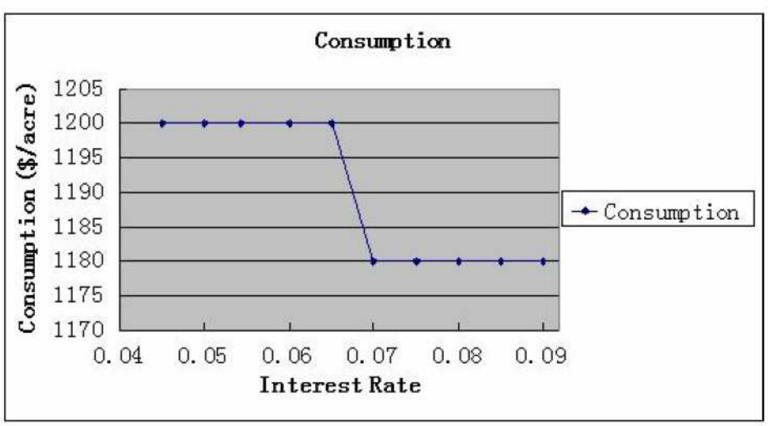

Figure 5.27: Relationship between Consumption and Interest Rate under Liquidity Constraint

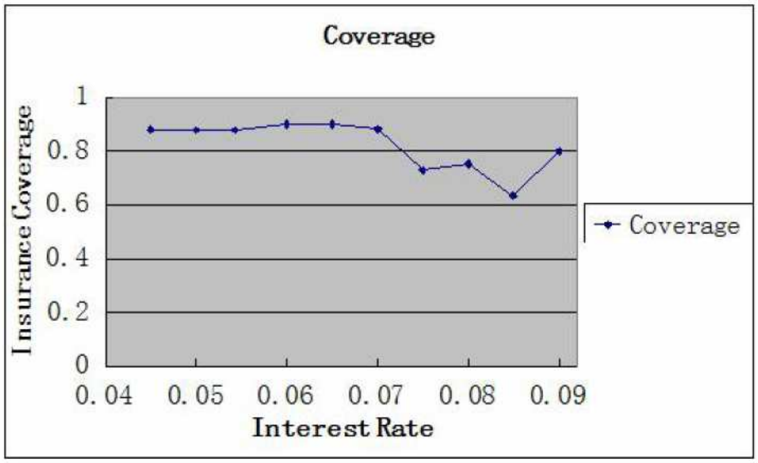

Figure 5.28: Relationship between Coverage and Interest Rate under Liquidity Constraint

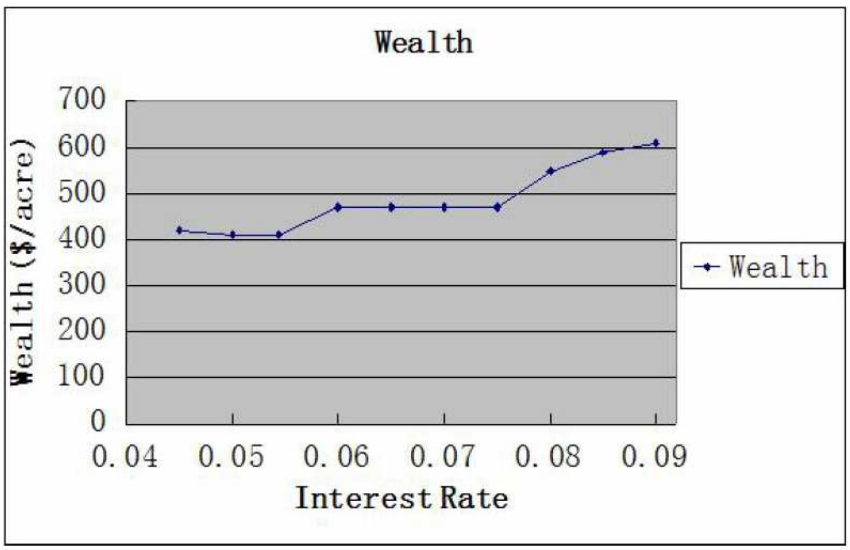

Figure 5.29: Relationship between Wealth and Interest Rate under Liquidity Constraint

This result implies that farmers' decision on consumption, insurance, credit, and precautionary wealth seems to be sensitive to the interest rate, implying that adjusting interest rates, together with adjusting farmers' credit limit would be very effective in monetary policy transmission. For example, when the policy requires banks to strengthen liquidity constraint or to increase interest rates of both debts and deposits, the volume of debt would fall, consumption would be reduced immediately, optimal insurance purchase would decrease, precautionary wealth would accumulate more, and the supply of deposits (precautionary saving) would also increase.

Another implication for local financial institutions is, to attract deposit and/or to reduce bad debt, they may consider offering more attractive options. According to Gomez-Soto (2007), local financial institutions are small, with higher portion of bad loans, and their loan portfolio is not diversified enough. Therefore, a systemic shock may undermine their soundness and solvency, and expose them to the risk of bankruptcy. Our results suggest that increasing account-specific interest rates, or applying higher APRs to farmers who have a higher probability of default may help local financial institutions attract deposits and reduce bad loans, and to help farmers accumulate wealth and mitigate the impact of income variation. However, increasing interest rates for the whole farmers would bring in new problem, such as adverse selection and moral hazard. It would be more appropriate to have a better credit evaluation system and apply higher interest rates on farmers with higher default risks. As Gomez-Soto (2007) pointed out, credit markets are not inclined to increase interest rate due to the adverse selection problem, because borrowers with higher default risks would have higher willingness to pay (WTP) for the increased interest rates. Gomez-Soto (2007) argued that financial institutions should engage in non-price credit rationing rather than purely increasing interest rate in order to avoid default risk. While this issue is interesting to policymakers, it is beyond the scope of this dissertation.

5.8 SIMULATION 7: BASIS RISK - GRP AND WD

This section presents simulation of the impact of basis risk. Compared with the benchmark case where farmers buy a Multi-Peril Crop Insurance (MPCI) without basis risk, two alternative insurance products that incorporate basis risk are used in this study: Group Risk Plan (GRP) and Weather Derivative (WD) insurance.

Figure 5.30 shows the consumption path for a farmer purchasing GRP insurance. It can be seen that the consumption pattern is similar to the MPCI insurance case. However, there are some minor differences. During the first 5 years of the optimization period, consumption is slightly lower than in the benchmark scenario, and it takes a longer time (around 10 years) to reach the steady state equilibrium consumption value, a value slightly larger than the equilibrium consumption level in the MPCI case (\$1210/acre as opposed to \$1200/acre). That is, with basis risk, farmers reduce current consumption to ensure higher levels of consumption and wealth in the future, compared with the benchmark case.

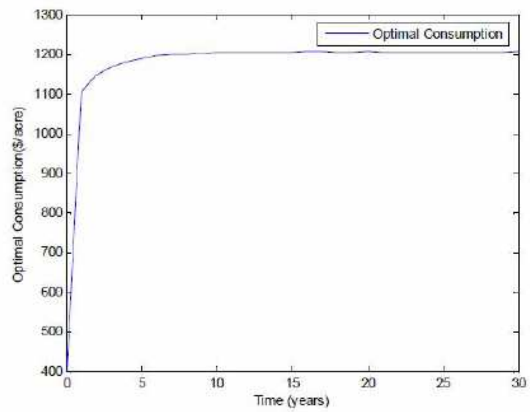

Figure 5.30: Time Path of Optimal Consumption in a GRP Scenario

Figure 5.31 shows how the expected debt evolves over time. Comparing with Figure 4.1, the equilibrium debt value with basis risk presence ($1270/acre) is lower than in the MPCI insurance case ($1385/acre). Thus, our results indicate that when there is higher uncertainty and higher residual uninsurable risk, farmers would decrease current consumption and reduce debt in the early period, in order to accumulate precautionary wealth in the future.

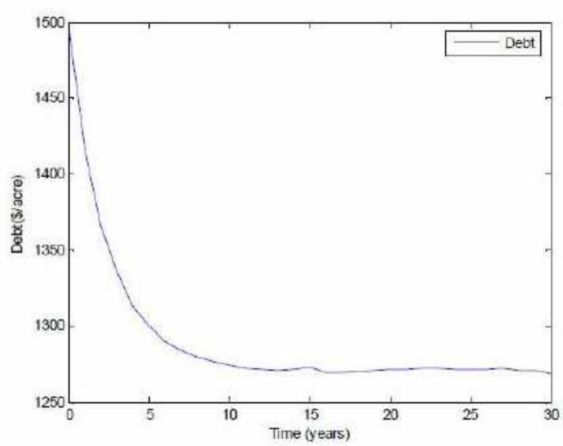

Figure 5.31: Time Path of Debt in a GRP Scenario

Figure 5.32 shows the relationship between insurance coverage and wealth for the GRP purchaser, at all wealth levels, the optimal insurance coverage is lower than that in the benchmark case. This result indicates that when the insurance products have basis risk, farmers are exposed to additional uninsurable residual risk, which discourages farmers from purchasing insurance. As a result, farmers choose to take lower insurance coverage than that in the MPCI insurance case in order to accumulate enough wealth to better protect consumption when bad states prevail.

The reason, as pointed out by Miranda (1991), is that the risk management ability of area-yield crop insurance is highly related to the correlation between the area yield and individual farm level yield. In other words, basis risk of area-yield crop insurance acts like an additional risk, which exposes farmers to a residual uninsurable risk. This increase in risk and uncertainty thus increases the insuree's demand for precautionary saving, as precautionary saving and insurance are two instruments in farmers' risk management portfolio, and thus farmers would prefer the risk-free deposit when insurance incurs basis risk.

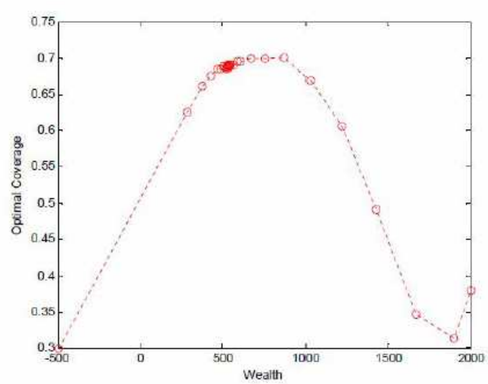

Figure 5.32: Relationship of Insurance Coverage and Wealth in a GRP Scenario

The Weather Derivative scheme also investigates the effect of basis risk on optimal decisions. Figure 5.33 compares the relationship between optimal consumption and wealth level in the benchmark scenario and in the Weather Derivative purchaser. Comparing with the benchmark case, current consumption level decreases to ensure same/higher level of future consumption at steady-state for farmers in all ranges of initial wealth. For example, for farmers with initial wealth equal to \$2000/acre, optimal consumption is \$1500/acre as opposed to \$1600/acre in the benchmark case; for farmers with initial wealth equal to -\$500/acre, optimal consumption is \$300/acre as opposed to \$400/acre in the benchmark case. Marginal propensity to consume (MPC) thus increases for poor farmers and decreases for rich farmers (for poor farmers, MPC is around 0.9 as opposed to 0.8 in the benchmark case; for rich farmers, MPC is around 0.21 as opposed to 0.266 in the benchmark case).

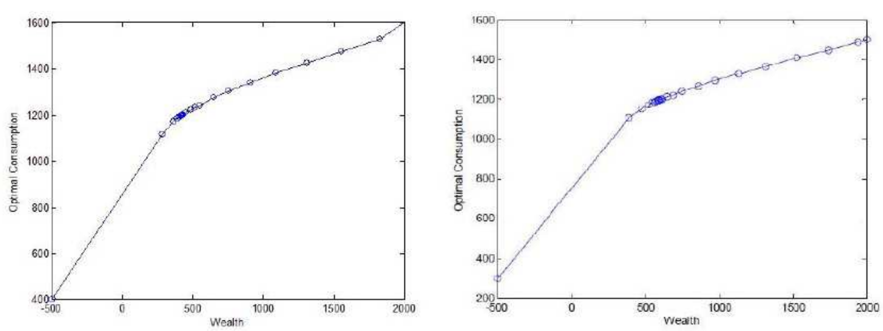

Figure 5.33: Relationship of Optimal Consumption and Wealth in the Benchmark Scenario and in a Weather Derivative Scenario

These results imply that in the presence of basis risk, the precautionary demand for accumulating wealth increases, which induces farmers to reduce current consumption to ensure high levels of consumption in the future. As for marginal propensity to consume, MPC is even higher for poor farmers, meaning that poor farmers' consumption is more influenced by transitory income (random shocks to net wealth) than in the benchmark scenario; MPC is even lower for rich farmers, meaning that their consumption depends even more on permanent income than in the benchmark scenario.

Figure 5.34 shows the relationship between optimal insurance coverage and wealth level in a Weather Derivative scenario. Similar to GRP, an increase in uninsurable residual risk of insurance induces farmers to save more with deposit facilities and to reduce insurance compared to the benchmark case.

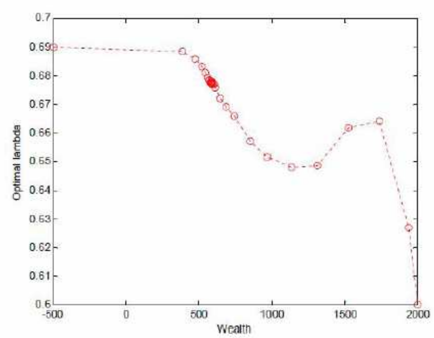

Figure 5.34: Relationship of Optimal Insurance Lambda and Wealth in a Weather Derivative Scenario

Table 5.7 summarized the steady-state statistics. Results shows that in both the GRP scenario and the Weather Derivative (WD) scenario, farmers faced with basis risk would spend less on insurance premium (\$*P* = 11/acre for GRP and \$10/acre for WD). Therefore, basis risk acts like an additional uninsurable residual risk which makes it less attractive to purchase insurance for precautionary purposes. The expected net wealth shows an increase from 22.6% of expected production revenue to

29.6% for GRP and 32.3% for WD, as a result of higher precautionary demand for accumulating wealth in the presence of basis risk. This in turn induces higher consumption level at steady state, as farmers have a higher ability to maintain higher levels of consumption because of higher precautionary wealth.

Table 5.7: SIMULATION 7: Effects of Basis Risk on Optimal Choice and Wealth Compositio

	BENCHMARK	**SIMULATION 7: GRP and Weather Derivative**	
		Basis Risk I	Basis Risk II
	MPCI	*GRP*	*WD*
Consumption (CON)	1200	1202	1197
Coverage (COV)	0.88	0.75	0.678
Debt (D)	1385	1314	1310
Expected Revenue (Y)	1860.1	1860.1	1860.1
Net Wealth (W)	420	550	600
Insurance Premium (P)	16.5	15	10
Deposit (DEP)	403.5	439	590
Ratios			
W / Y	22.6%	26.7%	32.3%
D/Y	74.5%	70.6%	70.4%
CON / Y	64.5%	64.6%	64.4%
P / W	3.9%	3.02%	1.67%
DEP / W	96.1%	96.98%	98.33%

In addition to the level effect on precautionary wealth, basis risk also has a composition effect on the portfolio of precautionary wealth, which is composed of two risk management instruments (insurance and deposit). In the presence of basis risk, farmers would prefer deposits (the risk-free instrument) to insurance holdings (the risky instrument). As a result, the share of insurance in the precautionary wealth drops from 3.9% in the benchmark case to 2% in the GRP scenario and 1.67% in the WD scenario.

Debt is stabilized at around \$1270/acre for GRP and around \$1040/acre for WD, which are lower than that in the MPCI insurance scenario (\$1385/acre), implying that in the presence of basis risk, farmers would restrain from borrowing to finance consumption, insurance, and production for the whole year, and reduce current consumption to ensure higher precautionary wealth and higher future consumption levels.

The simulation on GRP and WD products illustrates that under basis risk, precautionary wealth becomes larger, as it serves another purpose in addition to consumption smoothing: mitigating the impact of basis risk, which is an added element of farmers' risk profile. As there is remaining uninsurable risk, farmers expect to suffer an income loss without the coverage of insurance (Nyambane 2005), and thus insurance still has downside risk and is no longer risk free; as a result, farmers would hold even larger stock of precautionary wealth compared to the benchmark scenario in which no basis risk exists and thus insurance can be regarded as a risk free risk management instrument. For this reason, the desired precautionary wealth becomes larger and its value also increases. As a result, farmers increase precautionary demand for accumulating wealth, which induces farmers to decrease current consumption to ensure a sufficiently high level of precautionary wealth and consumption in the future steady state, compared with the benchmark scenario.

Table 5.8 summarized the effect of different insurance products (without basis risk and with basis risk) on farmers' value function and Certainty Equivalent Consumption at the initial state. Table 5.8 shows that at the same initial wealth level, farmers would have lower value function and lower certainty equivalent consumption level in the GRP scenario and in the WD scenario (with basis risk).

Table 5.8: Effects of Basis Risk on Farmers' Value Function and Certainty Equivalent Consumption at Initial State

Initial Wealth ($/acre)	Insurance	Value	Certainty Equivalent Consumption ($/acre)
500	MPCI	-0.008268	1196.323
500	GRP	-0.008290	1193.148
500	WD	-0.008390	1178.927
-500	MPCI	-0.010083	980.978
-500	GRP	-0.010100	979.326
-500	WD	-0.010950	903.306

The presence of basis risk induces farmers to spend less on insurance than in the benchmark case, as basis risk in effect is an uninsurable residual risk which makes it more attractive for farmers to allocate a higher proportion of precautionary wealth to financial deposit than to insurance, as insurance is no longer a risk free asset compared to deposits with a financial institute.

5.8 SIMULATION 8: RANDOM PRICE AND REVENUE INSURANCE

This simulation examines the effect of random price on the optimization process and the resulting composition of wealth portfolio. Output price now is no longer fixed, and is assumed to be chosen randomly from the 31-year historical price. Further assume prices and yields are correlated; and therefore, price and yield each year are chosen simultaneously from the 31-year historical data, and one price data corresponds to one yield data for a given year.

The minimum possible revenue is lower (-$900/acre) because of varied price, as the lowest historical price is very low. Therefore, credit limit is stricter. In order to focus on the effect of random price on the optimal behavior, the simulation is conducted in a *ceteris paribus* way; the minimum allowable net wealth (*minnet*) in the benchmark is also adjusted accordingly to -$900/acre in order to be comparable with the random price scenario. When farmers are exposed to volatile market shocks, they will consume less (65.47% of the expected per-period revenue (permanent income) as opposed to 66.23% in the benchmark base), borrow less money from financial institutions (29.46% of the expected per-period revenue as opposed to 37.36% in the benchmark case). Both the wealth level and the wealth ratio (ratio of precautionary wealth to permanent income) are higher ($1250/acre as opposed to $1130/acre, and 68.20% of the permanent income as opposed to 60.75% in the benchmark case). However, insurance premium is very low ($1.2/acre), implying that MPCI which only insures against yield loss is not a good risk management strategy now, as output price is not covered by insurance. Another form of insurance – revenue insurance – is now designed to insure against price variation and yield together. The strike is the product of historical average price and historical average individual yield (still has the moral hazard problem). Results show that the insurance premium of revenue insurance is much higher than in the benchmark case, implying that this type of insurance provides higher value to farmers.

Table 5.9: SIMULATION 8: Effects of Varied Price on Optimal Choice and Wealth Composition

	BENCHMARK	SIMULATION 8: Correlation Between Price&Yield	
		Varied Price	Varied Price
	MPCI	*MPCI*	*Revenue Insurance*
Consumption (CON)	1232	1200	1210
Coverage (COV)	0.77	0.76	0.9
Debt (D)	695	540	660
Expected Revenue (Y)	1860.1	1832.9	1832.9
Minimum Net Wealth (*minnet*)	-900	-900	-900
Net Wealth (W)	1130	1250	1200
Insurance Premium (P)	2	1.2	45
Deposit (DEP)	1128	1248.8	1155
Ratios			
W / Y	60.75%	68.20%	65.47%
D/Y	37.36%	29.46%	36.01%
CON / Y	66.23%	65.47%	65.47%
P / W	0.1770%	0.096%	3.75
DEP / W	99.8230%	99.9%	96.25%

Table 5.10: Effects of Varied Price and Revenue Insurance on Farmers' Value Function and Certainty Equivalent Consumption at Initial State

Initial Wealth ($/acre)	Price& Insurance	Value	CEC($/acre)
500	Fixed Price&MPCI	-0.008268	1196.323
500	Varied Price&MPCI	-0.009191	1076.241
500	Varied Price&RI	-0.008986	1100.722
0	Fixed Price&MPCI	-0.008694	1137.717
0	Varied Price&MPCI	-0.011274	877.361
0	Varied Price&RI	-0.011069	893.562

Table 5.10 summarized the effect of varied price and the effect of revenue insurance on farmers' value function and on their Certainty Equivalent Consumption. The results show that varied price would reduce farmers' value function and Certainty Equivalent Consumption, and that revenue insurance is a better risk management tool compared with MPCI in the presence of price variation, as it leads to higher value function and higher CEC, although still lower than in the benchmark case without price variation.

5.10 SIMULATION 9: VARIATIONS IN CROP TYPE AND ROTION

The last simulation examines the impact of crop type and production rotation on the optimization process and the steady state wealth portfolio. In the rotation scenario, it is assumed that farmers allocate half acre for peanut production, and allocate the remaining for cotton production. Here the insurance product is still multi-peril crop insurance (MPCI) to be comparable with the benchmark case. Insurance strike is assumed to be equal to the average of the expected farm-level cotton yield and the expected farm-level peanut yield, based on DSSAT simulated data from 1976 to 2006.

Insurance indemnity is based on the difference between the product of coverage and strike and the average of actual cotton yield and peanut yield, and a weighted average output price, *EP*, which is determined by:

$$0.5P_1Y_1 + 0.5P_2Y_2 = P(0.5Y_1 + 0.5\mathrm{Y}_2) \tag{5.1}$$

where P_1 and P_2 are output prices for cotton and peanut respectively, and are assumed to be fixed (to be comparable with benchmark case); Y_1 and Y_2 are individual yield (lb/acre) for cotton and peanut respectively, and are chosen randomly from historical yield. Thus:

$$0.5P_1EY_1 + 0.5P_2EY_2 = EP(0.5EY_1 + 0.5\mathrm{EY}_2) \tag{5.2}$$

We know that EY_1 and EY_2 are 3152.72lb/acre and 11451.32lb/acre, and output prices are fixed and assumed to \$0.59/lb and \$0.28/lb respectively. *EP* then can be determined (\$0.3439/lb). The minimum net wealth in each scenario is assumed to be approximately the minimum possible revenue of each production strategy. In this way, although the magnitudes of credit limit for these types of production are different, the relative strictness of credit limit (with respect to revenue level) is similar among different production scenarios. We use different credit limits for different production strategies because it is possible for banks to determine farmers' credit limit based on their production information. However, it is more difficult for banks to adjust the credit limit taking into account future price change; and thus in the simulations about price changes (Simulation 3 and Simulation 8), the same credit limit is applied to different price scenarios).

Table 5.11 summarized the steady state statistics of optimal choices as well as the composition of wealth portfolio. Coefficient of variation (CV) is calculated as the standard deviation divided by the mean, multiplied by 100 percent, to handle the problem of standard deviation (depends on the units that are used). The rotation strategy leads to lower CV of Profit, and thus lower risk. Moreover, out results indicate that under the parameter values assumed in each scenario, the rotation strategy leads to highest level of precautionary wealth at the steady state. A higher level of precautionary wealth at the steady state would enable farmers to better avoid sharp reduction in consumption when bad states prevail, and thus to have higher ability to smooth consumption in the future.

Table 5.11: SIMULATION 9: Effects of Crop Type and Rotation on Optimal Choice and Wealth Composition

	BENCHMARK	SIMULATION 9: Crop Type and Rotation	
		Different Crop	Rotation
	Cotton	*Peanut*	*Cotton&Peanut*
Consumption (CON)	1200	1710	1465
Coverage (COV)	0.88	0.8725	0.8994
Debt (D)	1385	2820	1685
Expected Revenue (Y)	1860.1	3206.37	2533.07
Output Price (P_output)	0.59	0.28	0.3439
Production Cost ($cost$)	592.45	1344.24	968.35
Minimum Net Wealth ($minnet$)	-1500	-3000	-2000
Strike ($strike$)	3152.72	11451.33	7302.02
Net Wealth (W)	420	250	595
Insurance Premium (P)	16.5	6	10.2
Deposit (Dep)	403.5	244	584.8
Ratios			
W / Y	22.6%	7.8%	23.5%
D/Y	74.5%	87.9%	66.5%
CON / Y	64.5%	53.3%	57.8%
P / W	3.9%	2.4%	1.7%
DEP / W	96.1%	97.6%	98.3%

Table 5.12 summarized the effects of crop type and rotation on farmers' value function and Certainty Equivalent Consumption at the initial state. Table 5.12 shows that at the same initial wealth level farmers would have the highest value function and certainty equivalent consumption level in the peanut production scenario, and have the lowest value function and certainty equivalent consumption level in the cotton production scenario. The value function and certainty equivalent consumption level in the rotation production scenario are in between of the values in the single production scenarios. In this simulation the prices of peanut and cotton are assumed to the average prices. The results indicate that peanut production is a better strategy than cotton production. However, it should be noted that farmers don't know peanut price or cotton price when they plant the crop. It is possible that when prices change (cotton price increases and peanut price decreases), cotton might be a better choice than peanut production. In addition, farmers use rotation strategy for various reasons, such

as soil protection, pest control, utilizing nitrogen fertilizer, spreading risk, etc. These factors should also be taken into account when making a decision.

Table 5.12: Effects of Crop Type and Rotation on Farmers' Value Function and Certainty Equivalent Consumption at Initial State

Initial Wealth ($/acre)	Production	Value	Certainty Equivalent Consumption ($/acre)
500	Cotton	-0.008268	1196.323
500	Peanut	-0.005731	1725.911
500	Cotton&Peanut	-0.006838	1446.504
-500	Cotton	-0.010083	980.978
-500	Peanut	-0.006181	1600.258
-500	Cotton&Peanut	-0.008172	1210.377

CHAPTER 6

CONCLUSIONS

This dissertation formulates a structural dynamic model that stresses the interdependence between the alternative risk management methods, and takes into account a number of important features of the actual agricultural economy: income uncertainty, liquidity constraint, and the use of irrigation, insurance, and credit to mitigate income risk and to smooth consumption. A Bellman's equation with numerical technique is used to give approximation of the life-time behavior paths of consumption, insurance, credit, and accumulation of wealth, in a multi-period life-cycle model. This model provides additional insights concerning the risk management behavior for different farmers (with different initial net wealth) that could not be obtained from the static models.

According to Carroll (2001), as long as farmers are impatient, they will get converged consumption paths after sufficient time, even if the economy as a whole is not at the steady-state temporarily. Our results confirmed this contention, and show that the choice and state variables evolve to reach a steady-state distribution after only 5-10 years, which provide insight about the behavior of most farmers in the economy. This result is dramatically different from the certainty equivalent model noted by Modigliani (1966), in which no general conclusions can be derived about consumption behavior for any particular state as optimal behavior is different for different state.

The result concerning marginal propensity to consume (MPC) indicates that consumption by poor farmers is more influenced by transitory shock to their income than rich farmers. Moreover, our result seems to support Friedman's (1957) PIH theory, as the MPC for both poor and wealthy farmers are much less than 1, and dramatically larger than the 0.05 implied by the perfect foresight model or by the certainty equivalent model. The result concerning insurance confirms Gollier's (2003) conclusion, that wealthier farmers tend to reduce insurance purchase, due to the utility function's property of decreasing absolute risk aversion (DARA).

A variety of sensitivity analysis shows that, consistent with Carroll (2001), the overall pattern of the consumption function figure *c(w)* (increasing and concave) is unchanged under alternative simulation scenarios, indicating that the conclusions made above about consumption pattern are robust to alternative values of parameters. Under stricter liquidity constraint, MPC is higher, indicating that farmers would consume a larger proportion of transitory income than in benchmark case, and confirms the literature suggesting that liquidity constraint may be an important reason for the higher MPC. However, MPC is still much lower than 1 in our results, which still supports Friedman (1957).

As for insurance, with stricter liquidity constraint, most farmers adopt less insurance coverage; however, for very wealthy farmers, insurance coverage is higher than in the benchmark case. This result differs from Nyambane (2005), and implies that no strictly negative relationship can be established between liquidity constraint and insurance coverage. A possible reason is that a binding liquidity constraint induces more risk aversion (in effect, increases the relative risk aversion coefficient γ), and an increase in γ has two effects on farmers: one is to increase the demand for insurance; the other one is to increase the precautionary motive to save (at the expense of insurance) (Rothschild and Stiglitz 1971). These two effects, along with the budget restraining effect of liquidity constraint, work together on farmers; however, for very wealthy farmers, it seems that the demand for insurance outweighs the demand for precautionary saving (the reason might be that the demand for precautionary saving becomes very low when initial wealth increases to a very high level because of the DARA nature of utility), and thus insurance coverage is higher for very wealthy farmers compared with the benchmark case.

When farmers are subject to full credit constraint, that is, farmers are not allowed to borrow from financial institutions, optimal coverage now converges to around 84.5%, higher than in the second strictest case. A possible explanation is that full liquidity constraint limits farmers' ability to smooth consumption through lending facilities. As a result, a farmer will choose higher insurance coverage for risk management. In other words, when there is no borrowing available to smooth consumption, farmers will resort to insurance for risk management.

While no strictly negative relationship can be established between liquidity constraint and insurance coverage, a clear link can be found between stricter liquidity constraint, higher net wealth, and lower debt. In the stricter liquidity constraint scenario, farmers would borrow less money than in the benchmark scenario, to accumulate precautionary wealth and to attain consumption levels at a steady state.

This result implies that when policy requires banks to strengthen liquidity constraint, the volume of debt would fall dramatically, precautionary wealth would be accumulated much more, and the supply of deposits (precautionary saving) also increase dramatically. These results might be of interest to researchers working on monetary transmission mechanisms.

Sensitivity analysis on insurance premium loading implies that, when insurance is expensive, only poor farmers would be willing to keep the same insurance coverage and pay much more money to buy the more expensive insurance. Wealthier farmers would prefer deposits with a financial institution to expensive insurance for their risk management portfolio, and thus reduce insurance coverage. However, insurance premiums at the steady state are still higher than in the benchmark scenario in spite of the fact that coverage is lower, probably because demand for insurance is inelastic.

When insurance is subsidized, most farmers (within the main range of net wealth) would choose to purchase higher insurance coverage, and for very wealthy farmers with net wealth in the range of \$1800/acre and \$2000/acre, they choose the maximum allowable insurance coverage (90%). These results may imply that imposing higher premium loading, especially to poor farmers, would be beneficial to insurance companies; subsidizing insurance by government, on the other hand, may not be very efficient in increasing farmers' welfare, as the increase in consumption and precautionary wealth at the steady-state is modest at best.

Simulation of risky market environments implies that the lower output price would decrease both farmers' consumption level and their ability to smooth consumption through the decrease in permanent income. These two effects in combination reduces farmers' welfare. This result implies that the patterns of consumption and insurance behavior indeed vary across different environments. Thus, different environments would call for different insurance and financial services. Particularly, in the scenario of riskier markets, precautionary saving and insurance becomes more critical in farmers’ consumption smoothing and risk management strategies, as these types of assets provide risk-free risk management strategies to protect farmers from sharp income loss.

Simulation of relative risk aversion shows that increasing relative risk aversion levels would have the effect of increasing precautionary wealth from 22.6 percent of permanent income to 26.9 percent, which is accomplished at the expense of current consumption and debt. A decrease in debt and consumption in the early periods when wealth level is low allows farmers to have more end-of-season deposits each year and thus have higher wealth in the subsequent periods to better protect from consumption reduction.

Simulation on time-preference factor - impatience - indicates that in extremely poor places where farmers are highly impatient, the farmers would keep a very low level of precautionary wealth (22.6%), and the precautionary saving (*DEP*) is even lower (96.1% of precautionary wealth). Thus, for extremely poor people, innovative safety nets are more critical in absorbing and sharing the risk of consumption fluctuation. With regard to policy making implications, our results indicate that impatient farmers have a higher tendency to invest in insurance for precautionary purposes. This result, along with the sensitivity analysis on premium loading, indicates that poorer and more impatient farmers have a higher intention to invest in insurance for precautionary purposes, even if the insurance is expensive, which may be of interest to policymakers who want to help extremely poor and impatient farmers to manage their risk.

The simulated results for the increase in account-specific interest rates shows that farmers' decisions on consumption, insurance, credit, and precautionary wealth appear to be very sensitive to the risk-free interest rate. Our results indicate that increasing the account-specific interest rate will, *ceteris paribus*, induce farmers to reduce consumption and to hold a larger amount of net precautionary wealth, from about three to four months' worth of permanent noncapital income. The relative attractiveness of debts (to finance consumption, insurance, and production for the whole year) is reduced. Since deposits have become more attractive, farmers choose to attain more protection by accumulating precautionary savings. The insurance component in the precautionary wealth portfolio is lower, implying that farmers would prefer savings to insurance for precautionary purposes when interest rates increase.

These results imply that changes in interest rates, along with changes in farmers' credit limits, would be very effective in monetary policy transmission. For local financial institutions to attract deposits and/or reduce bad debt, they may consider offering more attractive options. Our results suggest that increasing account-specific interest rates, or applying higher APR to farmers who have higher probability of default may help local financial institutions attract deposits and reduce bad loans, and help farmers accumulate wealth and mitigate the impact of income variation. This result has valuable empirical significance for agricultural financial institutions.

The changes in the dynamic paths for GRP and WD products illustrate that when there is remaining uninsurable risk (basis risk), precautionary wealth serves another purpose in addition to consumption smoothing: mitigating the impact of basis risk, which is an added element of farmers’ risk profile. Therefore, the desired precautionary wealth increases, and the consumption at the steady state also increases. In addition to the level effect on the precautionary wealth, basis risk also has composition effect on precautionary wealth portfolio, as the wealth is composed of two parts, insurance and deposit. The presence of basis risk makes it more attractive to hold precautionary wealth as precautionary savings (deposits, which are risk-free assets) than as insurance (also for precautionary purposes, but now a risky asset).

As for the impact of basis risk on consumption, as farmers increase precautionary demand for saving, they decrease current consumption; moreover, the marginal propensity to consume (MPC) for rich farmers decreases compared to the benchmark case, while the MPC for poor farmers increases compared to the benchmark scenario, which implies that in the presence of basis risk, poor farmers' consumption is more influenced by transitory income, and rich farmers' consumption depends even more on permanent income than in benchmark case.

Simulations of the varied price and revenue insurance show that varied price would reduce farmers' value function and Certainty Equivalent Consumption, and that revenue insurance is a better risk management tool compared with MPCI in the presence of price variation, as it leads to higher value function and higher CEC, although still lower than in the benchmark case without price variation.

Simulation on crop types and rotation shows that the rotation strategy leads to a lower Coefficient of variation of Profit, and thus lower risk. Moreover, out results indicate that under the parameter values assumed in each scenario, the rotation strategy leads to highest level of precautionary wealth at the steady state. A higher level of precautionary wealth at the steady state would enable farmers to better avoid sharp reduction in consumption when bad states prevail, and thus to have higher ability to smooth consumption in the future.

Sensitivity analysis helps predict the consequences of alternative government interventions. This could have valuable policy implications for government agencies (e.g., USDA's Risk Management Agency (RMA), Agricultural Stabilization and Conservation Service (ASCS)), policymakers, deposit/debt financial institutions, and insurance companies (Velandia *et al.* 2009), who want to know farmers' demand for consumption, credit, or insurance and in what time frame. For example, our results indicate that more impatient and poorer farmers have a higher tendency to invest in insurance for precautionary purpose, even if the insurance is expensive. Change in interest rates, along with change in farmers' credit limits, would be effective in monetary policy transmission. With basis risk, desired precautionary wealth becomes larger and insurance holdings become lower. An awareness of how farmers adjust their insurance and credit decisions with respect to liquidity constraint and interest rates would help policymakers adjust monetary policy and/or regulate banks in making their lending/deposit taking decision. An understanding of what type of farmers (rich or poor, low risk averse or high risk averse, patient or impatient, etc.) are more inclined to buy agricultural insurance when it is expensive and in what time frame would assist insurance companies in screening and attracting potential clients (Velandia *et al.* 2009), and designing dynamic insurance products to satisfy their changing needs.

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