ABSTRACT

Title of Dissertation: THE INFLUENCE OF HETEROGENEOUS RISK PREFERENCES ON WATER MARKET ACTIVITY: AN APPLICATION TO THE PALOMA SYSTEM OF THE LIMARÍ WATER BASIN, CHILE

Oscar E Cristi, Doctor of Philosophy, 2007

Dissertation directed by: Professor Lars Olson,
Department of Agricultural and Resource Economics

This dissertation contributes to our knowledge about water markets by analyzing the factors that explain market transactions of water rights when there is also a spot market for water volumes. I hypothesize that risk heterogeneity among farmers can explain those transactions. To test the aforementioned hypothesis I model farmers' decisions on investment in water rights each season under the assumptions that they face output risk and that uncertainty is generated by future water availability and price. The first order condition to this problem, which is represented by the Euler Equation, indicates that the current period reservation value of a water right depends on the current value of the amount of water accorded to water rights in the spot market, the stochastic discount factor, and the expected future prices of water rights. Using the relationship between the reservation value of a water right and the stochastic discount factor I show analytically how heterogeneous preferences are a sufficient condition for an active market for water rights. Then, I test for heterogeneous preferences by allowing them to be a function of specific characteristics of farmers. That requires the estimation of a system of equations that includes a parametric specification of the Euler Equation and the first order conditions for optimal input quantities. For that, I use an exponential utility function and a production function of the Just-Pope type. I jointly estimate the parameters that describe a farmer's utility function along with production function parameters. The empirical application uses farmer micro-level data from a two-round survey that I conducted on a sample of Limarí Basin farmers. That Basin is located in the northern part of Chile and is characterized by an active water market that has existed since 1981. Evidence rejects the hypothesis of homogeneity among farmers and suggests that those better educated and more experienced Limarí Basin farmers are less risk-averse. Results also show that water, labor and fertilizers have a positive impact on mean output per hectare but their effect on yield variability implies that those inputs are risk increasing.

THE INFLUENCE OF HETEROGENEOUS RISK PREFERENCES ON WATER MARKET ACTIVITY: AN APPLICATION TO THE PALOMA SYSTEM OF THE LIMARÍ WATER BASIN, CHILE.

By

Oscar E. Cristi

Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2007

Advisory Committee:
Professor Lars Olson
Professor Maureen Cropper
Professor Bruce Gardner
Professor Richard Just
Professor Erik Lichtenberg

Dedication

To my mother and Gislaine, Yuviza and Francois

Acknowledgements

This dissertation would not have seen the light of day without the help of a number of individuals and institutions. I thank the chair of my committee, Professor Lars Olson, for his permanent encouragement and the valuable insights and advice that he provided. I thank Professor Richard Just for the detailed comments and valuable guidelines on previous versions which led to substantial improvements. I am also appreciative of the input from committee members, especially Professor Erik Lichtenberg whose careful reading of the manuscript yielded many suggestions for clarifications and improvements.

I express my deepest gratitude to all the members of AREC for their permanent support and enormous kindness and professionalism.

I thank the Universidad de los Andes, Chile, and the World Bank for the financial support. Their generosity allowed me to gather the data for this dissertation.

I have had many fruitful discussions about the dissertation process with Professor Ivar Strand and my colleagues. Especially important have been conversations with Fernando Díaz, William Foster, Jean Sepulveda, Eugenio Bobenrieth and Ricardo Bórquez.

Finally, I would like to thank Abel Mejía, from the World Bank, who not only suggested me to study the economic aspects of water markets, but also provided permanent support for this dissertation.

Table of Contents

Dedication ii

Acknowledgements iii

Table of Contents iv

List of Tables vi

List of Figures vii

Chapter 1: Introduction 1

Chapter 2: Literature Review 7
  2.1 Water management 7
    2.1.1 Water markets in Chile and the Chilean Limarí Basin 13
  2.2 Asset pricing models 21
  2.3 Identifying risk preferences 25

Chapter 3: The Limarí River Basin's Water Market 29
  3.1 Mechanism for the Allocation of Waters in the Paloma System 31
  3.2 Market Activity 34
    3.2.1 Spot Market 35
    3.2.2 Permanent Market 38
  3.3 Price Behavior in the Water Market 41
    3.3.1 Spot Market 41
    3.3.2 Permanent Market 42
  3.4 Market Expectations and Access to Information 44
  3.5 Summary 46

Chapter 4: Theoretical Model 48
  4.1 A Simple Model 48
  4.2 The Farmer's Decision Rule under Water and Output Uncertainty 52
  4.3 Market Frictions and Consumption-Based Asset Pricing for Water Rights 66
  4.4 Summary 72

Chapter 5: The Econometric Estimation 74
  5.1 Parametric specification of the system of equations 74
  5.2 Data 89

Chapter 6: Estimation and results 98
  Appendix: A Hausman test for endogeneity 119

Chapter 7: Conclusions and Suggestions for Future Research 122

Annex: Survey instrument 127

References 149

List of Tables

Table 3.1 Average water accorded to water rights between 1980 and 2000……………………………………………………..….. 33
Table 5.1: Basic statistics of the main variables…………………….. 93
Table 6.1: Descriptive statistics for variables used in the estimation of the system of equations………………………….....…. 104
Table 6.2: Estimates of the parameters of the equation system using FIML…………………………..……………………. 110
Table 6.3: List of instruments to test for possible endogenous regressors……………………………………………… 120

List of Figures

Figure 3.1:	Limarí Basin and the Paloma System……...........................	31
Figure 3.2:	Water accorded to water rights between 1980 and 2000……	33
Figure 3.3:	Transfers of water in the spot market……………………........	38
Figure 3.4:	Number of water rights transferred by each association during the period 1980-2000………………………………..	39
Figure 3.5:	Real average prices of water rights in each WUA…….........	42
Figure 3.6:	Reservation value for the right to one cubic meter of water in ACEC…………………………………………………..	43
Figure 3.7:	Reservation value for the right to one cubic meter of water in ACER…………………………………………………..	44
Figure 3.8:	Transfers of water through the spot market………………....	45
Figure 4.1:	Water right transactions……………………………………..	70
Figure 6.1:	Actual value of standardized output income per hectare against the imputed values for that variable………………...	113
Figure 6.2:	Actual value of standardized investment in water rights against the imputed values for that variable………………...	113
Figure 6.3:	Plot of the residuals from the FIML regression based on estimates in Table 6.2………………………………........	118

Chapter 1: Introduction

The study of water resources is a passionate task as their increasing value and unique characteristics are appealing for economists working on natural resources and have important implications for peoples' well-being**.**

Almost any paper or document that tackles water management will begin by pointing out that worldwide, even countries and regions where water is abundant face increasing water scarcity (Rosegrant et al., 1997, Tsur, 2004, Saleth and Dinar, 2004). Demands for water from all sectors – agriculture, industry, households, and even environmental conservation – combined with increasing difficulty in developing new structural solutions to increase water supply, explain growing water scarcity. Projections of water withdrawals by sectors show the dramatic increase in pressure on water resources over the next three decades (Rosegrant et al., 1997).

Water has special characteristics because it is not a resource like others that can be easily appropriated, traded and used without affecting others. Water is a mobile resource that generates multiple levels of physical inter-dependence among users, while farmers' water use and transfer decisions create externalities. Water diversion requires expensive devices for volumetric or flow measurements and costly conveyance systems. Finally, water for irrigation is characterized by the randomness of supply and the high cost of reducing variability through storage capacity.

Since the 1950s, the literature has debated the merits of water allocation institutions, and now wise water management policies are among the most crucial challenges of nearly all countries. If Julian Simon – whom I met for the first time in 1986 and who encouraged me to come to study at the University of Maryland – were still alive, surely he would have seen this problem as a challenge for the people. Likely he would have said that this new challenge could best be resolved by allowing people to deal freely with this problem, as he extensively documented in his works on decreasing scarcity of several natural resources. The public-good approach with public water ownership and state involvement in its development and distribution does not work well in the present context of water scarcity. Thus, as Saleth and Dinar (2004) point out, “The current trend is toward an alternative system that can allow private decision-making in water resource development, allocation, and management. For the alternative system to function effectively and equitably, legal changes are needed to facilitate private and transferable water-rights system that ensures full legal, physical and tenure certainty of water rights.”

Worldwide, irrigation continues to be, by far, the largest sector of water consumption accounting for nearly 70% of water withdrawals worldwide and over 90% in low-income developing countries. Another 23 percent of water is used in industry and the remainder is consumed by households. These numbers indicate that the increasing demand for water will need to be met from water savings in irrigated agriculture by improving efficiency. Traditionally, economists have argued that efficiency can be achieved through a water pricing system that reflects water scarcity. This approach has some problems. First, water users have been able to use their political power to prevent major increases in water prices, especially for irrigation. Second, the water authority needs to define a mechanism to value water, which may differ from water users’ willingness to pay for water.

Given those problems, water markets are receiving increasing attention from policymakers in an attempt to improve the efficiency of water allocation. Although, in spite this and the fact that numerous informal water markets have evolved around the world, very few countries have implemented formal and legal free markets for water. This is a result in part from the difficulty that researchers face in studying rights that are attached to a mobile resource like water. Therefore, relevant policy questions about water markets have not been addressed with empirical evidence. Moreover, policymakers have tended to claim state "ownership" of water and have been reluctant to develop tradable water rights by separating them from land rights, which would allow the transfer of the former. They recognize the theoretical value of water market institutions, but some think that the number of recorded instances where water is reallocated by market transactions is far too limited due to physical constraints and third-party effects associated with water exchanges. There are also doubts about whether the market can reallocate water to its optimal social use. Hence, still the main question about water markets, as Saliba (1987) pointed out is "Do water markets 'work'?"

Chile has formal water markets that have been operating for more than 24 years, and has become, along with Australia, an example of how institutional reforms that treat water as an economic good improve water-use efficiency and water allocation. Nonetheless, more empirical research based on extended data is required to support those hypotheses (Bauer, 2004). Thus, Chilean water markets offer an excellent opportunity for researchers who seek to answer relevant policy questions about water markets.

The purpose of this dissertation is to contribute to the understanding of water right transactions. I attempt to answer a basic question: What explains water rights trading when farmers can exchange water in the spot market, which has lower transaction costs? In answering this question, I emphasize the link between the spot and water rights markets where differences in marginal returns to water among farmers are solved in the spot market while the water rights market address differences in the stochastic discount factor among farmers.

In this dissertation, I develop a theoretical model in which I characterize optimal decision making by farmers faced with the decision of investment in water rights. This model assumes that farmers face water and output uncertainty, and that they may trade water in the market for water rights and/or the spot market. Because investment decisions affect future levels of consumption and farmers face uncertainty, the theoretical model for farmer decisions is modeled as a stochastic dynamic problem. This results in a Consumption Capital Asset Price Model (CCAPM) whose solution is described by an Euler Equation that ties asset returns (water right returns in this case) to marginal rates of substitution of consumption at different points in time. This model provides insights into how farmers determine their reservation value for water rights when it is considered an asset, often the main asset for farmers, and it allows me to emphasize the role of farmers' heterogeneous risk preferences on their reservation values and on marketing activity.

This theoretical analysis provides the foundation for a case study of water transfers for irrigation in the Limarí Basin, an important agricultural region in the northern part of Chile, which has one of the most active Chilean irrigation water markets. With farmer-level data obtained from a survey among farmers for two different agricultural seasons, the case study allows me to estimate jointly the parameters that describe a farmer's utility function and production function. The estimation is based on the Euler Equation and the first order conditions for input quantities. Using observed economic behavior I test for heterogeneous preferences among farmers. The use of an asset price model to jointly determine farmers' preferences and production technology in developing countries is a contribution to the literature on agricultural finance.

The present analysis of a Chilean water market and its empirical application provide insights into how water markets work in a developing country. It is hoped that the results of this dissertation will supplement our knowledge of the outcomes and experiences of developing countries with active, but undocumented, water markets, and help move the debate beyond principles to empirical results on the operation of water markets. This analysis will serve countries that are contemplating adopting market-based reallocation systems where policymakers wish to inform themselves of other experiences in water markets in different cultures and geographic regions before they make a decision.

This dissertation proceeds in 7 sections. In Chapter 2, I present a brief survey of the literature on water markets. I then proceed to provide a detailed description of the operation of the water market in the Limarí Basin. In Chapter 4, I develop a theoretical model for optimal decision making by farmers who must decide on investment in water rights and input quantities in every season. Data availability and the econometric model are discussed in Chapter 5. In Chapter 6, I describe the estimation procedures and I report estimation results. Finally, Chapter 7 concludes with a summary of the main results and suggestions for future research.

Chapter 2: Literature Review

In this chapter I review the relevant portions of the extensive literature on water management and water markets. I also review the part of the literature on asset pricing models and the estimation of heterogeneous risk preferences that is related with the analysis and methodology of this dissertation.

2.1 Water management

There is a broad consensus in the literature on water management that increasing water scarcity requires a shift from supply-oriented approaches focused on technical and hydrological solutions towards allocation-oriented approaches centered on economic and institutional solutions that provide the right incentives for water savings. These efforts focus primarily on agricultural irrigation, the main use of water all around the world[1] (Saleth, 2004). This is the starting point for a wide literature on alternative institutional arrangements to promote efficient use (Bruns and Meinzen-Dick, 2000, Saleth and Dinar, 2004)

Since at least the 1950s, there has been a debate in the literature over socially appropriate water allocation institutions (for an excellent summary of that debate, see Lynne and Saarinen, 1993). Traditionally, economists and policymakers have argued that what is needed is a centralized water pricing system[2] that reflects the opportunity cost of water. Centralized water pricing systems have two main problems. First, water users have been able to use their political power to prevent major increases in

---

[1] Irrigation is the largest sector of water consumption; accounting for nearly 70% of total water withdrawals worldwide and over 90% in low income developing countries.

[2] In such a system the water authority determines the value of water in different uses and fixes a price for the use of that resource.

water prices, especially for irrigation (Easter et al., 1998). Second, under a centralized system of water pricing, the water authority needs to define a mechanism to value water, which may differ from water users' willingness to pay for water.

Non-market techniques to value water rights include the farm-budget residual valuation for water[3] as in Hearne and Easter (1995 and 1997). Another approach is to estimate the value of marginal productivity of water using a crop-water production function. Marginal values of water in municipal uses or in instream and recreational uses are usually derived by estimating consumer willingness-to-pay through contingent valuation and travel cost methods. Another procedure that has been used to evaluate willingness to pay for water is the least cost alternative technique as in Hearne and Easter (1995 and 1997)[4]. Person and Michelsen (1994) offer a good review of different methods for estimating water values and they summarize the willingness to pay estimates for different water uses in studies until 1994.

The current trend of water allocation institutions is toward an alternative system that allows private decision-making in water resource development, allocation, and management (Saleth and Dinar, 2004). Thus, market-type allocation institutions such as water markets and water banks, that recognize water as an economic good rather than a social good, are receiving increasing policy attention in attempts to improve the efficiency of water allocation (Rosengrant and Binswanger, 1994, Vermillion, 2000, Brookshire and Ganderton, 2004). In that framework, the

---

[3] In the residual method, subtracting all non water and land input cost from the total revenue yields a residual value, which can be viewed as the maximum price that the operator could pay for land and water and still break even. The researcher then allocates the residual value between the two components, land and water.

[4] In this case, the technique is used to compare the present value of the cost of buying water rights against the cost of building a new storage capacity to increase water availability for municipal uses.

market provides the mechanism by which water is valued. This new paradigm has been promoted by the United Nations at the Rio Convention on Environment and Development in 1992 and by the World Bank (1993).

The literature on the design of water markets within the variety of legal settings that exist around the world has focused on the distinction between formal and informal markets. In the formal market a variety of transactions take place, such as the rental of water rights, water volume sales for a specific time period, and water entitlement transferences, whereas in the informal market only short term transactions are observed (Bjornlund, 2004).

Formal water markets have been implemented in the western United States in Colorado (early 1960's) and California (since 1982), and in Chile (since 1981), Australia (since 1983), South Africa (since 1998), New Zealand (since 1991) and Mexico (since 1994). Peru, Bolivia, Argentina, Nicaragua are among the countries that are discussing policy reforms oriented towards water markets (Bauer, 2004).

Saleth (2004) and Bruns and Meinzen-Dick (2000), advocate that for formal water markets to function effectively and equitably, legal changes are needed to ensure full legal, physical, and tenure certainty of water rights separated from rights to land. The costs associated with these institutional changes necessary to move to market mechanisms explain in part the reduced number of countries that have formal markets (Coward, 2000). Those costs have been addressed by McCann and Easter (2004), but as Saleth and Dinar (2004) point out, "A study of the full transaction cost associated with the change to an alternative water allocation mechanism has not been attempted to our knowledge."

With regard to informal markets, those markets have been widely implemented in a number of countries such as India (Saleth 1998), Pakistan (Meinzen-Dick, 1998) and Jordan (Shatanawi and Orabi, 1994).

Most critics of water markets argue that they do not work at all or that transactions are too few due to market failures, and that they are not compatible with integrated water resource management because they do not jointly solve critical economic, environmental and social issues (Bauer, 1995 and 2004, Crase et al., 2000 and 2003, Gleeson, 2003). Supporters emphasize the benefits of water markets and how these markets are actively working in various parts of the world (Rosengrant and Binswanger ,1994; Holden and Tobani ,1995; Briscoe, 1996)

The emergence of water markets as allocation institutions has led economic analysis to focus on what type of market is likely to appear, how water prices may be formed, and whether water markets improve efficiency of use by reallocating water to its highest use value.

Up to now, the description of how water markets function has focused primarily on developed regions including the Western States of the USA (Michelsen and Young, 1993, Israel and Lund, 1995, Susan M Burke et al., 2004) and, more recently, Australia (Bjornlund and McKay, 2002, Bjornlund, 2004, Crase et al., 2004). Attention is now shifting toward the developing regions of Africa, Asia, and Latin America. Examples of empirical research on Latin American countries are the works done for Chile by Rios and Quiroz (1995) and Bauer (1995 and 2004). Rosengrant and Binswanger (1994) describe markets in tradable water rights in Chile and Mexico. A major contribution to the literature on the outcomes of water negotiation is the book edited by Bruns and Meinzen-Dick (2000), which documents cases primarily from South Asia and Indonesia. These cases show how negotiation is frequently used by water users, and the successful outcomes that have resulted from the process.

Understanding the factors that determine water right prices and their variation has become important for establishing whether water markets reallocate water to its most efficient use. Initial studies explain price formation as a result of a bargaining process between farmers for which the value of marginal product of water differs. Several studies use hedonic price function to estimate the value of water rights and the factors that influence prices of water rights and its fluctuations, such as water right characteristics, institutional constraints, physical transferability of water, bargaining power of sellers and buyers, and speculative behavior over water right prices (Colby et al., 1993, Person and Michelsen, 1994, Bjornlund and Mckay, 1998). Numerous authors have constructed the theoretical arguments that some type of market based trading mechanism would greatly increase the efficient use of water (for a good summary of the state of art on water markets see Brookshire and Ganderton, 2004). The basic argument is well established: water is a natural resource with varying value in different uses and with clearly defined social and political constraints. In terms of applied research, qualitative analyses as well as increasingly sophisticated empirical studies have been published to verify whether water markets allocate water to its highest valued use. To make this determination several studies simulate market performance (Saleth et al., 1991, Dinar and Latey, 1991, Tisdell et al., 2004, Dinar et al., 1998, Murphy et al., 2000). Also, an increasing number of studies provide empirical analysis for assessing water right market efficiency with data on existing water markets, mainly in some states in the USA (Brown et al., 1982, Saliva, 1987, Crouter, 1987, Michelsen, 1994, Rosegrant and Binswanger, 1994, Brookshire at al., 2004) and Australia (Crase et al, 2000, Bjornlund ,2004). For the case of developing countries such as Chile, Rios and Quiroz (1995) and Bauer (1995 and 2004) provide qualitative analysis of water market performance whereas Hearne and Easter (1995 and 1997) provide quantitative analysis of water market efficiency. A good number of these studies analyze whether water allocated through the market moves from its lower to its highest value by empirically identifying who are the buyers and the sellers. This is the case of Nieuwoudt and Armitage (2004), Bjornlund (2004) and Crase et al. (2004) for developed countries as South Africa and Australia, and Hadjigeorgalis (2000) and Zegarra (2002) for the water market in the Limarí Valley, Chile. In general, studies that analyze water market efficiency conclude that the major benefits of the formal market are associated with a reallocation of water to 1) more productive soils, 2) more efficient water users, 3) higher-value uses, and 4) new developments and the consolidation of water into larger more viable units.

The work by Bjornlund (2004) is quite interesting because he measures and compares temporary trade with permanent trade in the Goulburn System and Murray System, Australia. Bjornlund (2004) finds that the temporary market has by far the highest amount of traded water, and that the practice of using both markets has been widely adopted to shift an irrigator’s risk position and to manage increased supply uncertainty. He also indicates that trade in water rights surged after farmers became familiar with water trading and aware of the potential benefits. This took around 7 years in the area he studied. Finally, he presents evidence that shows how liquidity constraints cause farmers to participate as buyers in the temporary market because they cannot afford to buy water rights. Crase et al. (2004) found similar results for the water markets in the Murray Darling Basin of Australia. In New South Wales permanent and temporary transactions took 10 years to be significant, with temporary transactions always much more important. In Victoria's water market trade in water rights surged after 7 or 8 years. These results of Bjornlund and Crase et al. on the relative size of the temporary market with respect to the permanent market and on the time that the permanent market takes to become established are very similar to the ones that I obtain for the Limarí Basin, and which are reported in Chapter 3 of this dissertation.

Nevertheless, there still exists a real need for more applied work on water markets. Brookshire and Ganderton (2004) point out that "it is necessary to understand beyond theoretical considerations how well these alternative institutions perform from an empirical standpoint and what are some of the institutional design issues that remain" and that "It is also needed to move beyond the simple description of markets to identify the forces operating within those markets."

2.1.1 Water markets in Chile and the Chilean Limarí Basin

Chile, together with Australia, has become one of the world's leading examples of how institutional reforms that treat water as an economic good improve water use efficiency and water allocation. Yet more empirical research based on extended data needs to be done to support those hypotheses. Bauer (2004) points out that “much of the discussion about Chilean water markets has been long on theoretical or ideological argument and short on reliable information”.

The first real empirical study of water markets in Chile was done by Hearne and Easter (1995 and 1997), followed by Hadjigeorgalis (2000) and Zegarra (2002). All these studies examine the water market in the Limarí Basin. Hearne and Easter (1995 and 1997) also analyze water markets in the adjacent Elqui Basin, and Cristi et al. (2003) also use that basin in their case study.

The Limarí River Basin, in north central Chile, has attracted national and international attention through the 1990s and first half of the 2000s. The Limarí River Basin is the one example that is widely agreed to have an active and successful agricultural water market, including both temporary and permanent sales, and even local real estate agents broker and facilitate water rights trading. Hearne and Easter (1995 and 1997) estimate economic gains (net return to society) and financial gains (individual net benefits) from trade in that basin. Economic gains correspond to the difference between the value of water to the buyer after a purchase and the value of water to seller before a sale minus transaction costs of the transfer. Financial gains for a seller equal the sale price less both the value of water to the seller and the seller’s transaction cost, whereas for a buyer it is the difference between the value of water to the buyer and the sum of the buyer’s purchase price and transaction costs. They conclude that market transfers of water rights produce substantial economic and financial gains from trade in the Limarí Basin.

While their results are interesting they do not consider key features of water used in irrigation that affect individual values for water rights, such as uncertainty about water availability and future water prices, output uncertainty, and farmers' attitudes towards risk. They also do not consider that in the Limarí Basin there are two markets for water that coexist and interact: the market for water rights sales (permanent transactions or permanent water rights sales) and the spot market for water (short-term or temporary transactions). As a consequence, they fail to recognize the relationship between the value of a water right and the price of water in the spot market.

Hadjigeorgalis (2000) provides the first empirical analysis of actual trading outcomes in both spot and water rights markets in the Limarí Basin. For the spot market, she measures the number of transactions, volumes sold, and the number of participants - separated by buyers and sellers - for the period 1994-1997. She also analyzes price behavior for the 95/96 and 96/97 seasons, using field data for around 332 farmers. She concludes that there exists an active spot water market with prices highly sensitive to water scarcity, and that the facility to transfer water volumes between sectors has resulted in an equalization of water prices for water volumes between geographically segmented sectors. With respect to market activity in the market for water rights she identifies the existence of physical constraints that prevent transferring rights between different reservoirs and institutional constraints that prevent trading rights that are stored within the same reservoir, but that have different legal locations (i.e. farmers with water rights in different Water User Associations)[5]. These constraints produce segmentation into local market sectors below the dams and this segmentation allows for water right price differences between local markets. She

---

[5] Cortés, M (1997) offers a lucid explanation of the legal constraints to water right trades in the Paloma System.

also presents the first formal, theoretical analyses of the impact of risk and uncertainty on water market trading and water decisions on the amount of water to be used in the production process[6]. In her theoretical approach she allows for output price and spot market price uncertainty, water endowment uncertainty and capital production risk for farmers that produce perennial crops. She presents formal expressions for reservation spot market prices and reservation values for water rights. The former are a function of the net value of the marginal product of water in irrigation, irrigation efficiency, risk aversion and uncertainty cost associated with selling and buying water volumes. Reservation values for water rights – which she derives by emphasizing that water rights are an asset – are a function of the sum over time of the discounted per period net values of the marginal product of water in irrigation (benefits from water use in irrigation less the cost of holding water rights), irrigation efficiency, risk aversion, and uncertainty cost associated with stochastic water supplies. For perennial crop producers, reservation value is also a function of the risk of future loss of their stock of perennial crops from a water supply shortfall. In the empirical application she analyzes market participation and the probability that a farmer participates in either the spot market or the water right market, and whether the farmer will buy or sell water volumes and/or water rights. Among the explanatory variables, she includes risk aversion proxied by farmer's wealth. She shows that trades occur from farms with low irrigation efficiency to farms with high irrigation efficiency and that transaction costs in the spot market as well as in the

---

[6] Howitt (1998) provides a first theoretical analysis of the impact of risk and uncertainty on water markets and water decisions in a case study for the existing water market in California.

market for water rights are minimal. The main limitation of Hadjigeorgalis's work is that, although in the theoretical model she clearly addresses the effect of risk and risk preferences in the farmers' reservation value for a water right, in the empirical application that relationship vanishes and is replaced by a set of prior assumptions regarding what type of farmers are more or less risk averse. Thus she cannot clearly show how risk affects farmers' water trading decisions. An empirical test of the relationship among farmers' characteristics and risk aversion would have helped her to explain what she called unexpected results. One of these unexpected results is that perennial crop producers are not exclusively buyers of water rights but appear consistently on both sides of the market. An empirical estimation of heterogeneous risk preferences may show how differences in risk preferences explain differences in reservation values for water rights among perennial crop producers. If such differences exist then it would explain why water right trades occur as more risk-averse perennial crop producers would buy water rights from those perennial crop producers with lower risk aversion.

Zegarra (2002) focuses his research on the operation of the spot market in the Limarí Valley in the face of an extremely negative shock: the severe drought of 96/97. He models farmers' decisions about the amount of water to be used in production and the amount of water to be sold in the spot market. Farmers reach equilibrium when the water's marginal of value product equals the spot market price for water. Thus, farmers decide not to grow crops in those seasons in which the water return for selling water in the spot market is greater than their expected income from production. Farmers are risk neutral and with production functions characterized by a minimum water requirement constraint, which results in a non-convexity of the production technology. With production non-convexity one of the main assumptions for Pareto efficient allocation through market transactions is broken. Heterogeneity among farmers is given by their crop mix and this heterogeneity makes spot markets work. By simulating expected income in different scenarios he tests the hypotheses that the increasing presence of permanent crops creates demand rigidities that reduce the effectiveness of spot water markets. He finds that as crops become more concentrated in permanent crops the spot market water prices exhibit a higher average value and a greater dispersion. He also analyzes a farmer's participation in the spot market, i.e. if a farmer trades in the spot market and if so whether he is a buyer a seller or both. The main results from Zegarra are that the spot market for water solves differences in the marginal return of water among farmers, promoting the allocation of water from low value annual crops to high value permanent crops. He finds that in the context of severe drought, the water market starts to be less effective in allocating the resource, with greater water price dispersion. Unlike Hadjigeorgalis (2000), he concludes that water rights are heterogeneous with statistically significant differences in both the mean water per share and the standard deviation. He suggests that there are low transaction costs in the spot market. The main limitation of Zegarra's work is that it does not take into account farmers' risk aversion. This omission weakens one of his main results: that the spot market price at which the supply of water volumes starts to be greater than zero is $30 pesos. If farmers are risk averse his model overestimates that value because a risk-averse farmer will be willing to sell his seasonal amount of water – and obtain a sure income – at a price lesser than his expected marginal return of water use in irrigation.

From the above literature review, it is possible to infer some guidelines for economic water research. 1) There is a need to understand how well water markets perform and the forces operating within those markets from an empirical standpoint, especially in non developed countries. 2) There is a need to empirically estimate the impact of risk and uncertainty on water market trading and water decisions on the amount of water to be used in production. In the process it is advisable to infer reservation values for water rights from a model that recognizes that water rights are one of the farmer's main assets. 3) When a market for water rights and a spot market for water coexist there is a need to account for the link between the two markets in order to understand how spot prices affect water right prices over time. It also needs to be emphasized that the spot market resolves differences in the marginal return of water while the market for water rights resolves differences in farmers' reservation values for a water right. The latter are due to farmers' differences on risk of future loss on their stock of perennial crops from a water supply shortfall as well as heterogeneous risk preferences. 4) Finally, there is a need to move from institutional constraints that explain price differences in the market for water rights across sectors, to factors that explain differences in reservation values between farmers within the same Water Users Association.

The present dissertation contributes to the literature on water markets by providing new insights on several issues. It measures market activity and provides the first estimation of the size of the temporary water trades (spot market) in relation to the permanent markets (water right trades) in the most active Chilean water market. The analysis shows that the volume of water traded on the spot market is several times greater than on the permanent market. Contrary to what other researchers such as Hadjigeorgalis (2000) believe, it illustrates how the spot market is active not only during drought years but also in years with average water availability. The theoretical model that I develop infers reservation values for a water right from an asset pricing model that assumes heterogeneous risk preferences among farmers, incomplete asset markets and uncertainty about output, future water availability and future water prices. It also incorporates the interaction between the spot market and the market for water rights where the spot market mainly resolves differences in the marginal return to water and the market for water rights mainly resolves differences in the stochastic discount factor among farmers. The model explains differences in reservation values between farmers within the same Water Users Association as a function of farmers' risk preferences. The empirical application estimates an asset price model for water rights and input demands that allows testing for heterogeneous risk preferences among farmers. In addition, the effect of water on the mean and variance of yields is estimated using detailed farm data on output and input quantities for each crop. This is an improvement from previous studies, such as Hearne and Easter (1995 and 1997) and Hadjigeorgalis (2000), that rely on standard crop budgets to proxy the marginal revenue of water use in irrigation. The role of risk differences due to different types of crops or distance from the reservoirs is not included in this dissertation and it represents an important future extension of this work.

2.2 Asset pricing models

In this dissertation I model water right reservation values using a capital asset pricing model (CAPM). The empirical use of a CAPM requires choosing between the conventional consumption-based capital asset-pricing model (CCAPM) and a production-based capital asset-pricing model (PCAPM). Next I briefly review some of the literature related to these approaches and some of the literature related to the different issues embedded in the use of an asset pricing model to value water rights.

The CCAPM ties asset returns to marginal rates of substitution for consumption at different points in time and so must use a utility function defined on consumption over time. Alternatively, the PCAPM emphasizes the linkages between asset returns and investment and production variables. In it, production is used instead of consumption and so the production function is modeled instead of the utility function. A production model is proposed by Cochrane (1991 and 1996), where asset returns are tied to marginal rates of transformation (the rate at which the firm can transform goods from date t to date $t+1$, i.e. the rate of return on investment). Then he empirically tests the relationship between stock and investment returns in which the investment/capital ratio is a key variable. Arroyo (1996) explains asset returns as a function of capital productivity and the adjustment cost of capital proxied by the investment/capital ratio. Those who propose the use of PCAPM usually mention the mounting evidence against standard consumption-based models of asset returns. The empirical evidence indicates that returns on equity seem to be too high to be consistent with observed consumption behavior unless investors are extremely risk averse: a risk aversion often too large to be credible (Arroyo, 1996, Campbell et al., 1997). Cochrane (1996) and Campbell et al. (1977) point out that the poor empirical performance of CCAPM in explaining asset returns may be due, among other reasons, to measurement error in aggregate consumption and/or because growth of aggregate consumption is very smooth. Another source of criticism of the CCAPM arises from transactions costs, borrowing constraints and other market frictions that may invalidate the condition that discounted expected marginal utilities should be equilibrated across time, which is the heart of the consumption-based capital asset pricing model. In spite of the potential advantages of PCAPM over CCAPM, as I explain in Chapter 4, Section 4.2., I have chosen a consumption-based model because it emphasizes the role that preferences over consumption have in the determination of the reservation value for water rights, and as Moschini and Hennessy (2001) point out "…one should keep in mind that farmers ultimately likely care about their consumption, itself the result of an intertemporal decision". In that same line, Cochrane (2005, Chapter 9.1: 157) points out that "…good economists are unhappy about a utility function that has wealth in it. Few of us are like Disney's Uncle Scrooge, who got pure enjoyment out of a daily swim in the coins in his vault. Wealth is only valuable because it gives us access to more consumption. Utility functions should always be written over consumption. One of the few real rules in economics to keep our theories from being vacuous is that ad "hoc utility functions" over other objects like wealth should eventually be defended as arising from a more fundamental desire for consumption or leisure."

In this dissertation the CCAPM is derived from farmers' optimal decisions about investment in water rights in each season. The optimality conditions of the model are described by Euler Equations. Empirically, the Euler Equations are estimated together with the first order conditions for input quantities, using farm-level data.

A number of requirements for high quality empirical production research in agriculture, or what Just (2000) calls guiding principles, are addressed by the way in which farmers' decisions are modeled in this dissertation. First, it deals with the need to focus on long run considerations of investment and cost adjustments, and the need to consider the role of serial correlation of farm income and the intertemporal dependence of farmers' marginal utilities. I model intertemporal decisions on investment which emphasizes the long-run nature of farmers' decisions. Although I model farmers' decisions assuming non-serial correlation of farmer's consumption and a time-additively separable utility function over consumption, the model indirectly links consumption and utilities over different periods. This link arises because in this model the optimal consumption path depends on the stock of water rights which is related both to present and past investment in water rights (Bossaerts, 2002). Second, I identify risk preferences using an asset pricing model for water rights, which arises from farmers' investment decisions that reflect the greatest consequences of risk on farmers' decisions (Just, 2000, Just and Pope, 2003). Usually, the problem is that data on asset choices are very limited, thus the data on water right choices gathered for this dissertation provides an important piece of information to be able to build an asset pricing model for these rights and from there to analyze the effect of risk and risk preferences. Third, I use data at the individual farmer level and I incorporate farmers' heterogeneity, which helps to improve the empirical quality of the CCAPM (Campbell et al., 1997, Heaton and Lucas, 1996, Constantinides and Duffie, 1996). Studies that estimate Euler Equations or more general first-order conditions with data at individual level include, among others, Zeldes (1989), Langemeier and Patrick (1993) and Phimister (1995), all of them in the context of testing for liquidity constraints in the permanent income/life cycle model for consumption. Blundell et al. (1994) estimate an Euler Equation using micro data in order to estimate the parameters of household preferences that determine the allocation of goods within the period and over the life cycle. Most models of asset pricing assume homogeneous preferences among individuals or, equivalently, the existence of a representative agent. Allowing farmers to differ in their utility functions is a contribution to the empirical literature on asset pricing. The assumption of heterogeneous preferences is also a sufficient condition for the occurrence of asset trading among individuals. Niehaus, (2001) considers a simple economy, where only a riskless bond, shares of a stock and an option written on the stock are available in the financial market, and shows that differences in investors' preferences have an impact on asset prices and the amount of trading in the market. He finds that the amount of trading and the price of the option grow with increasing divergence in risk aversion, and the agents with a higher degree of risk aversion sell shares and options and buy the riskless bond. The agents with a lower degree of risk aversion take the opposite position: they buy shares and options and sell bonds. This is the same approach that I use in my dissertation, where each farmer has one asset – a water right – and the following options: to sell the water right and buy a riskless asset (or just put the money in bank at a riskless interest rate), to take more risk by selling the water right and buying water in the spot market for use in farming activities, or to keep the water right and use it in a risky farming activity. These are the relevant contributions of my dissertation to the literature on the analysis of farmers' behavior along time, subject to limitations associated with the extent of the data which is at the farmer level for two agricultural seasons**.**

2.3 Identifying risk preferences

The inclusion of heterogeneous risk preferences in the CCAPM requires attention to the literature on identifying risk preferences for agricultural producers. A comprehensive review of the large literature on this issue exceeds the scope of this dissertation. Thus I limit discussion to the main issues identified in the review by Moschini and Hennessy (2001). I then review some of the studies that specify risk aversion as a function of socioeconomic characteristics such as age, education level and family size.

Moschini and Hennessy (2001) show how early empirical studies of agricultural decision making under risk elicited risk preferences from choices between hypothetical lotteries. Later, using an econometric approach, studies imputed a measure of risk aversion from the divergence between actual farmers' production decisions and optimal decisions under risk neutrality. Due to the limitations of inferring risk from observed production decisions and because hypothetical payout surveys can give unstable results, Binswanger (1980) made real payments to peasants farmers in India to elicit risk preferences. Antle (1987) described the optimality conditions of expected utility maximizing choices in terms of a given individual's absolute risk aversion and downside risk aversion, and as an econometric procedure he used the generalized method of moments (GMM). Later on, Antle (1989) developed a method to estimate risk preference structures separately from the production technology. Myers (1989) assumed constant relative risk aversion (CRRA) and joint lognormality of the distributions of output prices and producer consumption, and developed a reduced-form rational expectations approach to test for the aggregate level of relative risk aversion for US producers who store crops. Exploiting technical attributes of CRRA and of constant partial relative risk aversion (CPRRA), Pope (1988) developed implications for optimal choices by individuals expressing such preferences. Several studies have followed Pope's approach or variations of it. Another characteristic of research that attempts to determine farmers' risk preference structures is that most of them are based on aggregate data (Just, 2000). Exceptions to this are the already mentioned Binswanger's lottery experiment and the Bar-Shira, Just and Zilberman (1997) study.

For this dissertation it is relevant to make a brief review of the literature that identifies risk preferences by assuming that farmer's risk aversion is a function of socioeconomic characteristics such as age, education level and family size, among others. This is necessary because in my dissertation farmers' risk preference heterogeneity is tested by estimating risk aversion for each farmer as a function of his socioeconomic characteristics. Moscardi and Janvry (1977) analyze the relationship between risk aversion and a number of socioeconomic variables that characterize Mexican peasant households, their access to income-generating opportunities, and their relation to public institutions. Binswanger (1980) analyzes the effect of wealth, education level, more progressive farmers, and off-farm salaries on farmer's risk aversion. Zeldes (1989) allows a household's utility function to be influenced linearly by tastes that may differ across families and shift across time. Tastes differ due to observable (for the econometrician) and unobservable factors. The observable factors, which vary across families and time, are family size, age and age squared. This linear specification for family utility function is included in the Euler Equation which is estimated with data at the family-level. Blundell et al. (1994), who also estimate an Euler Equation, allow the parameters that describe individual preferences over consumption to be a linear function of variables such as the number and age of children and labor market status: whether the head of the house and/or the wife are in paid employments, and the level of consumption itself. Dubois (2001) also parameterizes agent preferences by specifying a linear function for the absolute risk aversion coefficient as a function of observable individual characteristics (age, household size, number of children, etc.).

At the end of this section it is worthwhile to mention that the approach followed in this dissertation, where water rights are assets and farmers' optimal decisions about water rights are treated as an investment problem that affect present and future income and consumption, is closely related to the so called literature on Agriculture Finance. Barry and Robinson (2001) offer a good review of the main issues in Agriculture Finance. One of those issues is intertemporal farm-level analysis in the context of life cycle planning and performance models of farm business, where production and consumption are linked. Intertemporal analysis is expressed as the maximization of the utility of multiperiod consumption, constrained by the present value of wealth and the available investment alternatives, including both productive investments and lending and borrowing in a perfect or imperfect financial market. A second issue is the effect of farmers' risk attitudes on their portfolio decisions. In this dissertation those two elements: intertemporal farm-level analysis where production and consumption are linked and the effect of farmers' risk attitudes on their decisions are carefully considered.

Up to now, research on Agriculture Finance has focused on real estate as the dominant asset for farmers. But now, due to the increasing interest on establishing transferable water rights not married to land rights, research on Agriculture Finance should also consider water rights as a primary asset in dry areas. Due to the special characteristics of water resources, this new challenge offers a significant opportunity for future research. This dissertation is an effort to contribute toward this goal.

Chapter 3: The Limarí River Basin's Water Market

The coexistence of a market for water rights and a spot market for water volumes is analyzed for four water user associations in the Limarí Basin in Chile's IVth Region. The existence of a legal framework that permits the transfer of water rights independent of land rights has contributed to the development of a very active water market with a variety of exchange mechanisms over the last 20 years. The Limarí River basin is a semi-arid zone with approximately 65,000 hectares of irrigated land used mainly in traditional crops such as maize, beans or potatoes, horticultural production (artichokes, peppers and tomatoes), grains, grasses and other valuable perennial crops such as avocados, export grapes and grapes used for *pisco*[7]. The farmer base is diverse and consists of orchard owners, medium-sized farms established by past land reform programs, and a few large multinational fruit exporters. Each irrigation district possesses distinct climatic characteristics that favor certain types of crops. The hydrologic system of the Limarí basin is characterized as being primarily niveous, that is to say that it is fed from the snow-covered Andes Mountains. The basin has an average annual precipitation of 140 ml. One essential characteristic of this basin is the existence of three interconnected dams: Cogotí, Recoleta, and the Paloma Dams. Together, these dams form the subbasin called the Paloma System, which has a storage capacity of one billion cubic meters and possesses a flexible physical system for the distribution of water based on floodgates and a network of siphons and canals that allow interconnection to different irrigation districts within this subbasin. The current Paloma System has six Water User

---

[7] Grapes used in making local liquor.

Associations (WUAs), four of which are analyzed in this study: i) *Junta de Vigilancia del Río Limarí* and its tributaries (JVRL); ii) *Asociación de Canalistas del Canal Camarico* (ACCC); iii) *Asociación de Canalistas del Embalse Recoleta* (ACER); and iv) *Asociación de Canalistas del Embalse Cogotí* (ACEC).

The data used in this section comes from a variety of sources. The series of prices[8] and transferred water rights for the period 1981-1992 were reported by Zegarra (2002) and, for the period 1992-2000, by Cristi et al. (2002) and Vicuña (2000). These authors obtained this information through *Conservador de Bienes Raíces* of Ovalle and the records of the WUAs. The series of prices and volumes of water exchanged in the spot market were constructed using the records of the WUAs, information obtained from the *Direccion de Riego*, and a farmer survey. This survey was applied to a sample of farmers in the Limarí Basin on three occasions, and information was collected for each of the five growing seasons between 1995 and 2000[9]. The surveyed sample was designed by Zegarra (2002)[10] who conducted the first round survey. I conducted the second and third rounds (a detailed description of the data is included in Chapter 5).

---

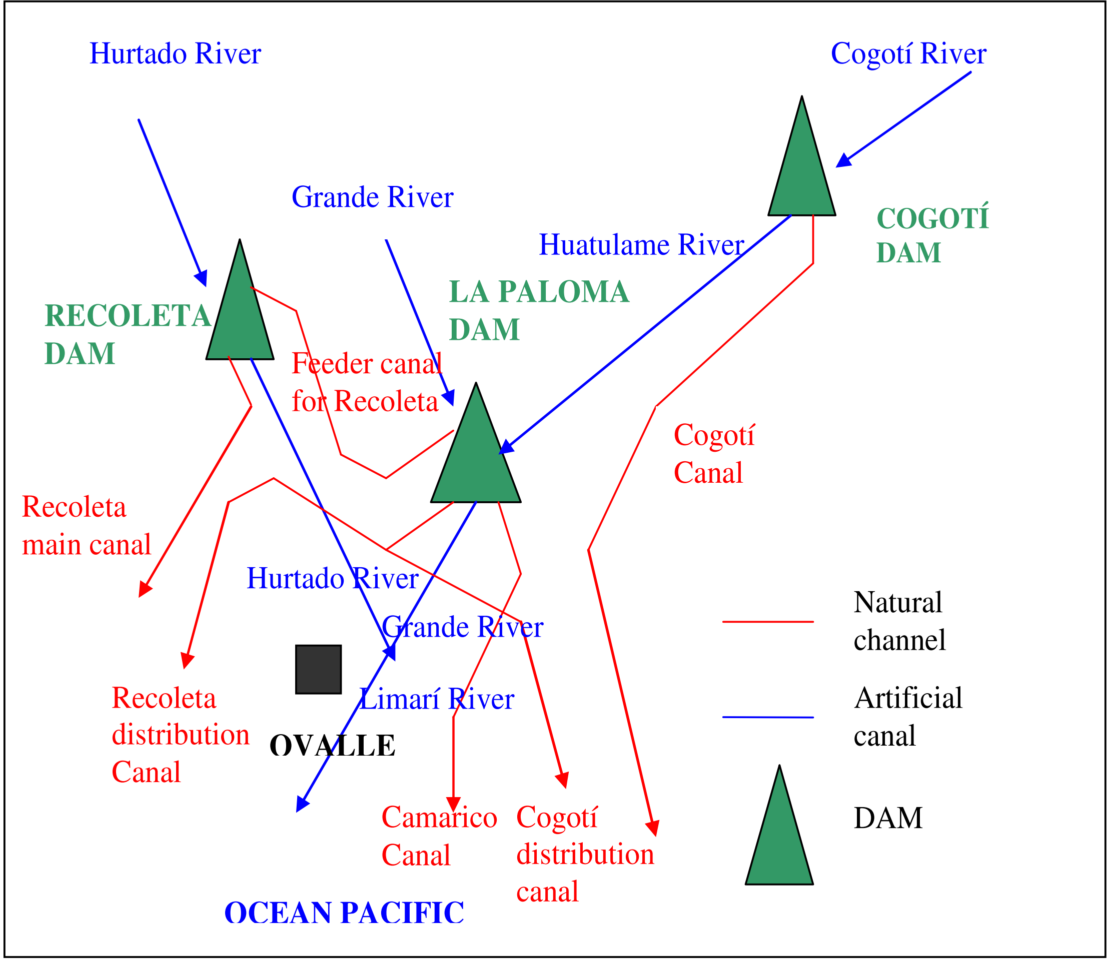
[8] Unless otherwise noted, all prices are expressed in 1990 Chilean *pesos*. The average peso-dollar exchange rate in 1990 was $304.9 pesos to the American dollar.

[9] This survey was applied to 195 farmers of the region and contains production data and figures on land and water use, among other information.

[10] He did not develop a list of farmers to interview based on a random sample due to the expense of finding each sampled individual; instead, he simulated random sampling for farmers who were present at their farm when he conducted the survey. He began at some point inside the irrigated area (stratum), interviewing farmers using a systematic round skipping for close neighbors. This results in a sample, which is geographically representative for each irrigation organization. The main limitation of this sampling procedure is that farmers who were not present at the moment of the survey had zero probability of being selected. The procedure also excludes farmers who, at the moment of the survey, had abandoned production.

The following diagram illustrates the Limarí Basin and the Paloma System.

Figure 3.1: Limarí Basin and the Paloma System



3.1 Mechanism for the Allocation of Waters in the Paloma System

The allocation process determines the amount of water to be received by each user. Conceptually, allocation is a distinct task from that of distribution. The latter is defined as delivering water in accordance with allocations (Bruns and Meinzen, 2000). Legally, the Paloma system divides the Limarí basin into two districts: the irrigation district that is located above the dams, and that below them, known as the Paloma System. The Paloma System is the subject of this study. In this system, water rights are defined in terms of cubic meters of stored water, and water is distributed simultaneously to the farmers' plots directly from the dams through its associated canal network except during severe droughts when a rotating system of distribution (also known as shifts) is implemented.

In the Paloma System, the responsibility of water allocation lies with the *Junta de Vigilancia del Sistema Paloma*, which reports to the *Dirección de Riego* (Irrigation Administration). Every year, the board adds up the amount of stored water in the system and establishes a quantity of water for each irrigated area (and therefore for each WUA) based on holder's historical shares. The total volume of water to be allocated in the system depends on existing levels. When the volume stored in the system is less than 500 million m^3, no more than half the stored water volume may be assigned. When the system contains more than 500 million m^3 but less than 1 billion m^3, the maximum global assignment is 320 million m^3. Lastly, when the volume exceeds 1 billion m^3, free use is granted to all WUAs.

Once water has been allocated among the WUAs, they assign the water volume to their members. To do this, every season each WUA determines the amount of water accorded to water rights. Then, by multiplying this amount by the number of water rights owned by a farmer, it determines each farmer's endowment of water (expressed in cubic meters). During most seasons, the amount of water accorded to water rights is determined by dividing the total allocated water to the WUA by the total water rights that exist within it. Nevertheless, the expectation of water availability for the next season can motivate the adoption of different criteria. This distribution of water by the WUAs is at a farm or user level, and the WUA is charged with the task of billing its associates for water use and administrative expenses.

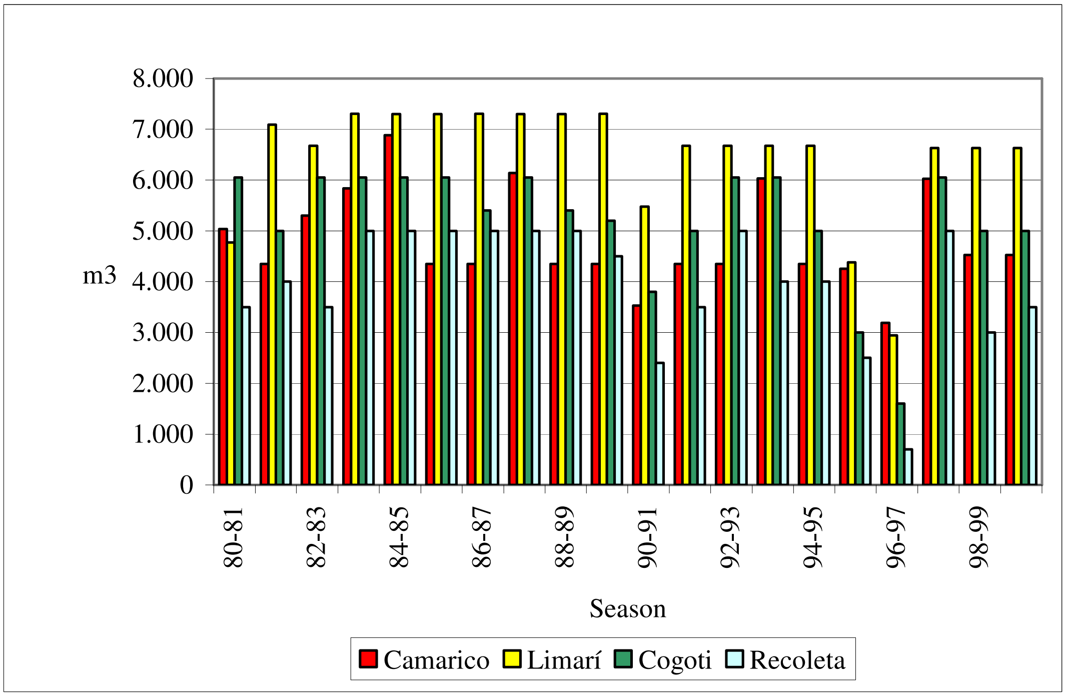
Table 3.1 and Figure 3.2 illustrate the variation in water accorded to water rights for the associations under study between 1980 and 2000.

Table 3.1: Average water accorded to water rights between 1980 and 2000

WUA	AVERAGE (m^3)	STANDARD DEVIATION (m3)
ACCC	4,800	941
ACEC	5,193	1,182
ACER	3,955	1,168
JVRL	6,450	1,172

Source: Water User Associations

Figure 3.2: Water accorded to water rights between 1980 and 2000



Source: Water user associations[11]

---

[11] In those seasons of free endowment, the highest amount of water accorded to water rights for the period was recorded as that for those seasons.

3.2 Market Activity

The Limarí Basin beneath the dams is characterized as having an active water market in which a spot market and a permanent transaction market coexist. In the former, volumes of water are exchanged. In the latter, the purchase and sale of water rights take place over time. After the annual allocation of water among water users associations based on historical criteria and the posterior distribution of it among farmers according to their number of water rights, the spot market reallocates this resource to equalize differences in the marginal return to water among farmers[12]. This process is facilitated by the existence of a significant number of farmers with non-perennial crops that can, with relative ease, modify their water consumption by varying the percentage of land used or the type of crops according to their water use intensity. Moreover, water volume transactions are relatively easy due to the existence of significant storage capacity. The use of flexible floodgates and the proper operation of the water users associations also facilitate short term transactions. Together, these factors support the existence of an active spot market. This dissertation examines reasons for simultaneous water rights market and spot market activity.

---

[12] Differences in the marginal return to water are measured by Hearne and Easter (1995). They estimated an average value for the marginal return to water rights in the case of table grapes of US$ 856.7 and US$ 865.7 for the case of grapes used in *pisco*. This compares to US$ 33.5 for potatoes and of US$317.5 for peppers, two of the main non-perennial crops of the basin.

3.2.1 Spot Market

Because the allocation of water in each season among the WUAs in the Paloma System does not necessarily coincide with the water demands of each WUA, significant volumes of water are transferred among associations. As such, the volumes of transfers received[13] by the four associations studied reached 24,189,000 m^3 in the 99/00 growing season representing 7% of the total amount of water assigned to these associations. This number reached 16% for the 95/96 growing season, a year of drought. As I analyze each association individually, I observe that, except for ACER, which owns a volume of entries very similar to its actual outflows or debits, the rest are net claimants of water (entries greater than debits) or net sellers (debits greater than entries). ACCC and ACEC are examples of net claimants, and JVRL stands out as an example of a net supplier. Thus, in the 99/00 growing season, the irrigators of the ACCC and the ACEC obtained additional water rights from another district equivalent to 34% and 7% of their water consumption, respectively. Such figures reached 35% and 12%, respectively, in the 95/96 season. On the other hand, during the 99/00 season the JVRL transferred 20% of its water assignment to other associations while in the 95/96 season, transfers from that same association reached 40%.

That some associations are net water claimants or suppliers is explained by differences in the marginal return to water and its availability. The fact that the

---

[13] I can distinguish two types of water transfers: inter-association transfers and intra-association transfers. The first group includes those transfers among WUAs, which can be both entrances (when water is received from another association) and exits (when water is transferred from one association to another). The second group includes those transfers among irrigators within the same association.

ACCC and the ACEC are net claimants is explained by the presence of highly profitable perennial crops such as grapes, and a significant share of irrigators who belong to the ACEC develop crops on the land located above the Paloma Dam and below the Cogotí Dam with excellent weather conditions and, thus, higher marginal returns to water. In the case of JVRL, the practice of river water recovery by farmers that increases their supply of water beyond that accorded to their water rights, partly explains its condition as a net water seller.

Inside each association, irrigators produce different crops resulting in varying marginal returns. This generates a significant level of internal water transfers between those farmers with lower marginal returns to water and those with higher marginal returns. During the 99/00 growing season, the total volume of internal transfers for the WUAs under study reached 26,633,000 m^3, which represents 8% of the total amount of water assigned to these associations during this season. During the period 1995-2000, the highest level of internal transfers occurred inside the ACCC and ACEC associations accounting for 24% and 13%, respectively, of the total amount of water assigned to each.

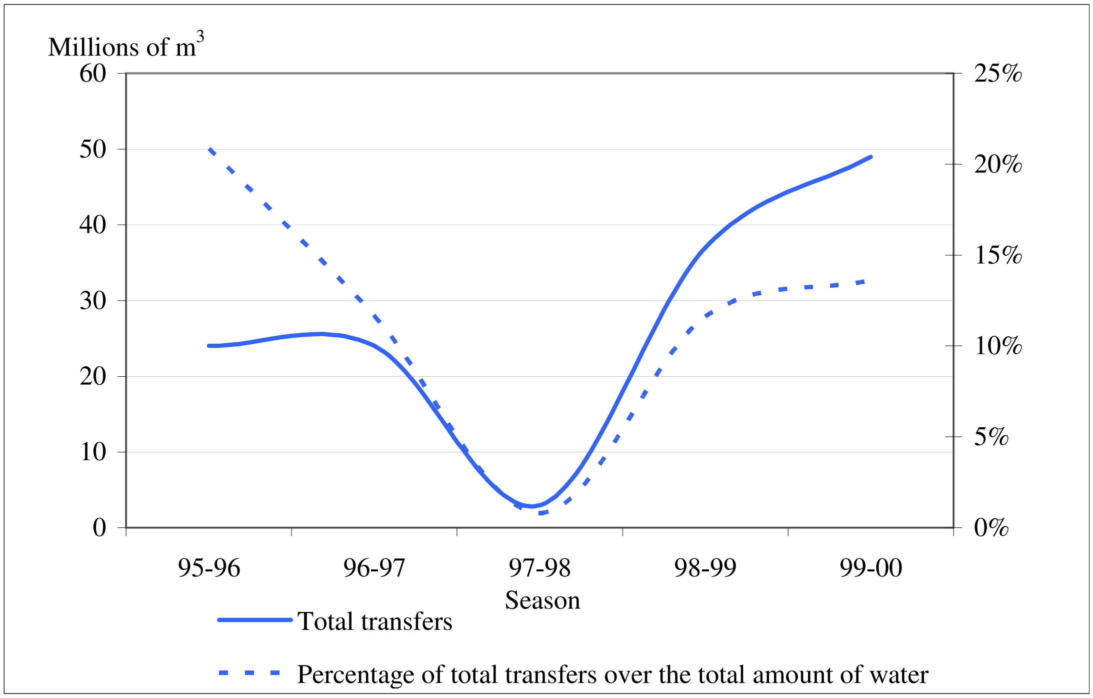
As the focus of this research is the water market, it is necessary to be precise about the definition of water transfer in the spot market. First, it is necessary to distinguish between the volumes of water transferred in the spot market from those outside the spot market. In the former, transactions may occur between farmers in different WUAs associations or among farmers within an association. Transfers that the associations register as entries and debits have two different sources. The first consists of transfers of water volumes made among different farmers and is counted as water transferred in the spot market. The second are the so-called intra-farmer water transfers. This is the case for farmers with two plots of land that are irrigated with water from different WUAs, and the transfer reallocates water from one plot to another. This is registered as a water transfer by the WUAs, but it occurs outside the market, and is not a spot market activity. Transfers of water volumes among farmers in different WUAs and transfers of water volumes among farmers within a same WUA are considered spot market activities.

Unfortunately, it is not possible from the analysis of the WUAs records to determine the exact magnitude of transfers between one farmer who has different plots of land. Nevertheless, based on their experience, the executive directors of the WUAs estimate that approximately 75% of the total transfers that imply an entry or debit from one water association to another are made among different farmers, and should be considered spot market transfers. For those transfers between an individual WUA, records are clear on the type of transfer that occurs. Figure 3.3 illustrates spot market activity obtained by adding together the total amount of transfers among farmers within each WUA with 75% of the transfers that occur between different WUAs[14].

---

[14] The evolution of spot market activity shows that the volume of water exchanged reaches a low in the 97/98 growing season, an occurrence that is explained by a drought during the first half of the season, and by heavy rains during winter that led the WUAs to declare free river. This is to say, during that same season, there was a lack of supply at the beginning of the season and a surplus later decreasing market activity for the season.

Figure 3.3: Transfers of water in the spot market



Source: *Direccion de Riego*, the Paloma System Administration.

3.2.2 Permanent Market

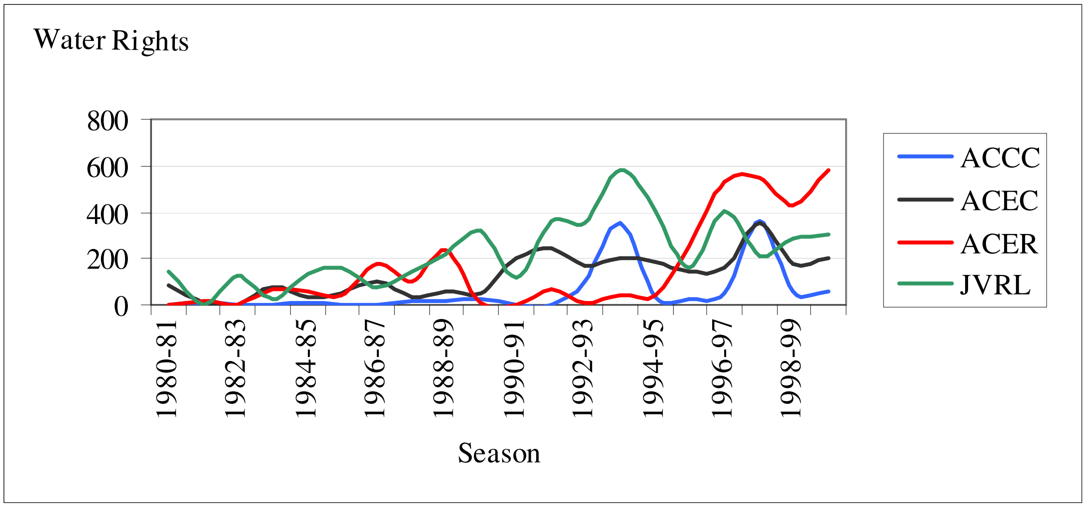
The spot market for water coexists with a separate market for water rights (henceforth referred to as the permanent market). Beginning from an initial assignment of water rights by the government, these rights are reallocated to farmers through the market. When analyzing the activity of this market, I observe that the total percentage of reallocated water rights, independent of land transactions during the period 1980-2000, varies from 20% to 50% by WUA. Since the approval of the water law in 1981, and until 2000, more than 27% of the total water rights have been transferred through the permanent transactions market[15] .

---

[15] Adding together the water rights of the different associations is imprecise because the volumetric specification of these water rights is different for each association.

The analysis of the behavior of the permanent transactions market over time shows how the activity in this market has grown. Figure 3.4 shows how the earliest transactions had lower volumes of trade than later periods reflecting a market that matured in its first decade.

Figure 3.4: Number of water rights transferred by each association during the period 1980-2000.



Comparing the size of the spot market with the permanent market is difficult because the former trades in volumes of water during a specific growing season while a water right transaction implies the transfer of variable volumes of water over time. In spite of these restrictions, I have compared the relative size of both markets through the following steps: i) expressing the trade in rights in volumetric terms for each season using the average amount of water accorded to water rights (see Table 3.1); ii) assuming that the sale (purchase) of a water right in any season is equivalent to the sale (purchase) of the amount of water accorded to that right in the spot market in all following seasons[16]; iii) assuming that only a portion of the transfers among WUAs are conducted through the spot market due to the accounting conventions discussed above in Section 3.2.1. These conventions require that we consider the following two scenarios. In one, only transfers among different farmers within a WUA are counted as spot market transactions (scenario 1); and in the other transfers among different farmers within a WUA plus 75% of the transfers among WUAs are counted as spot market transactions (scenario 2)[17]. A possible drawback of this method is that it could lead to an over estimation of the relative size of the permanent market because rights may be transferred several times in the period under study resulting in the volume of water associated with those rights being double counted. However, the history of water right transfers independent of land transactions shows that few farmers who buy water rights sell them later. The exceptions are a few water right holders who do not own land, but buy water rights to sell them when prices rise. The detailed operation of the market indicates that overestimation of the permanent market is not significant. As a result, I conclude that

---

[16] One possible scenario is as follows:

Association XX	95-96	96-97	97-98	98-99	99-00
Exchanged water rights (in cubic meters)	100	200	100	50	100
Total cubic meters	**100**	**300**	**400**	**450**	**550**

[17] As I already mentioned, 75% of the total transfers that involve a change of water association are assumed to be transfers among different farmers; therefore, they are considered to spot market transactions. This assumption is based on interviews of the executive directors of the four water user associations under study. Moreover, the content in this chapter was presented in the in the city of Ovalle (Limarí Valley) in a seminar with more than 20 attendees that included the executive directors and the water engineers of the WUAs. During the presentation, I emphasized the assumption that few farmers that buy water rights sell them later independent of land sales, and that approximately 75% of the transfers among WUAs are done through the spot market. However, many non-attendees disagreed with those assumptions.

for the period 1995-2000, the water transferred in the spot market was 3.8 times greater than transfers in the permanent market under scenario 1 and nearly 7 times that in scenario 2.

3.3 Price Behavior in the Water Market

To verify if a market behaves in an efficient manner, I test to determine whether prices reflect the relative scarcity of water. In the following sections, I will show that water prices in the spot market reflect its relative seasonal scarcity. In regards to the permanent market, the systematic rise in the real prices of water rights reflects a sustained expansion of the demand for water over time.

3.3.1 Spot Market

Evidence exists that the behavior of prices in the spot market reflects the relative scarcity of the resource. Analysis of the period 1995-2000 illustrates that the maximum real price per cubic meter of water is reached in all the WUAs in the 96/97 growing season, which suffered a drought. When comparing the real prices between the 96/97 season and a normal season such as 99/00, prices during the drought season are between 3 and 12 times greater than those of a normal season, varying by association. The capacity of the spot market to reflect the relative scarcity of water can also be observed through the correlation coefficient of water availability and the average real price per cubic meter, which is –0.921 for the five growing seasons between 1995 and 2000[18] .

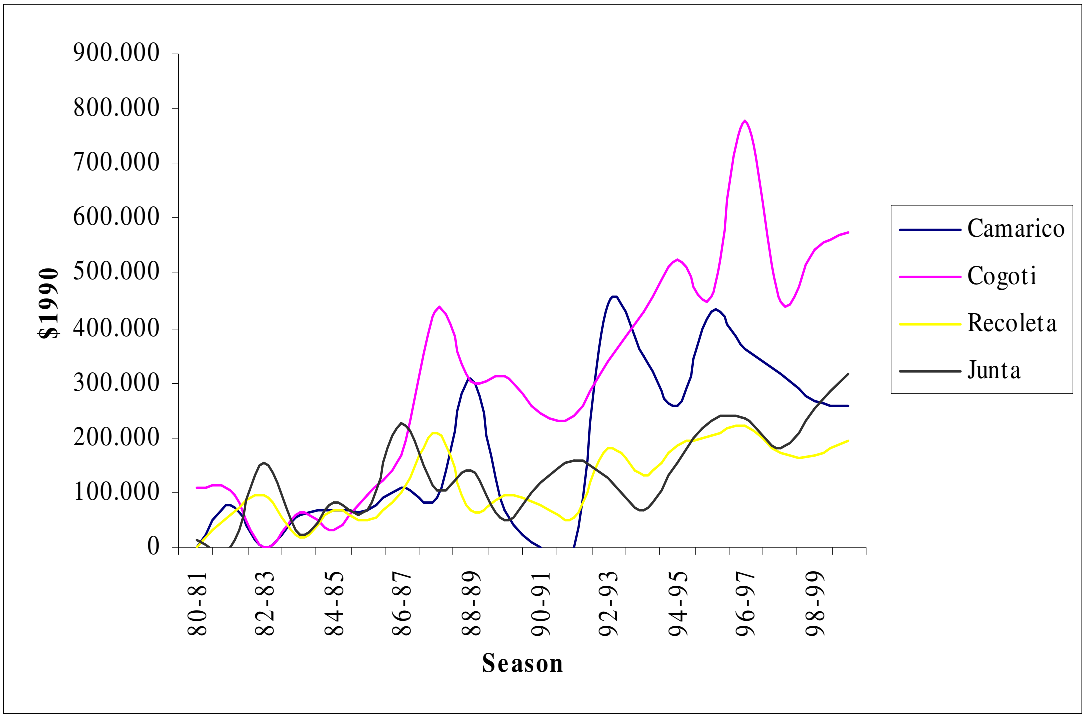
---

[18] This coefficient correlates the average real price of water in the spot market with the sum of the water accorded to water rights in the WUAs between 1995 and 2000. The price in the spot market is estimated as a weighted average of the prices as reported by surveyed farmers that exchanged water. Overall, 123 observations of temporal transfers in five growing seasons were used.

3.3.2 Permanent Market

The increasing scarcity of water due to a sustained expansion of the demand over time has produced a systematic rise in the real prices of water rights. Thus, during the period 1986-2000, the price of water rights experienced real increases ranging from 41% to 240% depending upon the association. Figure 3.5 illustrates the evolution of these prices over time.

Figure 3.5: Real average prices of water rights in each WUA



Heterogeneity in the prices of water rights among associations tends to diminish over time with exception of ACEC. The higher water rights prices in some associations are largely explained by differences in the alternative mechanisms to purchase water rights. More specifically, I can distinguish between two markets: The first is restricted to the area below the Cogotí Dam and above the Paloma Dam, which is characterized by limited suppliers of water rights due to the relatively small number of farmers. In addition, several farmers in this area grow export grapes and have a higher marginal return on water than farmers located in other zones in the basin. The second one includes the area below the Paloma Dam, and is characterized by the existence of a relatively large number of irrigators. Increasing the number of farmers increases the dispersion of reservation values improving the probability of water right sales. Figures 3.6 and 3.7 show the reservation values of a permanent right to one cubic meter of water as reported by farmers from the ACEC and ACER WUAs. As expected, water right reservation values are higher in the former market.

Figure 3.6: Reservation value for the right to one cubic meter of water in ACEC

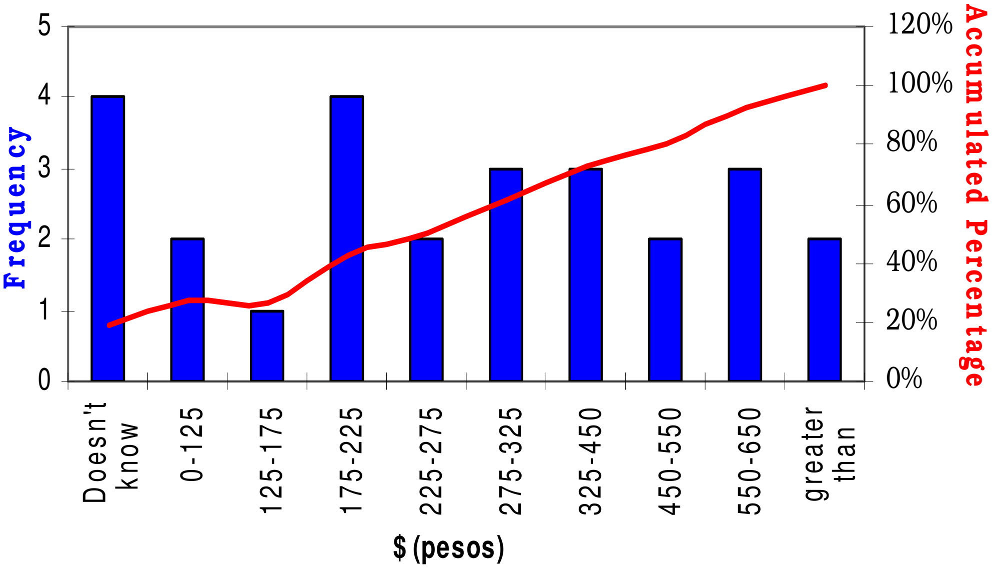
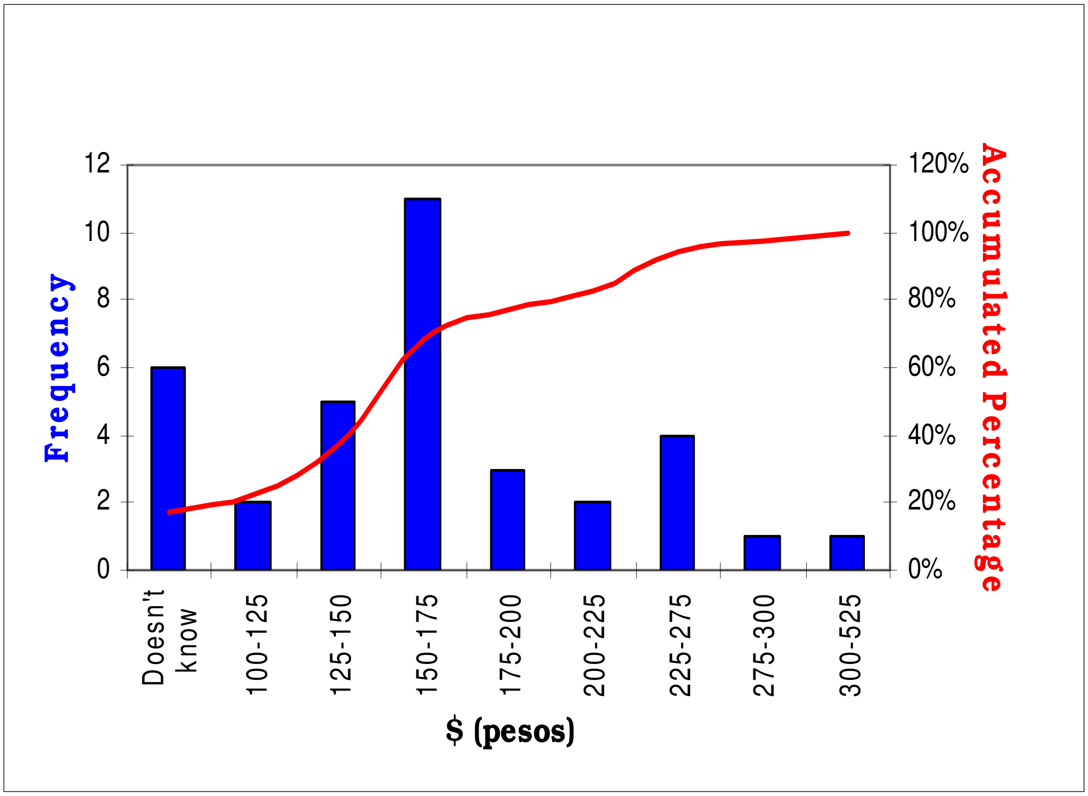


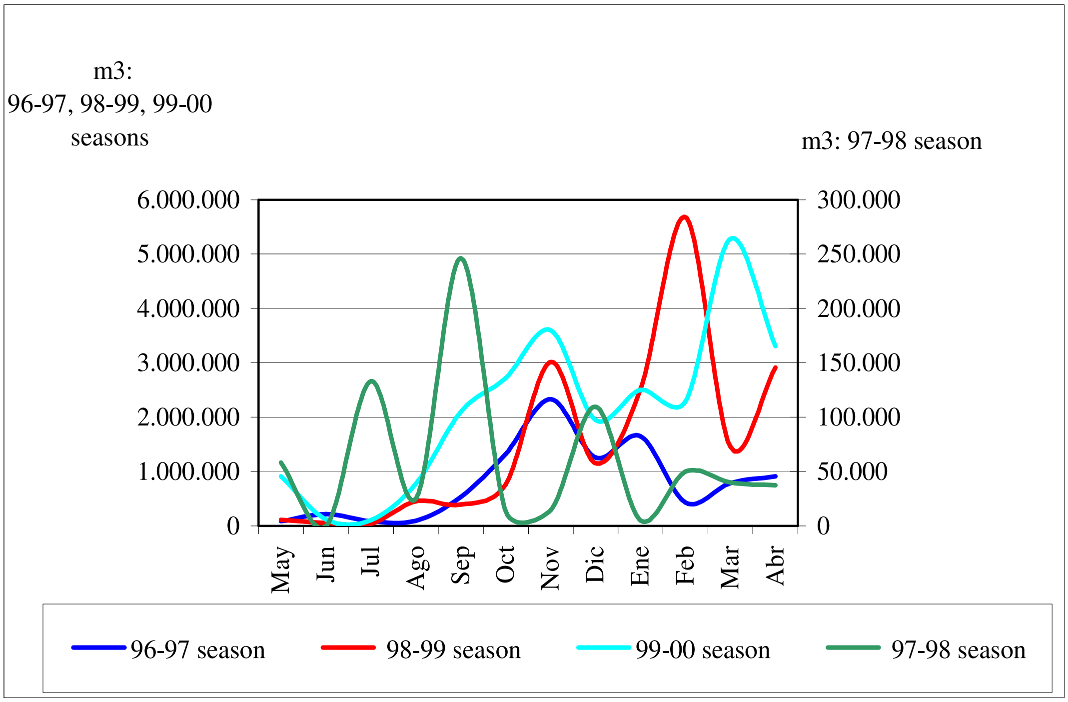
Figure 3.7: Reservation value for the right to one cubic meter of water in ACER



3.4 Market Expectations and Access to Information

By observing water transactions in the spot market in each season, it is possible to see that in most seasons the market does not become active until after the passage of winter when the volume of rainfall is known and the need for water increases due to the hot, dry summer weather. This seasonality provides some support to the statement that the farmers have homogeneous information with respect to the future; therefore, no additional benefits are associated with advance purchases and sales of water volumes. The exception to this behavior is observed in the 97/98 growing season, which was preceded by a severe drought. The experience of three previous years of drought and the relatively high prices in the spot market at the beginning of that season could have motivated advance water purchases by farmers who expected water prices to increase and advance water sales from sellers who expected water prices to decrease. This seasonal behavior of the spot water market and the advance sales of water in the 97/98 growing season are illustrated in Figure 3.8 for ACEC.

Figure 3.8: Transfers of water through the spot market



With respect to rain expectations and the expected amount of water accorded to water rights, I found agreement among surveyed farmers. When asked during the third round survey about rain expectations for the following season, 70% responded that it would be a normal year. In addition, farmers were asked in that same survey to estimate the amount of water accorded to water rights in the following year as a share of what they currently receive. Almost 50% of surveyed farmers estimated that the water accorded to their water rights in the following period would be between 90% and 120% of their current level. The majority of the remaining farmers (47%) admit that they do not have an estimate of the future level of water accorded to water rights.

With regard to information access, I observe that the majority of the farmers are well informed about water availability in the dams. When asked about the level of the dams, 85% of them correctly answered that the dam was half-full or full[19].

3.5 Summary

The current water law in Chile has been flexible enough to allow the Paloma System, in the Limarí Basin, to develop not only an active market for water rights, but also an active market for volumes of water, i.e. a spot market. The volume of water exchanged in this market indicates that this mechanism of water allocation is highly important. In the permanent market, more than 27% of existing water rights were exchanged independently of land transfers between 1981 and 2000.

A flexible water market such as the spot market in the Paloma System allows for the reallocation of water to those areas in which the water acquires its greatest value. This market -contrary to what other researches believe- is active not only in drought years but also in years with average water availability. Thus, in the 99/00 season characterized by the average water availability, approximately 14% of the water allocated to the four main WUAs of the basin was reallocated through exchange in the spot market. During the severe drought of the 95/96 season that figure reached a value of 21%.

The Water User Associations are a primary factor in determining the correct functioning of the market. Thanks to good organization and efficient management of their records of water allocation, it has been possible to develop an active spot market. Together with the Water Use Associations, it is also clear that the existence

---

[19] At the time of the third round survey the amount of stored water stood at 70% of its total capacity.

of a safe supply source, such as the three dams that form the Paloma System, is a necessary condition for the existence of a spot market.

The correlation between the growth in the relative scarcity of water over time and the prices of water rights, as well the correlation between the scarcity of water per season and the price of water in the spot market, indicates that water markets operate correctly. At the same time, for the market for water rights there is some heterogeneity in prices that tends to diminish over time with exception of ACEC. This heterogeneity is also captured when farmers are asked about their reservation price for a water right. As expected, water right reservation values are higher for the farmers that belong to ACEC.

Finally, survey questions regarding access to relevant information and water market expectations supports the hypothesis that farmers' access to information is homogeneous and farmers form similar expectations with regard to future water prices and the availability of water supplies. From this, I assume in the coming chapters that farmers have homogeneous expectations with respect to the main stochastic variables in the water markets.

Chapter 4: Theoretical Model

In this chapter I pursue an explanation for water rights trading, which arises whenever there are differences in the reservation value of the water right asset. I use this reservation value as a proxy for private valuation, and hypothesize that difference in reservation values arise from heterogeneity in farmers' preferences. To establish the importance of heterogeneity in farmer preferences, I first consider a simple model where investors are risk neutral. Under this assumption, the price of a water right is equal to the expected discount sum over time of the spot market values of the amount of water accorded to that water right.

4.1 A Simple Model

Let us define R_t as the return on a water right in period *t*. It is a function of the change in the water right price between *t+1* and *t*, where θ_t denotes the water right price in period *t*, the spot market price per cubic meter, s_t, and the total water (in cubic meters) accorded to each water right in season *t*, denoted by v_t. I assume that θ, s and v are stochastic variables that are revealed during each growing season. Thus, at *t* the values of θ_t, s_t and v_t are known. Hence, the return on a water right is what can be earned by buying a water right in period *t*, selling the assigned volume of water on the spot market in period *t+1*, and then re-selling the water right in period *t+1*:

$$R_{t+1} = \frac{\theta_{t+1} - \theta_t + s_{t+1} v_{t+1}}{\theta_t}. \tag{4.1.1}$$

In order to simplify the analysis I can assume that the expected water right return is equal to a constant, R, and:

$$E_t\left[R_{t+l}\right] = R \text{, for } l = 0,1,2,.. \tag{4.1.2}$$

where E_t stands for the expectation operator conditional on the information set available at time t, which is assumed to be known by all farmers.

The assumption that the expected return remains constant is sometimes known as the Martingale Model of stock prices. Although that assumption of constant stock returns contradicts the empirical evidence of returns behavior over time, it is analytically convenient for the goal of this section, which is to show the importance of heterogeneity in farmer preferences in the reservation values of water rights. Developing the model with time-varying expected returns will lead to the same conclusion, but the analysis is cumbersome because the relationship between prices and returns becomes nonlinear (Campbell, et al., 1997, Chapter 7.1).

By taking expectations in (4.1.1) over θ_{t+1} and $s_{t+1}v_{t+1}$, imposing (4.1.2), and rearranging terms, I obtain an equation that links the current water right price with the next period's expected water right price and the water price in the spot market:

$$\theta_t = E_t\left[\frac{\theta_{t+1} + s_{t+1}v_{t+1}}{1+R}\right] \tag{4.1.3}$$

Recursively iterating forward the future prices of water rights and using the Law of Iterated Expectations, the following equation is obtained:

$$\theta_t = E_t\left[\sum_{l=1}^{L}\left(\frac{1}{1+R}\right)^{l} s_{t+l}v_{t+l}\right] + E_t\left[\left(\frac{1}{1+R}\right)^{L}\theta_{t+L}\right] \tag{4.1.4}$$

Ruling out the possibility of a rational bubble in the market, i.e. the water right price θ_t is not expected to grow forever at a rate R or faster, the second term on the right-hand side of this equation shrinks to zero as the time horizon, L, increases. As such, equation (4.1.4) may be written as:

$$\theta_t = E_t\left[\sum_{l=1}^{\infty}\left(\frac{1}{1+R}\right)^l s_{t+l}v_{t+l}\right] \tag{4.1.5}$$

If all farmers have identical expectations about water right returns, R, water prices in the spot market, s_{t+l}, and water quantities accorded to each water right, v_{t+l}, then they would have identical private water right valuations (or reservation values), and no trading would take place.

To explain why water rights are exchanged in the Limarí Valley water market, some type of heterogeneity among farmers must be assumed. As I mentioned in Chapter 3, farmers' market expectations and access to information indicate that farmers have homogeneous information regarding the future of water prices and water quantities accorded to water rights and, thus, homogeneous expectations. The analysis of rain expectations and the expected amount of water accorded to water rights for the coming season revealed a high coincidence in answers among surveyed farmers who were also well informed about water availability in the dams. Consequently, I focus on other types of heterogeneity among farmers to explain differences in reservation values for a water right. One source for farmer heterogeneity arises from differences in the marginal productivity of water due to differences in soil quality, equipment (for example tractor use), and irrigation systems, among others. These differences in marginal productivity are resolved in the spot market for water, where farmers with higher marginal productivity will buy water from farmers with lower marginal productivity until the differences vanish in each agricultural season. Hadjigeorgalis, (2000) provides a theoretical and empirical proof for this statement as well as empirical evidence of a unique price of water in the spot market for the whole area below dams in the Limarí Valley. Accordingly, differences in marginal productivity are not sufficient to explain trading in the market for water rights.

Another potential source of heterogeneity is a variety of idiosyncratic random shocks that affect farmers' income. Constantinides (1996) and Heaton and Lucas (1996), among others, consider the effect of idiosyncratic random shocks on asset prices. Farmers in the Limarí Valley face independent shocks to their incomes as revealed by the second survey when some farmers reported important frost damage to their crops in just one night. Pest infestations are another potential source of shock, although the farmers under study use pesticides. If farmers face incomplete asset markets these shocks affect consumption and hence the reservation values for a water right if farmers are not risk neutral. In practice, that is the case because most farmers do not insure against transitory idiosyncratic shocks. The spot market for water helps farmers to smooth household consumption, but does not totally preclude them from the need to modify consumption due to idiosyncratic shocks.

Finally, heterogeneity of farmers' preferences is a sufficient condition for differences in the reservation value of water rights among farmers. In the next section, I develop a model of a farmer's decision for optimal consumption and investment in water rights and use it to illustrate the role of incomplete asset markets[20] and farmers' preferences upon reservation values for water rights

4.2 The Farmer's Decision Rule under Water and Output Uncertainty

The goal of this section is to analyze the role of farmers' preferences in determining reservation values for water rights. I consider the case of irrigated agricultural land in a region with stochastic water availability. The farmer has income that can either be consumed or invested in water rights. In this problem uncertainty comes from different sources: output uncertainty in season t, future spot market and water right prices, and future amounts of water accorded to water rights.

The particular model I develop for farmer consumption and investment in water rights is based on the conventional consumption-based capital asset-pricing model (CCAPM) where the asset under study is a water right. In this model, water right returns are linked to marginal rates of substitution for consumption at different points in time. Alternatively, a production-based asset-pricing model (PCAPM) may be developed emphasizing the linkages between asset returns and investment and production variables. Data availability is key when it comes to deciding between the CCAPM and the PCAPM. The first requires consumption data and the second investment and capital data. Unfortunately, my data is not ideally suited to either of these. First, while it reports farm equipment, it differs broadly in regards to numbers, quality and age, and any effort to value farmer capital is unreliable. Second, it does not contain information on consumption. I do have reliable data on current net

---

[20] Incomplete asset markets occurs when some insurance markets are absent so that farmers can not insure against each state of nature.

income which, in a framework with incomplete asset markets, is correlated with consumption[21]. For this reason I have chosen the CCAPM.

I assume that the farmer's optimal decision rule regarding consumption and investment in each season is the solution to the maximization of the expectation of his intertemporal utility of consumption subject to a budget constraint. I consider the case of a farmer for whom the intertemporal utility of consumption takes the form of a time-additively separable function, such that the expected present value of his utility is given by:

$$\sum_{t=1}^{T} \rho^{t} E_{t} U\left(C_{it}\right) \tag{4.2.1}$$

with *i=1…,n* and *t=1…,T*. Here n is the total number of farmers, T is the total number of seasons, C_{it} denotes farmer i's consumption in season t and ρ is a constant discount factor measuring the rate of time preferences. Given that $0<\rho<1$, one unit of utility tomorrow is valued less than one unit of utility today. The utility function $U(\bullet)$ is assumed to be twice continuously differentiable, with $U_t' = \frac{dU(C_t)}{dC_t} > 0$ and $U_t'' = \frac{d^2U(C_t)}{dC_t^2} < 0$, i.e. the marginal utility of consumption is

---

[21] Under the permanent-income hypothesis, proposed by Milton Friedman in 1957, increases and decreases in income that farmers see as temporary have little effect on their consumption spending. Nevertheless, that independence between consumption and current income requires the capacity of farmers to counteract specific random shocks on their current income. They are able to do that if they have access to a complete asset market or have assets that deliver wealth when they face unexpected reductions on their current income. If none of those conditions is fulfilled then consumption is highly correlated with current income.

positive, but it decreases with consumption. Expectations in (4.2.1) are taken conditional on information available at *t*.

The assumption of a time-additively separable utility is standard in the literature, but it is not without restriction. It implies that farmers' current utility is not affected by the timing of the resolution of uncertainty (Duffie et al., 1997). In other words, it rules out preferences for early or for late resolution of uncertainty. A second drawback of this utility function is that the elasticity of intertemporal substitution is inversely linked with the coefficient of relative risk aversion (Epstein and Zin, 1981 and Just, 2000). Finally, farmers' current utility is assumed to be unaffected by past consumption. This rules out habit formation in consumption where the marginal utility of future consumption is increasing with the level of past consumption. Just (2000), demonstrates that assuming additive separability of utility may be inadequate for studying longer-term agricultural production problems. This is so because the expected utility over a time horizon with an additive separability function does not take into account possible correlations across time of the variable over which utility is specified. In my setting, the role of habit formation is mitigated for two reasons: i) survey field experience indicates that durable goods are only a small share of farmers' consumption bundles in the Limarí Valley; and ii) optimal consumption depends on state variables that are related to the past history of consumption and investment. This indirectly links utilities of different periods (Bossaerts, 2002). A primary advantage of time-additive utility is that preferences are recursive and this allows dynamic programming methods to be used to analyze optimal decisions. Chavas (2004) points out that nonadditive preferences are more difficult to specify and evaluate, and he concludes by stating that "The reader should keep in mind that the time-additive model remains a popular framework for the analysis of dynamic behavior".

Before developing a model of farmers' consumption and investment decisions, two main features of the water market under analysis require discussion. First, the aggregate demand curve for water volumes in the spot market is assumed to be deterministic**.** Consequently, s_{jt} which is the price of water in the spot market of WUA *j* in season *t*, varies from one season to another as water supply changes. Thus, I have:

$$s_{jt} = s\left(v_{jt}\right). \tag{4.2.2}$$

Because the number of water rights is fixed in every WUA, changes in water supply are explained only by changes in v_{jt}.

The second important feature of this case study is that water supply depends on the level of water in the dams, which is known at the beginning of the agricultural season in April. At this time each WUA determines the amount of water accorded to each water right, v_{jt}. Hence, uncertainty about water availability and the price of water in the spot market is eliminated at the beginning of each season although it remains unresolved for future seasons. Nevertheless, the WUAs may change the amount of water accorded to water rights after April. This can be due to high levels of rain in the winter or to the extraordinary size of snow packs, the main source of water for the dams formed in the surrounding mountains during the winter months of May, June and July, which could generate a water flow that overwhelms the storage capacity of the dams during the summer. In these cases, the WUAs declare "free river" so each farmer can take freely whatever amount of water he requires[22]. The analysis of the time series of v for ACEC over 46 seasons shows that this WUA declared free river in only 8 seasons and there were no seasons for which it modified the amount of v announced at the beginning of the season. The JVRL announced a modification on v at the beginning of a season in 5 out of the 22 observed seasons, with an average change of 17%, and declared free river in four seasons. For the other WUAs, either this information is not available or they did not modify v except when declaring free river[23]. For the purposes of my analysis I assume that the normal case is when water accorded to water rights is known at the beginning of the season and does not change. This means that v_{jt} and $s_{jt=}s\left(v_{jt}\right)$ are known by the farmers at that time.

The farmer's stochastic problem is to choose a sequence of consumption over time that maximizes the farmer's expected utility in equation (4.2.1) subject to: an

---

[22] In theory, the amount of water accorded to water rights announced at the beginning of the season may be reduced although this never occurred in the years under study. In addition, the WUA of the Cogotí dam permitted the dam to run dry in seven seasons between 1954 and 2000.

[23] Number of seasons in which the WUAs declared free river.

WUA	Number of growing seasons in the available series for v_{jt}	Number of years declared free river
ACCC	20	7
ACEC	46	8
JVRL	22	4
ACER	23	5

initial stock of water rights N_0, a budget constraint, and a water availability constraint.

Due to the fact that most of the farmers in the Limarí Valley face incomplete markets[24], it is reasonable to assume that farmers' decisions over consumption depend on net revenue from current production and current income from water transactions. Thus, the budget constraint for farmer *i* in WUA *j* is defined by:

$$\mathrm{C}_{it} = \theta_{jt}\left(N_{it-1} - N_{it}\right) + s_{jt}z_{it} + P_{it}T_{it}f\left(w_{it}, X_{it}, \varepsilon_{it}\right) - r_{it}'X_{it} + I_{it} \quad (4.2.3)$$

The first two terms of the right hand side of the budgets constraint represent net income from water transactions, where θ_{jt} denotes the price of a water right in WUA*j* at period *t* and is the same for all farmers in a WUA*j*; N_{it} is the number of water rights held by farmer *i* during season *t*; $\theta_{jt}\left(N_{it-1} - N_{it}\right)$ is the net cost of investment in water rights at time *t*; s_{jt} denotes the spot market price per cubic meter in WUA*j* in season *t,* and z_{it} is the volume of water exchanged in the spot market by farmer *i* in season *t,* where $z_{it} > 0$ implies sale of water volumes and $z_{it} < 0$ implies the purchase of water volumes. The third and fourth terms in the budget constraint represent net revenue from production, where T_{it} is the total amount of cultivated land; $f\left(X_{it}, w_{it}, \varepsilon_{it}\right)$ denotes a per hectare production function of an aggregate output; w_{it} denotes the volume of water used as an input in production and X_{it} is a vector of inputs different from water (all inputs are expressed in terms of per hectare); ε_{it} represents the value of a vector of shocks that are partially determined by nature;

---

[24] Farmers face incomplete markets because only few of them have crop insurance and access to credit is limited.

P_{it} is the price of the aggregate output faced by farmer *i* in season *t;* and r_{it} is the vector of input prices for X_{it}. Output and input prices are assumed to be known. Finally, I_{it} represents farmer's "other net income" sources including consumption or production credit, land transactions, livestock exchanges and work off-farm.

The water availability constraint is:

$$N_{it} v_{jt} \geq z_{it} + T_{it} w_{it}{}^{25}. \tag{4.2.4}$$

It limits the amount of water that a farmer can use for irrigation, $T_{it} w_{it}$, and the total volume that he can exchange in the spot market, z_{it}.

Without violating the rule that utility is function of consumption[26], I can substitute the budget and the water constraints inside the utility function and express the farmer's expected present value of utility as:

$$\sum_{t=1}^{T} \rho^t E\Big(U\Big(\theta_{jt}\left(N_{it-1} - N_{it}\right) + s_{jt}\left(N_{it} v_{jt} - T_{it} w_{it}\right) + P_{it} T_{it} f\left(w_{it}, X_{it}, \varepsilon_{it}\right) - r'_{it} X_{it} + I_{it}\Big)\Big) \tag{4.2.5}$$

The farmer's problem now involves choosing investment in water rights and input quantities to maximize his expected discounted sum of utility in equation (4.2.5), subject to an initial stock of water rights. Hence, the consumption decision problem has been transformed to an investment and production decision problem.

---

[25] This assumption is an oversimplification because farmers in some WUAs may occasionally use more water than the volume they obtain for the season by asking for an advance on water from the next season. Farmers also may save water from one season to the next, but there is a penalty of 15 to 20% of the endowment due to projected evaporation losses making this practice rare (Zegarra 2002).

[26] "..good economists are unhappy about a utility function that has wealth in it. Few of us are like Disney's Uncle Scrooge, who got pure enjoyment out of a daily swim in the coins in his vault. Wealth is only valuable because it gives us access to more consumption. Utility functions should always be written over consumption" (Cochrane, 2005, pg. 157).

The overall problem of finding the optimal sequence of water rights transactions can be solved by using a standard dynamic programming approach, i.e. by finding the optimal amount of water rights, N_{it} for *t=1,... T,* and input quantities (w_{it}, X_{it}), that satisfy the recursive functional equation:

$$V(N_{it-1},\mu_{it}) = Max_{w_{it},X_{it},N_{it}} \begin{Bmatrix} E_t\left[U\begin{pmatrix}\theta_{jt}\left(N_{it-1}-N_{it}\right)+s_{jt}\left(N_{it}v_{jt}-T_{it}w_{it}\right)+ \\ P_{it}T_{it}f\left(w_{it},X_{it},\varepsilon_{it}\right)-r'_{it}X_{it}+I_{it}\end{pmatrix}\right] \\ +\rho E_t\left[V(N_{it},\mu_{it+1})\right]\end{Bmatrix} \tag{4.2.6}$$

where μ_{it} is the vector $\mu_{it}=\left(v_{jt},\theta_{jt},s_{jt},T_{it},P_{it},r'_{it}\right)$. For notational simplicity, the dependence of the value function on the term μ_{it} will be suppressed in what follows unless it is needed to avoid confusion. The value function, $V(N_{it-1})$, denotes the value of the stock of water rights held from *t-1* to *t*, N_{it-1}, after the optimal sequence of N_{it}, *t=1,...T* has been determined and is the indirect utility function of that same stock of water rights. In the first term the expectation is over ε_{it} (its value is resolved at harvest time) and the random variable I_{it}. The values of θ_{jt}, s_{jt}, v_{jt} are known at *t* but their future values are unknown. The values of T_{it} and T_{it+1} are assumed to be known. Thus, the expectation in the second term is over ε_{it+1}, as well as s_{jt+1}, v_{j+1}, θ_{jt+1}, and I_{it+1}. Output prices, P_{it}, and input prices, r_{it}, are certain. The control variables are N_{it}, w_{it} and X_{it}. The state variables are N_{it-1} and μ_{it}. I assume that $U(\bullet)$ and $f(\bullet)$ are continuously differentiable, the value function is differentiable in N_{it}, and that the optimization problem has an interior solution.

The first order condition with respect to N_t (omitting the indices *i* and *j* for convenience) is:

$$E_t\left[U_t' * \left(\theta_t - s_t v_t\right)\right] = \rho E_t\left[V_{t+1}'\right] \tag{4.2.7}$$

where $V_{t+1}' = \partial V\left(N_t\right)/\partial N_t$ is the marginal value of a water right held at the beginning of period *t+1*.

Using the envelope theorem, the right hand term in (4.2.7) can be expressed in terms of the discount factor, marginal utility, water right prices and the spot market value of water accorded to each water right. I begin with the value function for period *t+1* evaluated at the optimal level of each one of the variables that are included in it:

$$V(N_t) = \left\{ \begin{array}{l} E_{t+1}\left[U\left(\begin{array}{l} \theta_{t+1}\left(N_t - N_{t+1}\right) + s_{t+1}\left(N_{t+1}v_{t+1} - T_{it+1}w_{t+1}\right) + \\ P_{t+1}f\left(w_{t+1}, X_{t+1}, \varepsilon_{t+1}\right) - r_{t+1}' X_{t+1} \end{array} \right) \right] \\ +\rho E_{t+1}\left[V(N_{t+1})\right] \end{array} \right\} \tag{4.2.8}$$

Then I differentiate equation (4.2.8) with respect to N_t, to obtain:

$$V_{t+1}' = E_{t+1}\left[U_{t+1}'\theta_{t+1}\right]. \tag{4.2.9}$$

Next I substitute equation (4.2.9) into equation (4.2.7), and use the Law of Iterated Expectations, to obtain the first order condition with respect to N_t:

$$\left(\theta_t - s_t v_t\right) E_t\left[U_t'\right] = \rho E_t\left[U_{t+1}'\theta_{t+1}\right] \tag{4.2.10}$$

Equation (4.2.10) is the so-called Euler Equation. The left hand side term indicates how much the farmer's utility increases if the available income for consumption rises due to a sale of a water right at the price of θ_t. The deduction of $s_t v_t$ from θ_t, to get the net income from selling a water right, is due to the fact that whenever a farmer sells a water right he will not be able to sell the amount of water accorded to that water right, v_t, on the spot market at a value of $s_t v_t$. The right hand side term is the farmer's expected discounted utility of keeping the water right from season *t* to *t+1*, which may also be interpreted as the farmer's expected forgone discounted utility if he sells a water right in season *t*. In other words, this term can be understood as the marginal cost of selling a water right in period *t*. Thus, (4.2.10) reflects the optimality condition that the marginal benefit of selling a water right (the left hand side term) is equal to its marginal cost (the right hand side term). This allows me to interpret equation (4.2.10) as giving the marginal value or willingness to pay for a water right (Cochrane, 2005, Chapter 2.1). More specifically, I can rewrite the Euler Equation as:

$$\theta_t = s_t v_t + \rho E_t \left[\frac{U'_{t+1}\begin{pmatrix} \theta_{t+1}(N_t - N_{t+1}) + s_{t+1}(N_{t+1}v_{t+1} - T_{t+1}w_{t+1}) + \\ P_{t+1}T_{t+1}f(w_{t+1}, X_{t+1}, \varepsilon_{t+1}) - r'_{t+1}X_{t+1} + I_{t+1} \end{pmatrix}\theta_{t+1}}{E_t U'_t\left(\theta_t(N_{t-1} - N_t) + s_t(N_t v_t - T_t w_t) + P_t T_t f(w_t, X_t, \varepsilon_t) - r'_t X_t + I_t\right)} \right] \tag{4.2.11}$$

where the term on the right hand side of (4.2.11) is the willingness to pay or the reservation value for a water right.

Furthermore, the stochastic discount factor in this problem is defined by the random variable M_{t+1}, where:

$$M_{t+1} = \rho \frac{U'_{t+1}\begin{pmatrix} \theta_{t+1}\left(N_t - N_{t+1}\right) + s_{t+1}\left(N_{t+1}v_{t+1} - T_{t+1}w_{t+1}\right) + \\ P_{t+1}T_{t+1}f\left(w_{t+1}, X_{t+1}, \varepsilon_{t+1}\right) - r'_{t+1}X_{t+1} + I_{t+1} \end{pmatrix}}{E_t U'_t\left(\theta_t\left(N_{t-1} - N_t\right) + s_t\left(N_t v_t - T_t w_t\right) + P_t T_t f\left(w_t, X_t, \varepsilon_t\right) - r'_t X_t + I_t\right)} \tag{4.2.12}$$

Thus, the Euler Equation becomes:

$$\theta_t = s_t v_t + E_t\left[M_{t+1}\theta_{t+1}\right] \tag{4.2.13}$$

Following the tradition of the literature on asset pricing, the Euler Equation can be written as:

$$1 = \frac{s_t v_t}{\theta_t} + E_t\left[M_{t+1}\frac{\theta_{t+1}}{\theta_t}\right]. \tag{4.2.14}$$

The right hand side term in (4.2.14) is the discounted expected value of the marginal rate of return to holding a water right from time *t* to time *t*+1. This marginal return is comprised of two terms: the first term is $s_t v_t / \theta_t$, and it represents the rate of return to a water right when the water accorded to it is sold in the spot market; and the second term is θ_{t+1}/θ_t , which represents the rate of change in the water right price from season *t* to season *t+1*. Finally, expression (4.2.14) indicates that the optimal investment in a water right occurs when the discounted expected value of the marginal return to holding an extra water right is equal to 1. This formula is the foundation of the consumption-based capital asset pricing model (CCAPM).

The Euler Equation can also be written in terms of the value of water accorded to each water right in the spot market, $s_{t+1}v_{t+1}$, for *t* = 0,1,2…*T*. To do this I solve equation (4.2.13) forward by repeatedly substituting out the future price of water rights, θ_{t+1}, for *l* = 1,2…*T*, and I obtain:

$$\theta_t = s_t v_t + E_t\left[M_{t+1}\theta_{t+1}\right]$$

$$\theta_{t+1} = s_{t+1} v_{t+1} + E_{t+1}\left[M_{t+2}\theta_{t+2}\right]$$

$$\theta_{t+2} = s_{t+2} v_{t+2} + E_{t+2}\left[M_{t+3}\theta_{t+3}\right]$$

$$\vdots$$

$$\theta_t = s_t v_t + E_t\left[M_{t+1} s_{t+1} v_{t+1}\right] + E_t\left[E_{t+1}\left[M_{t+1} M_{t+2} s_{t+2} v_{t+2}\right]\right]$$

which, by the Law of Iterated Expectations, becomes:

$$\theta_t = s_t v_t + E_t\left[M_{t+1} s_{t+1} v_{t+1} + M_{t+1} M_{t+2} s_{t+2} v_{t+2}\right] \tag{4.2.15}$$

This equation states that the reservation value of a water right in period *t* is determined by adding together the present and expected future values of the amount of water accorded to a water right in the spot market, discounted by the stochastic discount factor. In order to explain the economics behind this statement, consider a representative farmer who lives only two periods, *t* and *t+1*, and has only one water right, which is accorded one m^3 of water. If that farmer decides to use his cubic meter of water as an input in crop production, he does so because he obtains a greater return than what is expected from selling that water in the spot market. In equilibrium, he would then buy water in the spot market until the marginal benefit of water used as an input equals the expected present benefit of selling water in the spot market[27].

---

[27] This is the case for a costless spot market for water such as that of the Limarí Valley. Up to now, nobody has measured the real transaction cost on the spot market. Zegarra (2002) indicates costs should be significant because when he conducted his survey in the Limarí Valley, farmers were facing a severe drought and complaining about the difficulty in purchasing water in the spot market. However, that is not in itself a proof of high transaction costs. What happened is that, due to the severe drought, prices were quite high at that point, and several farmers were not willing to pay those prices. Indeed an active water market existed at that time in Ovalle's plaza with water being sold to the highest bidder.

In order to examine the role of risk preferences and incomplete asset markets in the reservation value for water rights as well as in water rights trading, it is convenient to write the Euler Equation in terms of the covariance between the stochastic discount factor and the price of a water right. Using the definition of covariance $E_t\left[M_{t+1}\theta_{t+1}\right]=Cov_t\left[M_{t+1},\theta_{t+1}\right]+E_t\left[M_{t+1}\right]E_t\left[\theta_{t+1}\right]$, I can write (4.2.13) with the sub index *i* and *j* as:

$$\theta_{jt}=s_{jt}v_{jt}+E_t\left[M_{it+1}\right]E_t\left[\theta_{jt+1}\right]+Cov_t\left[M_{it+1},\theta_{jt+1}\right] \qquad (4.2.16)$$

Equation (4.2.16) splits the farmer's reservation value of a water right into the expected discounted marginal rate of return to holding a water right from time *t* to time *t+1*, $s_{jt}v_{jt}+E_t\left[M_{it+1}\right]E_t\left[\theta_{jt+1}\right]$, and a risk premium, $Cov_t\left[M_{it+1},\theta_{jt+1}\right]$. Thus, differences in reservation values for a water right, among farmers in a same water association and under the assumption of farmers' identical expectations on θ_{jt+1}, require differences in the expected value of the random variables M_{it+1} and/or in the covariance between M_{it+1} and θ_{jt+1}.

If farmers are risk neutral then the expected value of M_{it+1} will be the same for all farmers and risk premium is zero. Risk neutral farmers utility function over consumption can be represented by: $U\left(C_{it}\right)=\alpha_0+\alpha_1 C_{it}$. Since $U'\left(C_{it}\right)=\alpha_1$, the stochastic discount factor becomes $M_{it+1}=\dfrac{\rho U'\left(C_{it+1}\right)}{E_t\left[U'\left(C_{it}\right)\right]}=\dfrac{\rho\alpha_1}{E_t\left[\alpha_1\right]}=\rho$ (Chavas, 2004, Chapter 10). In this case the covariance term, $Cov_t\left[M_{it+1},\theta_{it+1}\right]$, would vanish and the optimality condition reduces to $\theta_{jt} = s_{jt}v_{jt} + E_t \rho \theta_{jt+1}$, which is the same as derived from the simple model in equation (4.1.5).

If farmers face complete asset markets that provide full insurance, then a farmer's specific random shocks to current income will not affect his consumption. In this case the stochastic discount factor M_{it+1} depends on aggregate temporal shocks. If it is also assumed that farmers have homogenous preferences, then they are all characterized by the same, unique stochastic discount factor, i.e. $M_{it+1} = M_{t+1}$ (Campbell, 1997, Chapter 8.1). In this case the expected value of the random variables M_{it+1} and the covariance between M_{it+1} and θ_{jt+1} will not differ among farmers and water right reservation values will be the same for all farmers.

To summarize, under the assumption that farmers have identical expectations regarding θ_{jt+1}, differences in reservation values for a water right among farmers in the same water association can only arise if there are incomplete markets or if farmers have heterogeneous preferences that are not risk neutral. In that case there are multiple stochastic discount factors that satisfy equation (4.2.16).

How risk aversion affects water rights transactions depends on the sign of the risk premium, $Cov_t\left[M_{it+1}, \theta_{jt+1}\right]$. The risk premium increases with risk aversion, so if the covariance between M_{it+1} and θ_{jt+1} is positive then more risk averse farmers will place a higher value on water rights than less risk averse farmers, and the former will buy water rights from the latter. In the case under study, with incomplete asset markets, water rights are used not only to obtain water but also to smooth consumption. This is because water rights allow farmers to insure themselves against bad shocks to production income and hence consumption. Thus, water right prices covary negatively with consumption and because a farmer's marginal utility of consumption is decreasing in consumption, the $Cov_t\left[M_{it+1},\theta_{jt+1}\right]$ is positive.

Finally, optimal variable input quantities are obtained from the following first order conditions:

$$E_t\left[U_t'*\left(P_{it}T_{it}f_w\left(w_{it},X_{it},\varepsilon_{it}\right)-s_{jt}\right)\right]=0 \quad \text{(for water)} \qquad (4.2.17)$$

$$E_t\left[U_t'*\left(P_{it}T_{it}f_x\left(w_{it},X_{it},\varepsilon_{it}\right)-r_{it}\right)\right]=0 \quad \text{(for other inputs)} \qquad (4.2.18)$$

The first order condition for water in (4.2.17) can be written as: $E_t\left[P_{it}T_{it}f_w\left(w_{it},X_{it},\varepsilon_{it}\right)\right]=s_{jt}-\dfrac{Cov_t\left(U_t',P_{it}T_{it}f_w\left(w_{it},X_{it},\varepsilon_{it}\right)\right)}{E_t\left[U_t'\right]}$. This provides an intuitive interpretation of the first order condition for water: at the optimal input use, the expected marginal value product, $E_t\left[P_{it}T_{it}f_w\left(w_{it},X_{it},\varepsilon_{it}\right)\right]$, is equal to the input price, plus the marginal risk premium, $-\dfrac{Cov_t\left(U_t',P_{it}T_{it}f_w\left(w_{it},X_{it},\varepsilon_{it}\right)\right)}{E_t\left[U_t'\right]}$. An identical interpretation applies to the first order conditions for the other inputs (Chavas, 2004, Chapter 8).

4.3 Market Frictions and Consumption-Based Asset Pricing for Water Rights

Before concluding this chapter, I discuss market frictions that may affect the consumption-based capital asset pricing model upon which the expressions for the farmer's private reservation value of a water right are based. At the heart of the consumption-based capital asset pricing model is the condition that discounted expected marginal utilities should be equilibrated across time, as implied by equation

(4.2.14). In the presence of market frictions this equality may become an inequality such as $E_t\left[M_{t+1}\frac{\theta_{t+1}}{\theta_t - s_t v_t}\right] \leq 1$ or as $E_t\left[M_{t+1}\frac{\theta_{t+1}}{\theta_t - s_t v_t}\right] \geq 1$. He and Modest (1995) review some of the market frictions that may produce such inequalities including: i) a non-short sales constraint, which prevents the short selling of some assets; ii) solvency constraints, which restrict the wealth process at some future date from falling below some predetermined level; iii) transaction costs that include bid-ask spreads and commissions; and iv) borrowing constraints, which preclude investor's current consumption from exceeding their current wealth.

The two-round survey I conducted among farmers in the Limarí Valley shows that they have low levels of education, and most own less than 6 hectares. These figures suggest that sophisticated market activities, such as short sales or solvency constraints, are not relevant for this study. Excess liquidity and an intermediary institution are necessary for short selling to work properly and the development of more sophisticated markets where speculators can take short positions. Such is not the case for water markets in Chile where the size of the market greatly reduces the possibility that a market maker has a counterpart. The difficulty in hedging against production shocks and the lack of crop insurance creates uncertainty with respect to future income. The spot market for water plays a role in smoothing income, but not nearly enough to avoid distress land sales by insolvent farmers. This suggests that for the case under study there are two constraints that may be important: transaction costs and borrowing constraints.

A large literature on the impact of transaction costs on asset prices has developed. Some authors emphasize the cost in terms of bid-ask spreads (Luttmer, 1996), the existence of illiquid assets as a consequence of transaction costs (Vayanos and Jean-Luc Vila, 1999), or the presence of transaction costs that are endogenously determined because investors adjust trading frequencies (Constantinides, 1986). Heaton and Lucas (1996) interpret transaction costs not as a trading cost, but rather as a wedge between the borrowing and lending rates due to monitoring and other costs incurred in each period. Gollier (2001) emphasizes that risk reduces long-term savings on assets if the trading cost of the assets is high. In spite of differences in the definition of transaction costs among authors, they do agree that for short periods, transaction costs are important, but over time, they become insignificant. Thus, a one-period transaction cost will be less significant if traders that buy an asset hold it for many periods.

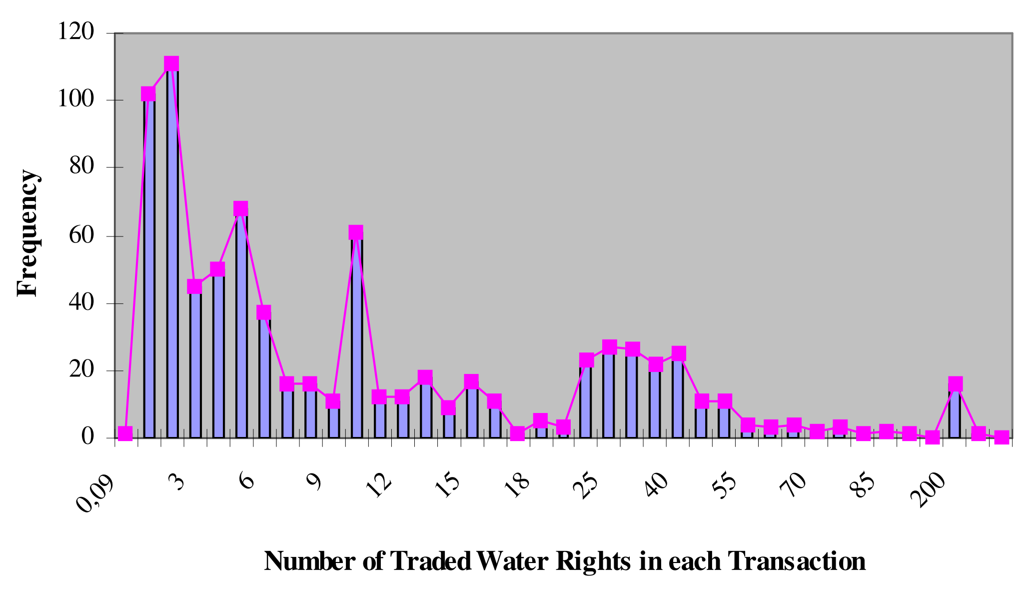
To show that transaction costs do not have much effect in the present study, I start with Gollier's (2001) findings on illiquid assets. I also assume that the existence of a costless spot market helps to smooth income variations and minimize the liquidity problem for water rights. For other types of transaction costs, both theory and empirical evidence support the hypothesis that transaction costs are not relevant for this study. In general, water right buyers want to keep them for long periods minimizing the impact of transaction costs on farmer decisions, and on the price of water rights or the degree of market activity. As mentioned in the previous chapter, Hearne and Easter (1995) have estimated that the transaction costs associated with the purchase and sale of water rights in the Limarí Valley range from 5% to 2% of the price for buyers and sellers, respectively. Although these costs do not appear to be high, problems arise when trade implies a change in the source of water because the

Direccion General de Aguas, a central governmental office, must approve the change of source, a process which may take several months because it must ensure that the petitioners meet certain requirements and evaluate possible negative externalities to other farmers. The length of this process explains why most of the water rights transactions are among farmers who obtain their water from the same source. Secondly, the size (measured by the number of water rights exchanged) of each water right transaction[28] is relatively small with little dispersion indicating that transaction costs are insignificant. The following figure presents the frequency of the number of water rights trades in each one of the 778 transactions included in the dataset.

---

[28] The database contains information for 778 transactions of water rights (independent of land transactions), in the four WUAs under study representing trade of 11,910 water rights.

Figure 4.1: Water Rights Transactions



As the Figure 4.1 illustrates, most transactions involve small amounts of water rights, indicative of low transaction costs. In fact, 50% of all transactions involve 6 or fewer water rights, and 80% involve less than 20 while the mean value is 15 and the mode is equal to 2. In dollar terms, a water right in 1999 had a minimum average price of US$ 927.40 (in ACER) and a maximum average price of US$ 2,766.4 (in ACEC). If I use the mode (2 water rights per transaction) and the upper bound of the transaction cost estimated by Hearne and Easter (1995), i.e. 5% of the transaction price, I arrive at an estimate for transaction cost that ranges from a minimum of $46.4 to a maximum of $138.32 U.S. dollars.

Borrowing or liquidity constraints may explain outcomes in which $E_t\left[M_{t+1}\frac{\theta_{t+1}}{\theta_t - s_t v_t}\right] \geq 1$. This implies that $s_t v_t + E_t\left[M_{t+1}\theta_{t+1}\right] \geq \theta_t$, i.e. the marginal expected benefit of buying a water right (the left hand side of the inequality) is greater than the marginal cost of buying a water right (right hand side term of the inequality). In such a case the farmer has an incentive to buy water rights and reduce his present consumption. With decreasing marginal utility of consumption ($U''(C_t)<0$), that will reduce the stochastic discount factor, M_{t+1} moving the inequality toward an equality. But if the farmer faces liquidity or credit constraints then he may not be able to buy all the water rights he desires and the inequality may not vanish. Accordingly to the Chilean Water Code, water rights are divorced from land. As a consequence water rights are accepted as collateral by most banking institutions. This allows farmers to obtain loans to buy water rights. Thus, credit constraints are mainly for consumption. The effect of this latter constraint is included in my model through the budget constraint for consumption.

I also consider the impact of liquidity constraints on farmer savings decisions and risk aversion. Deaton (1991), Carroll (1997), and Gollier (2001), among others, show that the risk of facing a liquidity constraint in the future introduces an important motive to save, since savings act as a buffer stock that reduces the probability that the liquidity constraint will be binding in the future. Agents accumulate assets to insulate themselves from a temporary drop in income that cannot be compensated by short-term debts. Nevertheless, in the case under study farmers can smooth revenues from production by trading in the spot market for water.

Now, if the inequality is such that $s_t v_t + E_t\left[M_{t+1}\theta_{t+1}\right] \leq \theta_t$, then the marginal expected cost of selling a water right (the left hand side of the inequality) is less than the marginal benefit of selling a water right in period *t* (the right hand side term of the inequality). In this case the farmer wishes to sell water rights and increase his consumption. A farmer without water rights is not able to do this leaving him at a corner solution where the inequality is strict. From a theoretical point of view, such farmers may exist, so I review the data to see how many farmers in the sample have no water rights. I find that only 5% of farmers had no water rights.

4.4 Summary

In this chapter, I have developed a framework that models a farmer's optimal decision making in regards to investment in water rights and input quantities for each growing season. This model is a consumption-based asset price model, and shows that a private farmer's reservation value for a water right depends on the value of his stochastic discount factor. Further analysis of that discount factor allows me to relate reservation values for water rights to the underlying preferences of farmers and risk aversion. I have shown how heterogeneous preferences generate differences in the stochastic discount factor, which creates differences in farmers' private reservation values for water rights and helps to explain water rights transactions among farmers. Moreover, I show how more risk averse farmers have incentives to buy water rights from farmers with lesser risk aversion. Lastly, I have discussed the effect of market frictions on the water rights market and on the validity of my model. Among the frictions that the literature addresses, I have focused on transaction costs and borrowing constrains. The analysis of the data for the case under study indicates that transaction costs do not affect the validity of the model and that the likelihood of a corner solution with a farmer holding zero water rights and with a reservation value less than water right market price is quite low. Moreover, borrowing constraints affect consumption decisions but not water right purchases because the rights can be used as collateral.

Chapter 5: The Econometric Estimation

In this section, I develop an approach to jointly estimate the parameters that describe a farmer's utility and production functions, based on observed economic behavior. Joint estimation preserves estimation consistency and allows exploiting cross-equations error correlations that might improve efficiency (Love and Buccola, 1991). I also summarize the data sources and the main characteristics of the data that will be used in later estimations.

5.1 Parametric specification of the system of equations

The joint estimation of the parameters that describe a farmer's utility and production functions is performed through the simultaneous estimation of the equation system described by the Euler Equation (4.2.10) and the first order conditions that solve for the optimal variable input quantities (4.2.17) and (4.2.18). That procedure requires a parametric specification of the instantaneous utility of consumption, the stochastic production technology and the variable that represents other net income, I_{it}.

For the utility function, I have chosen an exponential function:

$$U(C_i) = -\exp(-\gamma_i C_i) \tag{5.1.1}$$

where γ_i is restricted to be non-negative. The specification (5.1.1) has three main features. First, the marginal utility of consumption is positive, $U'(C_i) = \gamma_i \exp(-\gamma_i C_i) > 0$. Second, the utility function is concave, $U''(C_i) = -\gamma_i^2 \exp(-\gamma_i C_i) < 0$, which implies aversion to risk. Third, it assumes that the absolute Arrow-Pratt risk aversion coefficient for each farmer, denoted by R_A^i, is constant (CARA) and equal to γ_i, i.e. $R_A^i = \gamma_i$

The CARA preferences embodied in the use of the negative exponential utility function is a drawback of this specification because few decision-makers have the implied characteristic that their attitude towards risk remains the same regardless their wealth or asset position (Chavas, 2004, Chapter 4; Saha et al., 1994). Nevertheless, risk preferences displaying constant risk aversion are extremely easy to deal with analytically (Hammond, 1974). Moreover, the exponential function it is very suitable as a local approximation to anyone's utility function for evaluating small to moderate gambles (Pratt, 1964). For these reasons the CARA preferences have been widely used in applied decision analysis (Hammond, 1974, Keeney and Raffia, 1976, Gregory, 1978, Love and Buccola, 1991).

To describe the stochastic production technology I use a Just-Pope Cobb-Douglas (Just and Pope, 1978) production function that facilitates the estimation of production risk endogenous to inputs. Moreover, the Just-Pope form holds the best potential for mutual inference of preferences and technology (Love and Buccola, 1991). This function is:

$$y_{it} = f\left(w_{it}, L_{it}, F_{it}; \alpha\right) + h\left(w_{it}, L_{it}, F_{it}; \beta\right)\varepsilon_{it} = w_{it}^{\alpha_0} L_{it}^{\alpha_1} F_{it}^{\alpha_2} + w_{it}^{\beta_0} L_{it}^{\beta_1} F_{it}^{\beta_2} \varepsilon_{it} \tag{5.1.2}$$

where y is output per-hectare, w is water, L is labor, F is fertilizers (all inputs are divided by the number of cultivated hectares), ε represents output uncertainty. The vector of parameters of the non-stochastic component of the production function is represented by $\alpha = (\alpha_1, \alpha_2, \alpha_3)$, and $\beta = (\beta_1, \beta_2, \beta_3)$ is the vector of parameters of the stochastic component of the production function. Output uncertainty, ε_{it}, is assumed to be independent and identically distributed (i.i.d.) normal with $E[\varepsilon_{it}] = 0$ and $V[\varepsilon_{it}] = 1$[29]. Pope and Just (1977) point out that no generality is lost in assuming $V[\varepsilon_{it}] = 1$, since if $V[\varepsilon_{it}] = \sigma_\varepsilon^2$ then the $h(w_{it}, L_{it}, F_{it}; \beta)$ could simply be modified by a multiplicative factor σ_ε^2. Moreover, as in Just and Pope (1977 and 1979) and Love and Buccola (1991) I assume that $E_t\left[w_{it}^{\beta_0} L_{it}^{\beta_1} F_{it}^{\beta_2} \varepsilon_{it}\right] = 0$. That assumption implies that input quantities are either not stochastic or stochastic, but independent of ε.

Finally contemporaneous correlation among errors of the production function is not excluded i.e. $E\left[\varepsilon_{it}, \varepsilon_{jt}\right] \neq 0$

From this production function specification, I obtain $E[y_{it}] = L_{it}^{\alpha_1} w_{it}^{\alpha_2} F_{it}^{\alpha_3}$ and $V[y_{it}] = \left(L_{it}^{\beta_1} w_{it}^{\beta_2} F_{it}^{\beta_3}\right)^2$, which implies that the mean and variance of output are endogenous to input decisions.

For the "other net income" variable, I_{it}, I assume the following linear model:

---

[29] The equation system described by the Euler equation and the first order conditions that solve for the optimal variable input quantities are expressed in terms of conditional moments to the set of information in t. However, because ε_{it} is assumed to be i.i.d. its conditional and unconditional moments are the same (Cochrane, 2005, Chapter 1). Thus, if I have that $E_t[\varepsilon_{it}] = E[\varepsilon_{it}] = 0$ I also can say that $E_t[\varepsilon_{it+1}] = E[\varepsilon_{it+1}] = 0$.

$$I_{it} = a^* \left(\begin{array}{l} \theta_{jt}\left(N_{it-1} - N_{it}\right) + s_{jt}\left(N_{it}v_{jt} - T_{it}w_{it}\right) + P_{it}T_{it}L_{it}^{\alpha_1} w_{it}^{\alpha_2} F_{it}^{\alpha_3} + \\ P_{it}T_{it}L_{it}^{\beta_1} w_{it}^{\beta_2} F_{it}^{\beta_3} \varepsilon_{it} - r'_{it}X_{it} - \bar{c}_i \end{array} \right) + \Gamma_{it} \qquad (5.1.3)$$

where a is an unknown parameter, $\bar{c}_i$ is "normal" consumption, and Γ_{it} is a random error that represents random aggregate shocks plus idiosyncratic shocks different from production uncertainty that affect I_{it}.

The variable I_{it} represents farmer's "other net income" sources as consumption and production credit, land transactions, livestock exchanges and work off-farm that can be used to afford consumption. Equation (5.1.3) assumes that part of I_{it} is endogenous and depends on the differences between net income from production and water trading and some "normal" consumption level, $\bar{c}_i$, that is farmer specific. For instance, a farmer that owns livestock and who faces a situation in which her net production revenues plus water trading income is lesser than $\bar{c}_i$ may sell cattle.

Equation (5.1.3) also states that I_{it} is a function of the deterministic part of the net income, $\theta_{jt}\left(N_{it-1} - N_{it}\right) + s_{jt}\left(N_{it}v_{jt} - T_{it}w_{it}\right) + P_{it}T_{it}L_{it}^{\alpha_1} w_{it}^{\alpha_2} F_{it}^{\alpha_3} - r'_{it}X_{it}$, and two stochastic components: (1) farmer's output specific or idiosyncratic random shocks, $P_{it}T_{it}L_{it}^{\beta_1} w_{it}^{\beta_2} F_{it}^{\beta_3} \varepsilon_{it}$, and (2) the random term Γ_{it}.

I assume that output specific random shocks, ε_{it}, and Γ_{it} are distributed independently. That assumption follows from the fact that ε_{it} represents output uncertainty, for instance pests, while Γ_{it} represents uncertainty over "other net income sources” such as random variations in bank interest rates. If asset markets were complete then farmers’ specific random shocks would be aggregate temporal shocks and the assumption of independent distributions may not be valid any more. Nevertheless, because in the case under study asset markets are incomplete the above independence assumption should hold.

Incomplete asset markets may also imply heterogeneous variances for I_{it} among farmers. Different investment decisions of a surplus between “normal” consumption level, $\overline{c}_i$, and production and water trading incomes may lead to different variances in I_{it}. Whether or not a farmer faces credit constraints may also affect the variance of I_{it}. These differences in the variance of I_{it} among farmers lead me to assume that Γ_{it} is heteroskedastic. Thus I assume that Γ_{it} distributes normal with conditional expected mean zero and non constant conditional variance $\sigma_{i\Gamma}^2$.

Replacing the Euler Equation (4.2.10) with these structural forms, I get:

$$\theta_{jt} = s_{jt}v_{jt} + \rho E_t \left[\frac{\exp - \gamma_i \begin{pmatrix} (1+a) \begin{pmatrix} \theta_{jt+1}\left(N_{it} - N_{it+1}\right) + \\ s_{jt+1}\left(N_{it+1}v_{jt+1} - T_{it+1}w_{it+1}\right) + \\ P_{it+1}T_{it+1}L_{it+1}^{\alpha_1}W_{it+1}^{\alpha_2}F_{it+1}^{\alpha_3} - r'_{it+1}X_{it+1} + \\ P_{it+1}T_{it+1}L_{it+1}^{\beta_1}W_{it+1}^{\beta_2}F_{it+1}^{\beta_3}\varepsilon_{it+1} \end{pmatrix} \\ -a\bar{c}_i + \Gamma_{it+1} \end{pmatrix} \theta_{jt+1}}{E_t \left[\exp - \gamma_i \left((1+a) \begin{pmatrix} \theta_{jt}\left(N_{it-1} - N_{it}\right) + \\ s_{jt}\left(N_{it}v_{jt} - T_{it}w_{it}\right) + \\ P_{it}T_{it}L_{it}^{\alpha_1}W_{it}^{\alpha_2}F_{it}^{\alpha_3} - r'_{it}X_{it} + \\ P_{it}T_{it}L_{it}^{\beta_1}W_{it}^{\beta_2}F_{it}^{\beta_3}\varepsilon_{it} \end{pmatrix} - a\bar{c}_i + \Gamma_{it} \right) \right]} \right] \tag{5.1.4}$$

Further simplification of equation (5.1.4) can be achieved by taking logs on both sides

$$\ln\left(\theta_{jt} - s_{jt}v_{jt}\right) = \ln\rho + \ln E_t \left[\frac{\exp - \gamma_i \begin{pmatrix} (1+a) \begin{pmatrix} \theta_{jt+1}\left(N_{it} - N_{it+1}\right) + \\ s_{jt+1}\left(N_{it+1}v_{jt+1} - T_{it+1}w_{it+1}\right) + \\ P_{it+1}T_{it+1}L_{it+1}^{\alpha_1}W_{it+1}^{\alpha_2}F_{it+1}^{\alpha_3} - r'_{it+1}X_{it+1} + \\ P_{it+1}T_{it+1}L_{it+1}^{\beta_1}W_{it+1}^{\beta_2}F_{it+1}^{\beta_3}\varepsilon_{it+1} \end{pmatrix} \\ -a\bar{c}_i + \Gamma_{it+1} \end{pmatrix} \theta_{jt+1}}{E_t \left[\exp - \gamma_i \left((1+a) \begin{pmatrix} \theta_{jt}\left(N_{it-1} - N_{it}\right) + \\ s_{jt}\left(N_{it}v_{jt} - T_{it}w_{it}\right) + \\ P_{it}T_{it}L_{it}^{\alpha_1}W_{it}^{\alpha_2}F_{it}^{\alpha_3} - r'_{it}X_{it} + \\ P_{it}T_{it}L_{it}^{\beta_1}W_{it}^{\beta_2}F_{it}^{\beta_3}\varepsilon_{it} \end{pmatrix} - a\bar{c}_i + \Gamma_{it} \right) \right]} \right] \tag{5.1.5}$$

A convenient expression for the second term in the right hand of (5.1.5) can be obtained with the Jensen's inequality that states that:

$$\ln E_t \left[\frac{\exp -\gamma_i \left((1+a) \left(\begin{array}{l} \theta_{jt+1}(N_{it}-N_{it+1})+ \\ s_{jt+1}\left(N_{it+1}v_{jt+1}-T_{it+1}w_{it+1}\right)+ \\ P_{it+1}T_{it+1}L_{it+1}^{\alpha_1}W_{it+1}^{\alpha_2}F_{it+1}^{\alpha_3}-r'_{it+1}X_{it+1}+ \\ P_{it+1}T_{it+1}L_{it+1}^{\beta_1}W_{it+1}^{\beta_2}F_{it+1}^{\beta_3}\varepsilon_{it+1} \end{array} \right) -a\bar{c}_i+\Gamma_{it+1} \right) \theta_{jt+1}}{E_t \left[\exp -\gamma_i (1+a) \left(\begin{array}{l} \theta_{jt}(N_{it-1}-N_{it})+ \\ s_{jt}\left(N_{it}v_{jt}-T_{it}w_{it}\right)+ \\ P_{it}T_{it}L_{it}^{\alpha_1}W_{it}^{\alpha_2}F_{it}^{\alpha_3}-r'_{it}X_{it}+ \\ P_{it}T_{it}L_{it}^{\beta_1}W_{it}^{\beta_2}F_{it}^{\beta_3}\varepsilon_{it} \end{array} \right) -a\bar{c}_i+\Gamma_{it} \right]} \right] = E_t \ln \left(\frac{\exp -\gamma_i \left((1+a) \left(\begin{array}{l} \theta_{jt+1}(N_{it}-N_{it+1})+ \\ s_{jt+1}\left(N_{it+1}v_{jt+1}-T_{it+1}w_{it+1}\right)+ \\ P_{it+1}T_{it+1}L_{it+1}^{\alpha_1}W_{it+1}^{\alpha_2}F_{it+1}^{\alpha_3}-r'_{it+1}X_{it+1}+ \\ P_{it+1}T_{it+1}L_{it+1}^{\beta_1}W_{it+1}^{\beta_2}F_{it+1}^{\beta_3}\varepsilon_{it+1} \end{array} \right) -a\bar{c}_i+\Gamma_{it+1} \right) \theta_{jt+1}}{E_t \left[\exp -\gamma_i \left((1+a) \left(\begin{array}{l} \theta_{jt}(N_{it-1}-N_{it})+ \\ s_{jt}\left(N_{it}v_{jt}-T_{it}w_{it}\right)+ \\ P_{it}T_{it}L_{it}^{\alpha_1}W_{it}^{\alpha_2}F_{it}^{\alpha_3}-r'_{it}X_{it}+ \\ P_{it}T_{it}L_{it}^{\beta_1}W_{it}^{\beta_2}F_{it}^{\beta_3}\varepsilon_{it} \end{array} \right) -a\bar{c}_i+\Gamma_{it} \right) \right]} \right) + \phi_{it+1} \tag{5.1.6}$$

where φ_{it+1} is a positive expression that corresponds to a Jensen's inequality adjustment. The economic intuition for the adjustment can be seen by noticing that (using notation of Chapter 4) $\varphi_{it+1} = \ln E_t\left[M_{it+1}\theta_{jt+1}\right] - E_t \ln\left[M_{it+1}\theta_{jt+1}\right]$, where the difference on the right hand side of the expression is a measure of conditional volatility of the discounted water right price for each farmer (Alvarez and Jermann, 2005). As a special case, if the discounted price is distributed lognormal, then the volatility measure $\varphi_{it+1} = \frac{1}{2}\ Var_t\left[\ln\left(M_{it+1}\theta jt+1\right)\right]$ (Campbell et al. (1997, Chapter 8).

Substituting the right hand term of equation (5.1.6) in the Euler Equation (5.1.5) I get:

$$\ln\left(\theta_{jt} - s_{jt}v_{jt}\right) = \ln\rho + E_t \ln\left(\frac{\exp -\gamma_i \begin{pmatrix} (1+a)\begin{pmatrix} \theta_{jt+1}\left(N_{it} - N_{it+1}\right) + \\ s_{jt+1}\left(N_{it+1}v_{jt+1} - T_{it+1}w_{it+1}\right) + \\ P_{it+1}T_{it+1}L_{it+1}^{\alpha_1}W_{it+1}^{\alpha_2}F_{it+1}^{\alpha_3} - r_{it+1}' X_{it+1} + \\ P_{it+1}T_{it+1}L_{it+1}^{\beta_1}W_{it+1}^{\beta_2}F_{it+1}^{\beta_3}\varepsilon_{it+1} \end{pmatrix} \\ -a\bar{c}_i + \Gamma_{it+1} \end{pmatrix}}{E_t\left[\exp -\gamma_i \left((1+a)\begin{pmatrix} \theta_{jt}\left(N_{it-1} - N_{it}\right) + \\ s_{jt}\left(N_{it}v_{jt} - T_{it}w_{it}\right) + \\ P_{it}T_{it}L_{it}^{\alpha_1}W_{it}^{\alpha_2}F_{it}^{\alpha_3} - r_{it}' X_{it} + \\ P_{it}T_{it}L_{it}^{\beta_1}W_{it}^{\beta_2}F_{it}^{\beta_3}\varepsilon_{it} \end{pmatrix} - a\bar{c}_i + \Gamma_{it} \right)\right]} \right) +$$

$$E_t\left[\ln\theta_{jt+1}\right] + \phi_{it+1} \tag{5.1.7}$$

Because $E_t\left[P_{it+1}T_{it+1}L_{it+1}^{\beta_1}W_{it+1}^{\beta_2}F_{it+1}^{\beta_3}\varepsilon_{it+1}\right]=0$ and $E_t\left[\Gamma_{it+1}\right]=0$, equation (5.1.7) simplifies to:[30]

$$\ln\left(\theta_{jt}-s_{jt}v_{jt}\right)=\ln\rho-\gamma_i E_t\left[(1+a)\begin{pmatrix}\theta_{jt+1}\left(N_{it}-N_{it+1}\right)+\\ s_{jt+1}\left(N_{it+1}v_{jt+1}-T_{it+1}w_{it+1}\right)+\\ P_{it+1}T_{it+1}L_{it+1}^{\alpha_1}W_{it+1}^{\alpha_2}F_{it+1}^{\alpha_3}-r'_{it+1}X_{it+1}\end{pmatrix}-a\bar{c}_i\right]-$$

$$\ln E_t\left[\exp-\gamma_i\left((1+a)\begin{pmatrix}\theta_{jt}\left(N_{it-1}-N_{it}\right)+\\ s_{jt}\left(N_{it}v_{jt}-T_{it}w_{it}\right)+\\ P_{it}T_{it}L_{it}^{\alpha_1}W_{it}^{\alpha_2}F_{it}^{\alpha_3}-r'_{it}X_{it}+\\ P_{it}T_{it}L_{it}^{\beta_1}W_{it}^{\beta_2}F_{it}^{\beta_3}\varepsilon_{it}\end{pmatrix}-a\bar{c}_i+\Gamma_{it}\right)\right]+E_t\left[\ln\theta_{jt+1}\right]+\phi_{it+1} \tag{5.1.8}$$

Equations (4.2.3), (5.1.2) and (5.1.3) imply that the second term of the right hand side of equation (5.1.8) represents the expectation in *t* of the expected consumption in *t+1* conditional to the information in that same period, i.e.

---

[30] I have assumed that input quantities are not stochastic in the current period or stochastically independent from ε, i.e. $E_t\left[P_{it}T_{it}L_{it}^{\beta_1}W_{it}^{\beta_2}F_{it}^{\beta_3}\varepsilon_{it}\right]=0$. Now, to explore the value of $E_t\left[P_{it+1}T_{it+1}L_{it+1}^{\beta_1}W_{it+1}^{\beta_2}F_{it+1}^{\beta_3}\varepsilon_{it+1}\right]$ I use that assumption and the law of iterated expectations to obtain:

$$E_t\left[P_{it+1}T_{it+1}L_{it+1}^{\beta_1}W_{it+1}^{\beta_2}F_{it+1}^{\beta_3}\varepsilon_{it+1}\right]=E_t\left[E_{t+1}\left[P_{it+1}T_{it+1}L_{it+1}^{\beta_1}W_{it+1}^{\beta_2}F_{it+1}^{\beta_3}\varepsilon_{it+1}\right]\right]=$$

$$E_t\left[E_{t+1}\left[P_{it+1}T_{it+1}L_{it+1}^{\beta_1}W_{it+1}^{\beta_2}F_{it+1}^{\beta_3}\right]E_{t+1}\left[\varepsilon_{it+1}\right]\right]=$$

$$E_t\left[E_{t+1}\left[P_{it+1}T_{it+1}L_{it+1}^{\beta_1}W_{it+1}^{\beta_2}F_{it+1}^{\beta_3}\right]0\right]=0.$$

The result $E_t\left[\Gamma_{it+1}\right]=0$ follows from the law of iterated expectations and the assumption that $E_{t+1}\left[\Gamma_{it+1}\right]=0$. In fact the law of iterated expectations implies that $E_t\left[\Gamma_{it+1}\right]=E_t\left[E_{t+1}\left[\Gamma_{it+1}\right]\right]$, and $E_{t+1}\left[\Gamma_{it+1}\right]=0$ implies $E_t\left[E_{t+1}\left[\Gamma_{it+1}\right]\right]=0$.

$E_t\left[E_{t+1}\left[C_{it+1}\right]\right]$[31]. I then write that expression in a more conventional time-series notation as $E_t\left[E_{t+1}\left[C_{it+1}\right]\right]=C_{it+1}+\xi_{it+1}$, where ξ_{it+1} is random error with conditional expectation equal to 0 (Cochrane, 2005, Chapter 9).

Assuming $E_t\left[\xi_{it+1}\right]=0$ implies that the unconditional mean $E\left[\xi_{it+1}\right]=0$ and that ξ_{it+1} is not correlated with the information set at time *t* (Wooldridge, 2002, Chapter 2.2.3). Thus, the proposed transformation presumes that, based on the set of information in period *t*, farmers can predict part of random consumption in *t+1,* but there is another part of future consumption represented by ξ_{it+1} that can not be predicted because is not related with the set of information at time *t*.

An identical argument can be used to transform the expectation of the natural log of the price of a water right in the right hand side of equation (5.1.8) as: $E_t\left[E_{t+1}\left[\ln\theta_{jt+1}\right]\right]=\ln\theta_{jt+1}+\zeta_{jt+1}$. As in the case of the transformation for consumption and for the same reasons that I have indicated above I assume that $E_t\left[\zeta_{jt+1}\right]=0$.

Substituting these transformations, $E_t\left[E_{t+1}\left[C_{it+1}\right]\right]=C_{it+1}+\xi_{it+1}$ and $E_t\left[E_{t+1}\left[\ln\theta_{jt+1}\right]\right]=\ln\theta_{jt+1}+\zeta_{jt+1}$, in equation (5.1.8) gives:

---

[31] Because production uncertainty realized its value at the end of the season, consumption in t+1 is not known until the end of that season. Thus, in t+1 the farmer only has an expectation of his consumption level for that season.

$$\ln\left(\theta_{jt}-s_{jt}v_{jt}\right)=\ln\rho-\gamma_i\left[(1+a)\left(\begin{array}{l}\theta_{jt+1}\left(N_{it}-N_{it+1}\right)+\\ s_{jt+1}\left(N_{it+1}v_{jt+1}-T_{it+1}w_{it+1}\right)+\\ P_{it+1}T_{it+1}L_{it+1}^{\alpha_1}W_{it+1}^{\alpha_2}F_{it+1}^{\alpha_3}-r'_{it+1}X_{it+1}\end{array}\right)-a\bar{c}_i\right]+\xi_{it+1}-$$

$$\ln E_t\left[\exp-\gamma_i\left((1+a)\left(\begin{array}{l}\theta_{jt}\left(N_{it-1}-N_{it}\right)+\\ s_{jt}\left(N_{it}v_{jt}-T_{it}w_{it}\right)+\\ P_{it}T_{it}L_{it}^{\alpha_1}W_{it}^{\alpha_2}F_{it}^{\alpha_3}-r'_{it}X_{it}+\\ P_{it}T_{it}L_{it}^{\beta_1}W_{it}^{\beta_2}F_{it}^{\beta_3}\varepsilon_{it}\end{array}\right)-a\bar{c}_i+\Gamma_{it}\right)\right]+\ln\theta_{jt+1}+\zeta_{jt+1}+\phi_{it+1}$$

(5.1.9)

In equation (5.1.9) the term $a\bar{c}_i$ cancels out. Then, reordering terms, equation (5.1.9) can be written as:

$$\ln\left(\theta_{jt}-s_{jt}v_{jt}\right)=\ln\rho-\gamma_i(1+a)\left(\begin{array}{l}\theta_{jt+1}\left(N_{it}-N_{it+1}\right)+\\ s_{jt+1}\left(N_{it+1}v_{jt+1}-T_{it+1}w_{it+1}\right)+\\ P_{it+1}T_{it+1}L_{it+1}^{\alpha_1}W_{it+1}^{\alpha_2}F_{it+1}^{\alpha_3}-r'_{it+1}X_{it+1}\end{array}\right)+\ln\theta_{jt+1}-$$

$$\ln E_t\left[\exp-\gamma_i\left((1+a)\left(\begin{array}{l}\theta_{jt}\left(N_{it-1}-N_{it}\right)+\\ s_{jt}\left(N_{it}v_{jt}-T_{it}w_{it}\right)+\\ P_{it}T_{it}L_{it}^{\alpha_1}W_{it}^{\alpha_2}F_{it}^{\alpha_3}-r'_{it}X_{it}+\\ P_{it}T_{it}L_{it}^{\beta_1}W_{it}^{\beta_2}F_{it}^{\beta_3}\varepsilon_{it}\end{array}\right)+\Gamma_{it}\right)\right]+\upsilon_{1it+1}$$

(5.1.10)

where $\upsilon_{1it+1}\equiv\phi_{it+1}+\xi_{it+1}+\zeta_{jt+1}$ is a composite error with $E_t\left[\upsilon_{1it+1}\right]=E_t\left[\phi_{it+1}\right]$.

The structural forms proposed in equations (5.1.1), (5.1.2) and (5.1.3) implies that the first order conditions for optimal quantities of water, labor and fertilizer, represented by equations (4.2.17) and (4.2.18) are, respectively:

$$E_t\left[\begin{array}{l} \exp-\gamma_i\left[(1+a)\begin{pmatrix}\theta_{jt}\left(N_{it-1}-N_{it}\right)+\\ s_{jt}\left(N_{it}v_{jt}-T_{it}w_{it}\right)+\\ P_{it}T_{it}L_{it}^{\alpha_1}W_{it}^{\alpha_2}F_{it}^{\alpha_3}-r_{it}'X_{it}+\\ P_{it}T_{it}L_{it}^{\beta_1}W_{it}^{\beta_2}F_{it}^{\beta_3}\varepsilon_{it}\end{pmatrix}-a\bar{c}_i+\Gamma_{it}\right]\\ \dfrac{\alpha_1P_{it}T_{it}w_{it}^{\alpha_1}L_{it}^{\alpha_2}F_{it}^{\alpha_3}+\beta_1P_{it}T_{it}w_{it}^{\beta_1}L_{it}^{\beta_2}F_{it}^{\beta_3}\varepsilon_{it}}{w_{it}}-s_{jt}\end{array}\right]=0 \qquad (5.1.11)$$

$$E_t\left[\begin{array}{l} \exp-\gamma_i\left[(1+a)\begin{pmatrix}\theta_{jt}\left(N_{it-1}-N_{it}\right)+\\ s_{jt}\left(N_{it}v_{jt}-T_{it}w_{it}\right)+\\ P_{it}T_{it}L_{it}^{\alpha_1}W_{it}^{\alpha_2}F_{it}^{\alpha_3}-r_{it}'X_{it}+\\ P_{it}T_{it}L_{it}^{\beta_1}W_{it}^{\beta_2}F_{it}^{\beta_3}\varepsilon_{it}\end{pmatrix}-a\bar{c}_i+\Gamma_{it}\right]\\ \left(\dfrac{\alpha_2P_{it}T_{it}w_{it}^{\alpha_1}L_{it}^{\alpha_2}F_{it}^{\alpha_3}+\beta_2P_{it}T_{it}w_{it}^{\beta_1}L_{it}^{\beta_2}F_{it}^{\beta_3}\varepsilon_{it}}{L_{it}}-r_{it1}\right)\end{array}\right]=0 \qquad (5.1.12)$$

$$E_t\left[\begin{array}{l} \exp-\gamma_i\left[(1+a)\begin{pmatrix}\theta_{jt}\left(N_{it-1}-N_{it}\right)+\\ s_{jt}\left(N_{it}v_{jt}-T_{it}w_{it}\right)+\\ P_{it}T_{it}L_{it}^{\alpha_1}W_{it}^{\alpha_2}F_{it}^{\alpha_3}-r_{it}'X_{it}+\\ P_{it}T_{it}L_{it}^{\beta_1}W_{it}^{\beta_2}F_{it}^{\beta_3}\varepsilon_{it}\end{pmatrix}-a\bar{c}_i+\Gamma_{it}\right]\\ \left(\dfrac{\alpha_3P_{it}T_{it}w_{it}^{\alpha_1}L_{it}^{\alpha_2}F_{it}^{\alpha_3}+\beta_3P_{it}T_{it}w_{it}^{\beta_1}L_{it}^{\beta_2}F_{it}^{\beta_3}\varepsilon_{it}}{F_{it}}-r_{it2}\right)\end{array}\right]=0 \qquad (5.1.13)$$

In the above equations the price for labor is denoted by r_1, and for fertilizer by r_2.

Using the already mentioned distributional assumptions for ε_{it} and Γ_{it}, and the assumption of distributional independence between $\left[P_{it}T_{it}L_{it}^{\beta_1}W_{it}^{\beta_2}F_{it}^{\beta_3}\varepsilon_{it}\right]$ and Γ_{it} (discussed above), plus the properties of the moment generating functions of the normal distributed variables ε_{it} and Γ_{it}[32], the system of equation (5.1.10) to (5.1.13) simplifies to:

The Euler Equation:

$$
\begin{aligned}
&\ln\left(\theta_{jt}-s_{jt}v_{jt}\right)=\ln\rho+\ln\theta_{jt+1}-\\
&\gamma_i(1+a)\left(\begin{pmatrix}\theta_{jt+1}\left(N_{it}-N_{it+1}\right)+s_{jt+1}\left(N_{it+1}v_{jt+1}-T_{it+1}w_{it+1}\right)+\\ P_{it+1}T_{it+1}L_{it+1}^{\alpha_1}W_{it+1}^{\alpha_2}F_{it+1}^{\alpha_3}-r'_{it+1}X_{it+1}\end{pmatrix}\right)+\\
&\gamma_i(1+a)\begin{pmatrix}\theta_{jt}\left(N_{it-1}-N_{it}\right)+\\ s_{jt}\left(N_{it}v_{jt}-T_{it}w_{it}\right)-r'_{it}X_{it}+\\ P_{it}T_{it}L_{it}^{\alpha_1}W_{it}^{\alpha_2}F_{it}^{\alpha_3}\end{pmatrix}-\\
&\gamma_i^2(1+a)^2\left(\frac{1}{2}\left(P_{it}T_{it}L_{it}^{\beta_1}W_{it}^{\beta_2}F_{it}^{\beta_3}\right)^2\right)-\gamma_i^2\frac{\sigma_{i\Gamma}^2}{2}+\upsilon_{1it+1}
\end{aligned}
\qquad (5.1.14)
$$

---

[32] For a random variable X distributed normal with mean μ and variance σ^2 the generation moment function is: $E\left(\exp tx\right)=\exp\left(t\mu+\frac{\sigma^2t^2}{2}\right)$. That implies

$$\frac{\partial E\left(\exp tx\right)}{\partial t}=E\left(x\exp tx\right)=\left(\mu+t\sigma^2\right)\exp\left(t\mu+\frac{\sigma^2t^2}{2}\right)$$ or

$$E\left(x\exp{-tx}\right)=\left(\mu-t\sigma^2\right)\exp\left(-t\mu+\frac{\sigma^2t^2}{2}\right)$$

The equations for the optimal variable input quantities:

$$\left(\frac{P_{it}\alpha_0 T_{it} w_{it}^{\alpha_0} L_{it}^{\alpha_1} F_{it}^{\alpha_2}}{w_{it}} - s_{jt} - \frac{\gamma_i (1+a)\beta_0 \left(P_{it} T_{it} w_{it}^{\beta_0} L_{it}^{\beta_1} F_{it}^{\beta_2}\right)^2}{w_{it}}\right) + \upsilon_{2\mathrm{it}} = 0$$

(5.1.15)

$$\left(\frac{P_{it}\alpha_1 T_{it} w_{it}^{\alpha_0} L_{it}^{\alpha_1} F_{it}^{\alpha_2}}{L_{it}} - r_{1it} - \frac{\gamma_i (1+a)\beta_1 \left(P_{it} T_{it} w_{it}^{\beta_0} L_{it}^{\beta_1} F_{it}^{\beta_2}\right)^2}{L_{it}}\right) + \upsilon_{3\mathrm{it}} = 0$$

(5.1.16)

$$\left(\frac{P_{it}\alpha_2 T_{it} w_{it}^{\alpha_0} L_{it}^{\alpha_1} F_{it}^{\alpha_2}}{F_{it}} - r_{2it} - \frac{\gamma_i (1+a)\beta_2 \left(P_{it} T_{it} w_{it}^{\beta_0} L_{it}^{\beta_1} F_{it}^{\beta_2}\right)^2}{F_{it}}\right) + \upsilon_{4\mathrm{it}} = 0$$

(5.1.17)

Those first order conditions indicate that input decisions depend on the marginal productivity of inputs, input prices, risk aversion and the effect of each input on the variance of output. The last two effects on optimal input quantities are captured by the second term within brackets in each of those equations. Given that γ_i is positive, that term is negative (positive) for risk decreasing (increasing) inputs. Thus for a risk-averse farmer, when an input is risk decreasing (increasing), he has an incentive to increase (decrease) the demand for this input.

It is important to notice that in equations (5.1.14) to (5.1.17) if the parameter *a* is equal to -1, then risk aversion does not affect farmer decisions on either water rights or input quantities. As it can be seen from equations (4.2.3) and (5.1.13) a value of -1 for *a* implies that the farmer's expected consumption in any season is equal to his "normal" consumption level. Moreover, with *a* = -1 farmer's consumption is not affected by random shocks in production, i.e. $C_{it} = \overline{c}_i + \Gamma_{it}$. This implies that the farmer has production full insurance or unlimited access to "other income sources" such as credits. Nevertheless, because neither production full neither insurance nor unlimited access to "other income sources are feasible I rule out the possibility of a = -1.

As in Love and Buccola (1991), Saha et al. (1994), Chavas an Holt (1996) and Kumbhakar (2002), among others, I added to equations (5.1.15), (5.1.16) and (5.1.17) the additive disturbances, υ_{2it}, υ_{3it}, υ_{4it}, associated with errors in optimization. Pope and Just (2003) find credible evidence in U.S. agricultural production of errors in optimization. I assume that these optimization mistakes occur in form of random failures, which support a stochastic structure to the equation system. That stochastic structure is needed to achieve an econometric estimation of the parameters of interest. In addition, I assume that these υ_{it}'s have conditional expected value equal to zero. I do not restrict the error terms of the first order condition for input quantities to be independent among equations for each farmer. Only the error term of the Euler Equation, υ_{1it+1}, is assumed to be independent of the error terms υ_{2it}, υ_{3it}, υ_{4it}. This assumption about the independence of the error term of the Euler Equation with respect to the error terms of the input equations is based on the structure of υ_{1it+1}. That structure indicates that υ_{1it+1} is a function of the random variable ξ_{it+1} that realizes its value in *t+1* and which I expect not to be correlated with errors in optimization for input quantities in period *t*.

I also assume that disturbances are correlated across farmers within equations. Therefore, $Cov_t\left[\upsilon_{hit},\upsilon_{hmt}\right]\neq 0$ for $i\neq m$ and for h=1,2,3,4. I only exclude correlations between errors associated with different farmers and across equations.

Given these assumptions regarding the error terms, $\upsilon=\left(\upsilon_1,\upsilon_2,\upsilon_3\right)$, the variance- covariance matrix of υ, which is denoted by Ω is specified as follows:

$$\Omega=E_t\left(\upsilon\upsilon'\right)=\begin{bmatrix}\Sigma_{11} & 0I_{N*N} & 0I_{N*N} & 0I_{N*N}\\ 0I_{N*N} & \Sigma_{22} & \sigma_{23}I_{N*N} & \sigma_{24}I_{N*N}\\ 0I_{N*N} & \sigma_{32}I_{N*N} & \Sigma_{33} & \sigma_{34}I_{N*N}\\ 0I_{N*N} & \sigma_{42}I_{N*N} & \sigma_{43}I_{N*N} & \Sigma_{44}\end{bmatrix}$$

Here Ω is a matrix of order *N*H x N*H* with *N* the number of farmers, *H* the number of equations, $\Sigma_{hh}=E_t\left[\upsilon_h\upsilon_h'\right]$ and $\sigma_{gh=Cov_t}\left(\upsilon_{git},\upsilon_{hit}\right)$, for *g*=2,3,4 and *h*=2,3,4.

5.2 Data

The data set has two parts and contains data for the four main WUAs associations in the Limarí Valley[33]. The first part contains a cross-section time series sample on farmers over two agricultural seasons (98/99 and 99/00). It includes micro level data for farming activity. The second part of the data contains time series for: i) water right prices and water right transactions for the period 1981 to 2001; ii) spot market water prices and water transactions for the period 1995 to 2000; and iii) water accorded to water rights for the period 1980 to 2000.

The farmer micro-level data is obtained from a two-round survey that I conducted. This survey was performed in the Limarí Valley (see the survey

---

[33] Those WUAs are: *Asociación de Canalistas del Canal Camarico* (ACCC); *Asociación de analistas del Embalse Cogotí* (ACEC); *Junta de Vigilancia del Río Limarí* (JVRL); and *Asociación de Canalistas del Embalse Recoleta* (ACER).

instrument in the Annex). Farmers from the main irrigated areas within this key agricultural region were interviewed. The sample was designed by Zegarra (2002)[34] who conducted a previous survey on that same valley. In the first round (SI), surveyed in 1999, I collected information for the 98/99 season from 161 farmers. The second round (SII) was conducted in 2000 and I collected information for the 99/00 season from 151 farmers.

The farm level data set includes seasonal information on crop production, input use for each crop, output and input prices, irrigation methods, water right transactions, volume of water bought or sold in the spot market, land transactions, livestock inventory, renting in or out of machinery, asset ownership, farmer's liabilities, household characteristics, family labor, well access and water storage capacity, marketing, governmental subsidies to improve irrigation systems and water expectations for the coming season.

As is usual in surveys that collect data, I have gaps in the data due to attrition and survey non-response. Balgati (2001) presents the rate of attrition for a sample of studies that use panel data. In my sample, attrition from the first to the second round surveys that I conducted is comparable to that obtained in other empirical works. Non-response is caused by farmers that have sold or have decided to abandon their land, farmers previously interviewed that were not subsequently located and farmers

---

[34] Zegarra did not develop a list of farmers to interview based on a random sample due to the expense of finding each sampled individual; instead, he simulated random sampling for farmers who were present at their farm when he conducted the survey. He began at some point inside the irrigated area (stratum), interviewing farmers using a systematic round skipping for close neighbors. This results in a sample, which is geographically representative for each irrigation organization. The main limitation of this sampling procedure is that farmers who were not present at the moment of the survey had zero probability of being selected. The procedure also excludes farmers who, at the moment of the survey, had abandoned production.

who refused to answer (7 and 4 farmers in the first and second rounds refused to answer, respectively). The causes of non-response suggest few if any behavioral reasons behind this problem; hence, the consequences of attrition appear to be minimal.

There is missing data arising from partial response to survey questions. This is mainly due to the fact that most farmers do not keep written records of the information requested in the survey. In fact, only five among all surveyed farmers had written records on most of the surveyed data. Thus, in most cases, a partial response occurs when the respondent fails to answer a question because he has difficulty recalling events that occurred in the past.

One way to handle the missing data problem is by imputing missing observations. Nevertheless, as Cameron and Trivedi (2005) point out "there is a cost of imputing missing data that comes from having to make assumptions to support a procedure for generating proxies for the missing observations, and from the approximation error inherent in such a procedure."

Alternatively, it is possible to handle missing data by deleting them and analyze only the reduced sample of "complete" observations. That procedure is called listwise deletion. Its consequences for the econometric estimation depend on the missing data mechanism. If the probability of missing data of the variables in the data set depends neither on its own values nor on the values of other variables in the data set, then missing data process is completely at random. In that case the remaining set after listwise deletion remains a random sample from the original population and the estimates based on it are consistent (Cameron and Trivedi, 2005).

If the probability of missing data on a variable does not depend on its value but may depend on the values of other variables in the data set, then data is missing at random. If the data set has gaps due to data missing at random and the parameters for the missing data-generation process are unrelated to the parameters that one wants to estimate, then the missing data problem is ignorable and the complete data set after listwise deletion allows for consistent estimation of the parameters of interest (Cameron and Trivedi, 2005). Nonetheless, under either the missing data complete at random or just missing data at random assumptions, listwise deletion still reduces efficiency in the estimation.

For the case of the missing data problem in my survey, the causes of non-response suggest few if any behavioral reasons behind this problem. Furthermore, missing data due to a partial response to survey questions is mainly related to the difficulty of some farmers to recall past data. Thus, it seems reasonable to assume my data set is characterized by missing data complete at random or at least missing at random. Therefore I handle the missing data problem using listwise deletion.

The Euler Equation (5.1.14) links farmers' decisions in two seasons. This requires full data for each farmer in the two seasons under study. That requirement causes substantial sample loss and after the listwise deletion process the number of farmers that fulfill that requirement is 32.

The following table provides some statistics on the most important variables in the model for the whole sample as well as for sub-sample of 32 farmers used in this dissertation (referred to in what follows as the sub-sample).

Table 5.1: Basic statistics of the main variables

	Whole sample						**Sub-sample (3 2 farmers)**			
Variable	**SI**			**SII**			**SI**		**SII**	
	Number of observations.	mean	Standard deviation	Number of observations	mean	Standard deviation	mean	Standard deviation	mean	Standard deviation
Cultivated land (hectare)	161	12.1	25.2	148	10.3	17.9	12	21.3	11.4	18.5
Labor (hours per hectare)	148	1242	2115	137	1021	1674	1099	1437	987	1201
Nitrogen (kilograms per hectare)	117	258.2	458.6	137	109.8	151.5	320	591	125.7	170.9
Input water (cubic meters per hectare)	144	15766	20763	132	9145	9997	6958	5129	8674	16081
Number of water rights	155	20.7	37	141	20.2	36	15.6	14.7	17.3	19.0
Education (years of schooling)	151	8.3	4.7	139	8.0	4.7	8.6	4.7	8.7	4.6
Experience (years)	134	30.4	14.3	118	25.6	13.0	28.6	14.3	30.5	13.6
Household size	131	4.7	3.3	102	4.8	3.2	4.9	3.6	4.9	3.0
Percentage of multioutput producers	53.7%			52.11%			31.3%		34.3%	

Table 5.1 shows that sample mean values from the whole samples are close to the sample mean values from the sub-samples for all the reported variables but input water per hectare in survey I. The percentages of multioutput producers in the sub-samples are lower than in the whole sample. If farmers' decisions on the number of crops they grow are related to their risk aversion, then differences in the percentage of multioutput producers may cause a bias problem. That may be the case if an estimation of risk aversion for a "representative farmer" is intended with the sub-samples. In this dissertation I test for differences in risk aversion among farmers. As I explain in next chapter, that test is based on the effect of farmer's specific characteristics upon his risk aversion and, as a consequence, it is not subject to the above mentioned bias problem.

Annual average price for water rights and water right transaction time series for the period 1981 to 2001 were obtained through the *Conservador de Bienes Raíces* of Ovalle and the records kept by the WUAs[35]. Water prices and water transactions in the spot market time series for the period 1995 to 2000 were constructed using the records of the WUAs, information obtained from the *Direccion de Riego* and the two-round survey. For water accorded to water rights I use data from the WUAs.

In the equation system (5.1.14) to (5.1.17), the land input is measured as the total hectares of cultivated land. No distinction is made as to whether land is owned, rented or sharecropped[36].

---

[35] The series for water right prices and transactions between 1981 and 1992 were collected by Zegarra (2002) and between 1992 and 2000 by Cristi et al. (2002) and Vicuña (2000).

[36] Sharecroppers were considered as single producers.

Production input water is measured as the farmer's total number of water rights times the amount of water accorded to each right plus net sales of water volumes[37]. The amount of water obtained through that formula was weighted by farmer's average irrigation efficiency[38].

Labor is total hours per growing season and is obtained by grouping together three different types of labor: family workers, permanent hired workers, and hired workers for specific activities (temporary workers). The survey data show that some farmers only use family work, others have permanent hired workers and others hire workers for specific activities and time periods (temporary workers). For those farmers with a mix of workers it is not possible to infer from the available data how many hours worked correspond to each type of worker. Thus I restrict my econometric results by making no distinction among type of workers.

Fertilizer is measured in kilograms of nitrogen.

---

[37] Farmers may decide not to use all the water accorded to their water rights, but saving water from one season to the next has a penalty of 15% to 20% of the endowment which makes this practice rare (Zegarra 2002). Moreover, the existence of a price greater than zero for water in the spot market implies that rational farmers will not resign to any amount of water accorded to their water rights.

[38] Because irrigation systems vary among land plots within the same farm I use farmer's average irrigation efficiency. This was calculated as the arithmetic mean of the farmer's irrigation efficiency in his different plots within the same farm:

$$\frac{\sum_{q=1} \left(irrigation\ eficiency\ in\ plot\ q\right)}{total\ cultivated\ land},$$

where irrigation efficiency varies accordingly to the following table:

Irrigation system/ Efficiency	Drip	Sprinkler	Furrow	Flood
	90%	75%	65%	45%

Source: *Comisión Nacional de Riego, Gobierno de Chile*

Some farmers in the sample produce more than one crop. For those farmers I represent output price by a farmer-specific weighted average of all the farmgate prices of the farmer's crops. As in Saha et al. (1994) I use the product specific income shares as weights for each crop price. Furthermore, because prices depend on the arbitrary output units they value[39] I have divided each farmgate price by is sample mean[40]. This scaling procedure does not affect the relations that I intend to estimate econometrically with my model.

For wages paid to labor, η, I use the per hour payments to temporary workers. Those payments are a good proxy of the labor price that each farmer faces on the labor market. I also estimate total labor cost by multiplying wages by total hours worked. That procedure values the work of permanent hired workers and family workers as equal with the work done by temporary workers. Three farmers in the sample do not hire temporal workers. For them, I use the daily payment to their permanent workers as the wage rate. Finally, three other farmers use only unpaid family workers so I use the sample average of the per hour payments to temporary

---

[39] As an example, potatoes can be measured in kilograms and there is a price for the kilogram of potatoes. Nevertheless, potatoes are also exchanged in sack units of 50 kilograms and the price of a sack is higher than the price for a kilogram. In the estimation of an average price the price of potatoes will be given more weight if I arbitrarily use the price of a sack of potatoes. This problem can be eliminated by dividing potato prices by their sample mean. The sample mean for the price of each crop has to be calculated over farmgate prices that value identical units of that crop.

[40] The sample average price of crop *k* in season *t*, $\overline{p}_{kt}$, is calculated as: $\overline{p}_{kt} = \sum_{i}^{n_k} p_{kit} / n_k$ where p_{kit} is the farmgate price of crop *k* for farmer *i* in period *t*, and n_k is the total number of surveyed farmers that produce crop *k* in season *t*.

workers as proxy of their labor cost. Here I am assuming that family workers can at least get the average wages for temporary workers by working off-farm.

The nitrogen price aggregate, r_2, is computed as an arithmetic mean using expenditure shares as the weights. Different nitrogen prices are obtained by dividing unit fertilizer prices by kilograms of nitrogen per unit of fertilizer:

$$\frac{PF_{fit}}{UN_f} \tag{5.2.1}$$

where PF_{fit} is the unit price of fertilizer f paid by farmer i in period t and UN_f equals kilograms of nitrogen contained in one unit of fertilizer f. In the sample data there is one farmer that reports a value of zero for nitrogen. Because the underlying assumption of this dissertation is that observed farmers decisions are optimal, I take that amount of nitrogen as the farmer's optimal decision for the quantity of that input. The nitrogen price for this observation is set at the arithmetic sample average of nitrogen prices. The underlying assumption is that the farmer can do as well as the average farmer in buying fertilizer input.

Chapter 6: Estimation and results

The estimation of the parameters ρ, γ, a and the parameter vectors α, β, Ω is based on Full Information Maximum Likelihood (FIML) assuming a multivariate normal distribution in the residuals of the system of equations. The likelihood of the sample is:

$$L\left(\gamma,\alpha,a,\beta,\rho,\Omega\middle|Z\right)=(2\pi)^{-NT/2}\left|\Omega\right|^{-1/2}\exp\left(-1/2\right)F(Z,\rho,\gamma,\alpha,\beta)'\,\Omega^{-1}F(Z,\rho,\gamma,\alpha,\beta))\left|J_t\right| \tag{6.1}$$

where Z=(Z_1,Z_2) is the vector of variables in the model. Z_1 is the set of endogenous variables in the model, i.e. $Z_1=\left(N,w,X\right)$. Z_2 represent the set of exogenous variables, i.e.

$$Z_2=\begin{pmatrix}\theta_{jt},\theta_{jt+1},s_{jt},s_{jt+1},v_{jt},v_{jt+1},P_{it},P_{it+1},T_{it},T_{it+1},r_{i1t},r_{i1t+1},r_{i2t},r_{i2t+1},w_{it+1},\\ L_{it+1},F_{it+1},N_{it-1},N_{it+1}\end{pmatrix}.$$

$J\equiv\det\left[\dfrac{\partial F(Z,\rho,\gamma,\alpha,\beta)}{\partial Z_1}\right]$ is the Jacobian of the transformation from υ to Z_1.

Consistent estimation of the system of equations (5.1.14) to (5.1.18) requires that the exogenous variables in the model are not correlated with the error term of the Euler Equation, $\upsilon_{1it+1}\equiv\phi_{it+1}+\xi_{it+1}+\zeta_{jt+1}$. Nevertheless, because that error term contains an omitted variable, ϕ_{it+1}, some of the regressors may be correlated with υ_{1it+1}. If so, the explanatory variables that are correlated with υ_{1it+1} are endogenous (Kapetanios, 2004). Hence, I need to test for endogeneity of the regressors in the Euler Equation. For that purpose I use a test proposed by Hausman (1978), which I describe in detail in the Appendix at the end of this chapter. Also I test whether the conditional mean of the error term in the Euler Equation is zero, i.e. $E\left[v_{1it+1}\middle|Z_2\right]=0$. The latter test procedure is as follows. First I obtain the FIML estimated residuals for the Euler Equation. Then I estimate a linear regression of those errors on a constant. If the constant is not statistically significant I do no reject the hypothesis of a conditional mean value of zero for the error terms in the Euler Equation.

Due to the lack of a longitudinal data, the estimation of the parameter for preferences, γ_i, for each farmer is addressed by assuming that his utility function is based on known farmer characteristics (Zeldes, 1989, Blundell et al., 1994, Dubois, 2001). Thus, the parameter that represents a farmer's preferences is parameterized as an exponential function of that farmer's education (*ED*), experience (*EXP*) and household size (*HS*)

$$\gamma_i = \exp\left(\gamma_0 + \gamma_1 ED_i + \gamma_2 EXP_i + \gamma_3 HS_i\right) \tag{6.2}$$

where γ_0, γ_1, γ_2, γ_3 are unknown parameters. The exponential form ensures that γ_i is positive. Hence, the right hand side of (6.2) replaces γ_i in the system of equations (5.1.14) to (5.1.18).

For the variance of the random error Γ_{it} in the equation for the variable I_{it}, equation (5.1.3), I propose the following specification:

$$\sigma_{i\Gamma}^2 = \exp\left(\delta_0\right) D_{il}^{\delta_1} D_{ic}^{\delta_2} \tag{6.3}$$

where δ_0, δ_1, δ_2 are unknown parameters, and D_{il} and D_{ic} are dummy variables that indicate whether the farmer has livestock and whether the farmer has access to consumption or production credit, respectively[41]. The exponential form for the constant δ_0 ensures that the variance of Γ_{it} is positive.

Sample data indicates that a good number of farmers invest in livestock and that cattle are sold and bought quiet often by the farmers, probably to mitigate consumption volatility (Rosenzweig and Wolpin, 1993). The investment decision in livestock should affect the variance of I_{it} because asset returns do not have the same variances in a real situation. Moreover, farmers without credit restrictions can experience higher changes in I_{it} because when it is needed they can substitute for present net income from production and water transactions with market loans. Furthermore, for those farmers, when income is greater than their "normal" consumption levels they probably devote an important part of that difference to pay their debts. Additionally, farmers with access to credit can face riskier activities and therefore higher expected incomes precisely because they can solve consumption smoothing through indebtedness. As a consequence, it is expected that farmers without credit restrictions exhibit a higher variance in I_{it}.

That structure for the variance of Γ_{it} also allows me to control for the effect of two main other income sources (credits and sales of cattle) when choosing optimal decisions for consumption smoothing. In the present context of incomplete markets, farmers maintain water rights not only for production but also for consumption smoothing and this justifies the necessity for controlling from other income sources.

---

[41] The variable D_{il} takes the value of 2 if farmers have livestock and the value of 1 other wise. In the case of D_{ic} it takes the value of 2 if farmers have access to credit and the value of one other wise. I have used the value of 1 and 2 instead of 0 and 1 to allow convergence in the estimation procedure.

This allows me to better explain within my model, decisions upon the number of water rights held by a farmer.

In the construction of the dummy variable for credit, those farmers that have received a credit in any of the agricultural seasons that go from the 95-96 to 99-00 seasons where classified as farmers with access to credit, otherwise they were labeled as farmers without access to credit.

The parameter a in equation (5.1.3), the parameter δ_0 in equation (6.3), as well as the constants terms of the Just-Pope production function are not separately identifiable from the parameter γ_0 in the equation system (5.1.14) to (5.1.17). The latter is the constant term in the specification for risk aversion in equation (6.2). Thus the equation (5.1.14) should be written as:

$$
\begin{aligned}
&\ln\left(\theta_{jt} - s_{jt}v_{jt}\right) = \ln\rho + \ln\theta_{jt+1} - \\
&\exp\left(\gamma_0 + \tilde{a} + \gamma_1 ED_i + \gamma_2 EXP_i + \gamma_3 HS_i\right)\left(\begin{pmatrix} \theta_{jt+1}\left(N_{it} - N_{it+1}\right) + s_{jt+1}\left(N_{it+1}v_{jt+1} - T_{it+1}w_{it+1}\right) + \\ P_{it+1}T_{it+1}L_{it+1}^{\alpha_1}W_{it+1}^{\alpha_2}F_{it+1}^{\alpha_3} - r_{it+1}^{\prime}X_{it+1} \end{pmatrix}\right) + \\
&\exp\left(\left(\gamma_0 + \tilde{a} + \gamma_1 ED_i + \gamma_2 EXP_i + \gamma_3 HS_i\right)\right)\begin{pmatrix} \theta_{jt}\left(N_{it-1} - N_{it}\right) + \\ s_{jt}\left(N_{it}v_{jt} - T_{it}w_{it}\right) - r_{it}^{\prime}X_{it} + \\ P_{it}T_{it}L_{it}^{\alpha_1}W_{it}^{\alpha_2}F_{it}^{\alpha_3} \end{pmatrix} - \\
&\exp\left(2\gamma_0 + 2\tilde{a} + 2\gamma_1 ED + 2\gamma_2 EXP + 2\gamma_3 HS\right)\left(\frac{1}{2}\left(P_{it}T_{it}L_{it}^{\beta_1}W_{it}^{\beta_2}F_{it}^{\beta_3}\right)^2\right) - \\
&\exp\left(2\gamma_0 + \delta_0 + 2\gamma_1 ED + 2\gamma_2 EXP + 2\gamma_3 HS\right)\frac{D_{il}^{\delta_1}D_{ic}^{\delta_2}}{2} + \upsilon_{1it+1}
\end{aligned}
\tag{6.4}
$$

where $\exp\left(\tilde{a}\right) = \left(1 + a\right)$. Thus I estimate the parameters $\ln\rho$, $\tilde{\gamma}_0$, γ_1, γ_2, γ_3, $\tilde{\tilde{\gamma}}_0$ plus the parameter vectors α and β. With $\tilde{\gamma}_0 = \gamma_0 + \tilde{a}$ and $\tilde{\tilde{\gamma}}_0 = 2\gamma_0 + \delta_0$. In the input equations I also estimate $\tilde{\gamma}_0$ instead of γ_0. As a consequence, I can not estimate a specific value for the coefficient of risk aversion. Nevertheless, in spite of the identification problem of γ_0, I can still test whether risk aversion is heterogeneous among farmers.

FIML procedure requires an initial value for each of the parameters of the system. Love and Buccola (1991) and Saha et al. (1994) estimate farmers' preferences and production technology jointly in the presence of risk. They estimate parameters for preferences and production technology from the first order conditions of the maximization of the expect utility with respect to inputs. In both studies, starting values for the production function parameters are provided by a prior estimation of the Just-Pope production function. Nevertheless, if inputs are endogenous, they should be correlated with the error term in the production function. The Just-Pope parameter estimates are then inconsistent (Love and Buccola, 1991). Due to that problem with the estimation of the Just-Pope production function, I have chosen to obtain starting values for the production function parameters from a prior estimation of the input demand system in my model. The estimates from those equations provide the set of starting values for a new estimation of the whole system, i.e. the input equations together with the Euler Equation.

For the constant discount factor, ρ, I use as a starting value the reciprocal of one plus the market annual interest rate on year 1998. For the constant in the equation for the variance of Γ_{it} (equation (6.3)) I use a value of zero as starting value and a value of one for the parameters of livestock and credit.

Data used in the estimation presents large differences in the scale of the variables. Therefore, I have re-scaled the values of the variables dividing each variable by its sample standard deviation (with the only exception of dummy variables of the equation (6.3)). Scaling the data facilitates convergence of the estimation and does not affect the measurement of the underlying relationship among the variables in the model neither the t-statistics, but it does affect the interpretation of the parameter estimates (Carter et al., 1997, Chapter 6). The latter is not a problem for the analysis developed in this dissertation that focus on the significance and the sign of the parameter estimates rather than on their numerical values. Finally, a constant term was added to each input equation in order to ensure a zero mean value for the error terms.

The descriptive statistics for the variables used in the estimation of the system of equations are reported in Table 6.1.

Table 6.1: Descriptive statistics for variables used in the estimation of the system of equations.

Variable name (season) (all nominal variables are in Chilean pesos of year 1990)	**Variable description**	**Max**	**Min**	**Average**	**Standard deviation**
Number of water shares (96-97)	Units	65.5	0.25	18.2	17.5
Number of water shares (97-98)	Units	65	0.0	17.8	17.9
Number of water shares (98-99)	Units	65	0.25	15.6	14.7
Number of water shares (99-00)	Units	80	0.0	17.3	19
Water accorded to water rights (97-98)	Cubic meters	6633	5000	6039	526.0
Water accorded to water rights (98-99)	Cubic meters	6633	3000	4933	1193
Water accorded to water rights (99-00)	Cubic meters	6633	3000	4969	1227
Education (98-99)	Years of schooling	17	1	8.6	4.7
Experience (98-99)	Years	50	1	28.6	14.3
Household size (98-99)	Number of people leaving in the same house	18	1	4.9	3.6
Education (99-00)	Years of schooling	17	2	8.7	4.6

Cont. Table 6.1: Descriptive statistics for variables used in the estimation of the system of equations

Variable name (season) (all nominal variables are in Chilean pesos of year 1990)	Variable description	Max	Min	Average	Standard deviation
Experience (99-00)	Years	51	10	30.5	13.6
Household size (99-00)	Number of people leaving in the same house	15	1	4.9	3.0
Land (98-99)	Total cultivated land	116	0.2	12	21.3
Labor (98-99)	Total number of hours on the season per cultivated hectare	7400	15.36	1099	1437
Fertilizers (98-99)	Kg. of nitrogen per cultivated hectare	2818	0.00	320	591
Water used as input by the farmer (98-99)	Cubic meters per cultivated hectare	18720	1485	6958	5129
Land (99-00)	Total cultivated Land	90	0.12	11.4	18.5
Labor (99-00)	Total number of hours on the season per cultivated hectare	4533.3	8.5	987	1201
Fertilizers (99-00)	Kg. of nitrogen per cultivated hectare	816.7	0.0	125.7	171
Water used as input by the farmer (99-00)	Cubic meters per cultivated hectare	93750	1782	8674	16081

Cont. Table 6.1: Descriptive statistics for variables used in the estimation of the system of equations

Variable name (season) (all nominal variables are in Chilean pesos of year 1990)	**Variable description**	**Max**	**Min**	**Average**	**Standard deviation**
Labor price (98-99)	Chilean pesos	7800	2750	4238.8	919.7
Fertilizer price (98-99)	Chilean pesos	2717	51.9	985.5	686.7
Water price in the spot market (98-99)	Chilean pesos	12.52	6.77	8.93	2.34
Labor price (99-00)	Chilean pesos	5500	3250	4107.2	664.4
Fertilizer price (99-00)	Chilean pesos	6512.9	157.7	1133.6	1141.3
Water price in the spot market (99-00)	Chilean pesos	9.72	2.11	6.61	2.65
Water right prices (97-98)	Chilean pesos	456876	176775	286788	106160
Water right prices (98-99)	Chilean pesos	554981	172496	361797	155830
Water right prices (99-00)	Chilean pesos	588887	197404	332714	131889
Output price index (98-99)	Chilean pesos	3.72	0.29	1	0.87
Output price index (99-00)	Chilean pesos	5.14	0.35	1.16	1.28
Labor cost (98-99)	Chilean pesos	31256007	15726	2010805	5434032

Cont. Table 6.1: Descriptive statistics for variables used in the estimation of the system of equations

Variable name (season) (all nominal variables are in Chilean pesos of year 1990)	**Variable description**	**Max**	**Min**	**Average**	**Standard deviation**
Fertilizer cost (98-99)	Chilean pesos	10641458	16163	665187	1860068
Labor cost (99-00)	Chilean pesos	42203503	12555	2314106	7486319
Fertilizer cost (99-00)	Chilean pesos	3132494	0.0	325774	645616
Gross output revenue per hectare (98-99)	Chilean pesos	13255140	47324	1759103	2675375
Gross output revenue per hectare (99-00)	Chilean pesos	8923973	84547	1579336	2115119

I specify the variance-covariance matrix allowing different variances for the disturbances of each equation and contemporaneous correlation among the disturbances of the input first order conditions corresponding to the same farmer. Heteroskedasticity for the errors of the Euler Equation is expected because they are defined as $\upsilon_{1it+1} \equiv \phi_{it+1} + \xi_{it+1} + \zeta_{t+1}$, and it is reasonable to expect that the $Var_t\left[\phi_{it+1}\right]$, i.e. the variance of the conditional volatility of the discounted water right price for each farmer, differs among farmers. Nevertheless, the correlogram of the square residuals, the conditional heteroskedasticity (ARCH) test and the Cusum squares test indicate that the null hypothesis of homokedastic error terms of the Euler Equation cannot be rejected. The same result is obtained for the error terms of the input equations for water and fertilizer. In the case of the errors of the labor equation, only the Cusum squares test does reject that hypothesis.

To test for correlation among errors corresponding to different farmers within the same equation, I use the Ljung-Box Q-statistic which is commonly used to test whether the disturbances are white noise. Based on this test I do not reject the hypothesis that the errors are not correlated.

The resulting variance-covariance matrix can be summarized by:

$$\Omega = E_t\left(\upsilon\upsilon'\right) = \begin{bmatrix} \sigma_{11} I_{N*T} & 0 I_{N*T} & 0 I_{N*T} & 0 I_{N*T} \\ 0 I_{N*T} & \sigma_{22} I_{N*T} & \sigma_{23} I_{N*T} & \sigma_{24} I_{N*T} \\ 0 I_{N*T} & \sigma_{32} I_{N*T} & \sigma_{33} I_{N*T} & \sigma_{34 N*T} \\ 0 I_{N*T} & \sigma_{42 N*T} & \sigma_{43 N*T} & \sigma_{44} I_{N*T} \end{bmatrix}$$

Estimates of the error covariances between input equations are obtained from:

$\hat{\sigma}_{gh} = \frac{1}{N} \sum_{i=1}^{N} \hat{\upsilon}_{gi} \hat{\upsilon}_{hi}$, where g=2,3,4 and h=2,3,4.

Residuals $\hat{\upsilon}_{gi}$ and $\hat{\upsilon}_{hi}$ are the maximum likelihood estimated residuals in each iteration.

Efficient estimation of the Euler Equation is required for the Hausman test in that equation (Wooldridge, 2002, Chapter 6.2.1). Because I ensure an efficient estimation of that Equation with the above mentioned specification of the variance-covariance matrix, I can use the Hausman test for possible endogeneity of some of the regressors due to an omitted variables problem in the Euler Equation. Result of the test indicates that I can not reject the null hypothesis that those variables are individually and jointly exogenous. This provides evidence that the parameters of the model are estimated consistently and that they are unbiased. In fact a maximum likelihood ratio test for the null hypothesis that the variables are jointly exogenous gives a value equal to 1.70 which is lower than the critical value of 12.8 for a Chi-Squared with 5 degrees of freedom and a significance level of 5%. Moreover, the test for the conditional mean of the error terms in each equation indicates that I can not reject the hypothesis that the residuals have conditional mean equal to zero. This result for the Euler Equation is fully consistent with the above result of the Hausman test, because $E\left[\upsilon_{hit+1} \middle| Z_2\right]=0$ implies $E\left[\upsilon_{hit+1} Z_2\right]=0$.

A Jarque-Bera test for normality of the errors shows that I cannot reject the null of normality for the residuals of each of the equations within the system but the equation that describes first order condition for labor.

Parameter estimates are shown in Table 6.2. Results indicate that all the parameters are significant at 1% of significance level, but the parameters for household size and the dummy variable that indicate whether the farmer has livestock are not statistically significant.

Table 6.2: Estimates of the parameters of the equation system using FIML

	Coefficients (Standard Errors)
Estimates of the deterministic part of the production function (vector α)	
Water inputs per hectare	0.86 (0.10)
Labor per hectare	2.43 (0.08)
Fertilizer use per hectare	0.44 (0.03)
Estimates of the stochastic part of the production function (vector β) Parameters	
Water inputs per hectare	2.28 (0.13)
Labor per hectare	0.04 (0.01)
Fertilizer use per hectare	0.15 (0.02)
Estimates of the parameters for the equation for farmers preferences (vector γ)	
Constant ($\tilde{\gamma}_0$)	5.2 (0.31)
Education	-1.92 (0.08)
Experience	-2.10 (0.14)
Family Size	-0.12 (0.08)
Estimates of the parameters for the variance of Γ_{it} (vector δ)	
Constant ($\tilde{\tilde{\gamma}}_0$)	-5.1 (0.34)

Cont. Table 6.2: Estimates of the parameters of the equation system using FIML

Livestock (D_l)	-0.44 (7.44)
Credit (D_c)	7.77 (1.22)
Estimates of other parameters	
Discount factor (ρ)[42]	0.93 (0.05)
Estimates of other parameters	**Values**
Estimated variance of the Euler Equation	0.08
Estimated variance of the water equation	0.88
Estimated variance of the labor equation	1.06
Estimated variance of the fertilizer equation	0.88
Estimated correlation between water and fertilizer errors	0.02
Estimated correlation between labor and fertilizer errors	0.33
Estimated correlation between labor and water errors	-0.12
Jarque-Bera Test for normality of the errors	**(p-value in parenthesis)**
Euler	0.31 (0.86)
Water	4.86 (0.09)
Labor	67.38 (0.0)
Fertilizer	5.74 (0.06)
	Values
Number of observations	32
Maximum Likelihood	82.5

---

[42] In the Euler equation I estimate the natural log of the discount factor ($\ln \rho$) and I use the Deltha Method to obtain the standard deviation of the discounted factor, ρ .

In order to check the accuracy of the estimation, I compute Theil's Inequality coefficient over gross output income per hectare[43] and water rights investments[44]. That coefficient always falls between 0 and 1. If it takes the value of 0 there is a perfect fit in the model; if it takes the value of 1, the predictive performance of the model is bad. Moreover, Theil's Inequality coefficient can be decomposed in the bias (variance) proportion that indicates how far the mean (variance) of the predicted values is from the mean (variance) of the actual data (Pindyck and Rubinfeld, 1998, Chapter 8). For good forecasts, the bias and variance proportions are small. Because gross output income per hectare and water rights investments have been normalized by their standard deviation respectively, the comparison between the variance of the predicted value and the variance of the actual data is meaningless. Thus, comparison is limited to the bias proportion. For gross output income per hectare Theil's Inequality coefficient is 74% and the bias proportion is 1.7E-5. For water rights investments Theil's Inequality coefficient is 76% and the bias proportion is 1.01E-5. Those low values of the bias in the means allow me to disregard the possibility of systematic bias in the prediction of those variables with my model. Figures 6.1 and 6.2 report the actual value of output income per hectare and water right investments against the imputed values for those variables, based on the estimates in Table 6.2.

---

[43] On my model the expected value of gross output income per hectare corresponds to: $P_{it} T_{it} w_{it}^{\alpha_0} L_{it}^{\alpha_1} F_{it}^{\alpha_2}$.

[44] Investment in water rights corresponds to: $\theta_{jt} \left(N_{it-1} - N_{it} \right)$

Figure 6.1: Actual value of standardized gross output income per hectare against the imputed values for that variable.

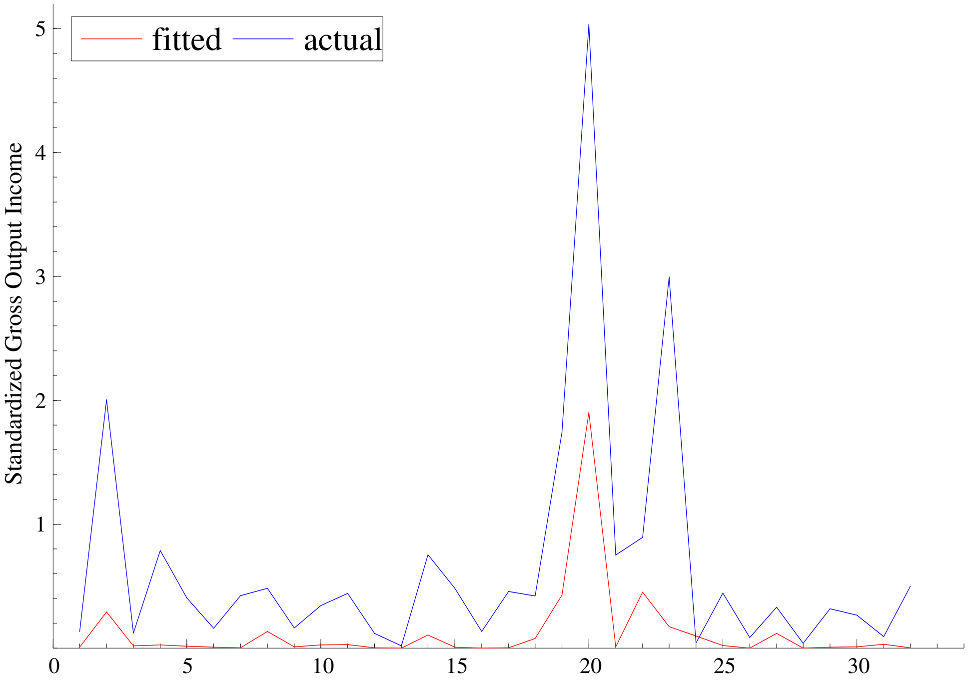
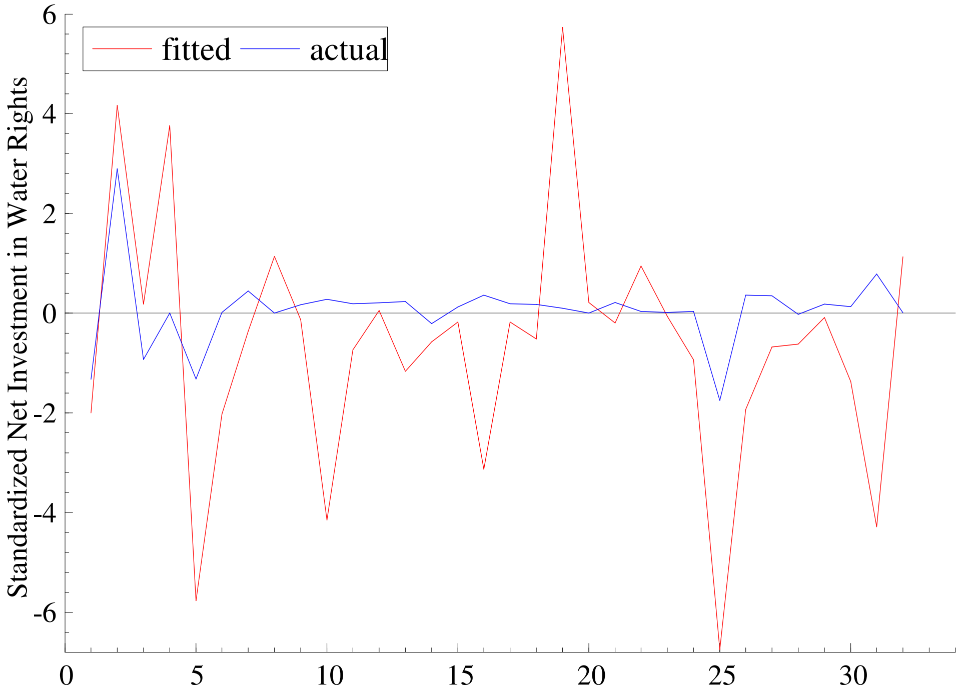


Figure 6.2: Actual value of standardized investment in water rights against the imputed values for that variable



Thus, at this time, I can ask whether heterogeneity of farmers' preferences is a valid hypothesis. That is tested by defining the null hypothesis that the parameters $\gamma_1, \gamma_2, \gamma_3$ are jointly zero. If the null hypothesis is rejected, I infer that farmers have heterogeneous preferences. A maximum likelihood ratio test is used to verify the null hypothesis that $\gamma_1 = \gamma_2 = \gamma_3 = 0$ against the alternative hypothesis that at least one of those parameters is different from zero. I obtain a value for the maximum likelihood ratio test of 112.23 that leads me to strongly reject the null of homogeneity on preferences.

Proper implementation of that test for heterogeneous preferences also requires controlling for incomplete markets (Dubois, 2001). The above specification for γ_i and equation (4.2.11) make clear that I am testing for differences in the farmers' stochastic discount factors by allowing them to be a function of farmers' characteristics. Those characteristics enter in the specification of the discount factor in equation (4.2.12) through their possible relationship with farmers' risk aversion. Nevertheless, as I discussed on Chapter 4, Section 2, differences in reservation values for a water right among farmers in the same water association may also differ due to incomplete asset markets. Because it is well known that farmers in the Limarí Valley face incomplete asset markets, testing for the effect of farmers characteristics on the stochastic discount factor requires controlling for incomplete asset markets. One way to do this is by allowing consumption to be a function of current income, which is a clear consequence of incomplete asset markets. That approach is used in this dissertation to control for incomplete asset markets. .

Estimates for the deterministic component of the production function summarized in Table 6.2, show that the three inputs under analysis have a positive effect on mean output. This result is as expected. In terms of output variance, the three inputs have a positive marginal effect on yield variability. The result that fertilizer has a positive marginal effect on production variance corroborates similar findings by Love and Buccola (1991) and Just and Pope (1979). The positive effect of labor on yield variability coincides with the result obtained by Di Falco, Chavas and Smale (2006) for a sample of farmers from highlands of Ethiopia.

The finding of water as an increasing risk input is an unexpected result. Usually, irrigation is considered as a risk-reducing input. As an example, irrigation reduces the effect of frosts on some type of crops and so their yield variance. It may be possible that the positive sign for water in the stochastic part of the production is being caused because crops with higher water requirement are also the ones with higher variance. Then, estimating the effect of water in output risk will require controlling for the latter relationship. That can be done by estimating different production functions for each specific crop type.

The signs of the estimates of the equation for risk aversion indicate that better educated farmers and with more experience are less risk-averse. The result that more educated farmers are less risk averse is consistent with the results obtained by Knight et al. (2003) with household data from rural Ethiopia. A possible explication for that relationship between risk aversion and education is that more educated farmers are better able to manage risk and so they are willing to take more risk. Nevertheless, that result contradicts the works of Bar-Shira et al. (1997) and Ajetomobi et al.

(2006), which find that higher levels of education are associated with greater risk aversion.

The finding that farmers with higher level of experience exhibit a lower degree of risk aversion confirms the result obtained by Z Bar-Shira et al. (1997). Those authors explain that result by pointing out that risk is a complicated factor that less-experienced farmers try to avoid.

Regarding the household size it can be hypothesized that the larger the size of the family, the higher the subsistence consumption needs and given a fixed amount of land, the lower the willingness of the farmer to assume risks. On the other hand, family size might affect the labor capacity of the peasant household in which case a larger family size implies greater capacity to assume risks. Furthermore, larger households may diversify their activities and better insure themselves efficiently reducing risk. Thus, those farmers will be lees reluctant to accept a bargain with an uncertain payoff rather than another bargain with more certain but possibly lower expected payoff. That makes them less risk-averse or more risk tolerant[45]. The result that household size does not affect risk aversion suggests the convenience of separating those two mentioned effects of that variable over risk aversion by including a variable that represents farmer’s diversification and another one for the farmer’s number of children in the specification for risk aversion of equation (6.2).

For the variance of the error term, Γ_{it}, in the linear equation for “other net incomes”, I_{it}, I found that whether or not farmers invest in cattle does not affect the

---

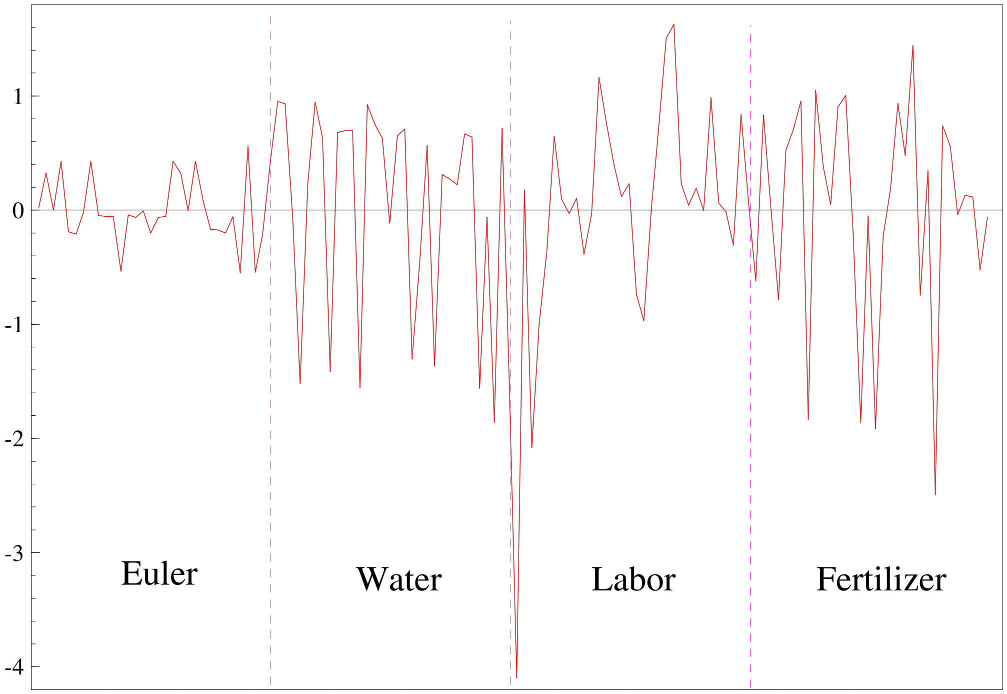
[45] The inverse of a person's risk aversion is sometimes called his risk tolerance (Wikipedia, the free encyclopedia)

variance of I_{it}. Furthermore, results indicated as it was expected that farmers with access to credit for consumption or production have higher variance in I_{it}. Nevertheless, these results are not robust to different specifications of the variance of Γ_{it} neither to variations in the number of observations in the sample.

The estimated value for the discount factor, $\rho = 0.93$, belongs to the expected range for this parameter, $0 < \rho < 1$. Nevertheless a value of 0.93 for the discount factor seems to be too high to be credible and indicates that the model is not suitable for the estimation of that discount factor. This occurs because I have an identification problem with the discount factor: ρ appears in the Euler Equation as the constant term, which is capturing not only the value of the discount factor but also a possible non zero mean of the error term as well as other constant terms of that equation.

Finally, the residuals for each equation based on the estimates in Table 6.2 are plotted in Figure 6.3.

Figure 6.3: Plot of the residuals from the FIML regression based on estimates in Table 6.2.



Appendix: A Hausman test for endogeneity

The error term in the Euler Equation (5.1.14), υ_{1it+1}, is a composite error: $\upsilon_{1it+1} \equiv \phi_{it+1} + \xi_{it+1} + \zeta_{jt+1}$. Thus for each *t+1* period, υ_{1it+1} is the sum of an unobserved effect, ϕ_{it+1}, and two random errors ξ_{it+1} and ζ_{jt+1}. As I discussed in Chapter 5, ϕ_{it+1} represents a measure of the volatility of the discounted water right prices. Because that unobserved effect, maximum likelihood estimation of equation (5.1.14) may not be consistent due to endogeneity issues. This would occur if some of the exogenous variables in equation (5.1.14) are correlated with ϕ_{it+1} and hence with the error term υ_{1it+1}. For example, if water right prices in *t+1* were correlated with the volatility of the discounted water right price in *t+1*, the FIML estimate of the parameters in the model would be biased due to endogeneity. A similar situation may also arise with respect to input quantities that affect output variance which may affect the volatility of the stochastic discount factor. Thus, the potential presence of endogeneity must be tested.

As in Di Falco, Chavas and Smale (2006) I use a residual-based form of the Hausman test that turns to be asymptotically equivalent to the original form of the Hausman test (Wooldridge, 2002, Chapter 6.2). The test involves estimating auxiliary reduced-form regressions for the regressors suspected to be endogenous. Those are linear regressions for each regressor suspected to be endogenous on a constant, all the exogenous variables of the model and regressor specific instruments. Then the Euler Equation is estimated including the reduced-form residuals as additional explanatory variables. The joint statistical significance of the coefficients associated with the residuals is then evaluated. If those parameters are jointly not significant then the Hausman test does not reject the hypothesis of exogeneity of the regressors. As Wooldridge (2002, Chapter 6.2.1) point outs, valid test for the individual and the joint significance of those parameters associated with the residuals requires an efficient estimation of the Euler Equation.

This test was implemented for those exogenous variables that are suspected of being correlated with the volatility of the discounted water right prices. Table 6.3 shows the list of instruments that I use for each possible endogenous regressor. Among those instruments I include all the exogenous variables in the system of equations that are not correlated with the error term. Column 1 of that table contains the list of variables that were tested to determine if they are statistically correlated with the error term υ_{1it+1}.

Table 6.3: List of instruments to test for possible endogenous regressors.

Possible endogenous regressors	**Instruments**
$s_{jt+1} * N_{it+1} * v_{jt+1}$	$s_{jt-1} * N_{it-1} * v_{jt-1}$, $(N_{it-1} - N_{it})$, T_{it}, T_{it+1}, P_{it}, P_{it+1}, s_{jt+1}, s_{jt}, η_{1it}, η_{1it+1}, η_{2it}, η_{2it+1}, v_{jt}, Educ., Exp., Household size.
$\theta_{jt+1}(N_{it} - N_{it+1})$	$\theta_{jt-1}(N_{it-2} - N_{it-1})$, $(N_{it-1} - N_{it})$, T_{it}, T_{it+1}, P_{it}, P_{it+1}, s_{jt+1}, s_{jt}, η_{1it}, η_{1it+1}, η_{2it}, η_{2it+1}, v_{jt}, Educ., Exp., Household size.
L_{it+1}	$(N_{it-1} - N_{it})$, T_{it}, T_{it+1}, P_{it}, P_{it+1}, s_{jt+1}, s_{jt}, η_{1it}, η_{1it+1}, η_{2it}, η_{2it+1}, v_{jt}, Educ., Exp., Household size.
w_{it+1}	$(N_{it-1} - N_{it})$, T_{it}, T_{it+1}, P_{it}, P_{it+1}, s_{jt+1}, s_{jt}, η_{1it}, η_{1it+1}, η_{2it}, η_{2it+1}, v_{jt}, Educ., Exp., Household size.
F_{it+1}	$(N_{it-1} - N_{it})$, T_{it}, T_{it+1}, P_{it}, P_{it+1}, s_{jt+1}, s_{jt}, η_{1it}, η_{1it+1}, η_{2it}, η_{2it+1}, v_{jt}, Educ., Exp., Household size.

A maximum likelihood ratio test indicates that the coefficients on the reduced-form residuals of the equations for the variables in column 1 of the above table were jointly not statistically different from zero at a 5% of significance level.

Chapter 7: Conclusions and Suggestions for Future Research

In this dissertation I have shown that heterogeneous risk preferences among farmers is a sufficient condition for water rights transfers when farmers can simultaneously exchange water in a spot market with lower transaction costs. To reach that goal I developed a model for water right reservation values in which water rights are investment assets and where the link between the spot market and market for water rights is explicitly considered. The model encompasses several aspects related to water market activity and a farmer's behavior. I described and measured transaction activity in markets for water rights and in a spot market for water volumes, in an existing market since 1981 in the Limarí Basin, Chile. That analysis allowed me to conclude that both markets are reallocating a significant amount of water among farmers, although the spot market has, by far, the highest amount of traded water. I also showed that, contrary to what other researchers believe, the spot market is active not only during drought years but also in years with average water availability. I characterized optimal decision making by farmers over the number of water rights to be held in each season. The model assumes incomplete asset markets, output uncertainty, as well as uncertainty about future water availability and water prices. Because investment decisions affect future levels of consumption and farmers face uncertainty, the theoretical model for farmer decisions was modeled as a stochastic dynamic problem. This results in a consumption-based capital asset pricing model (CCAPM) which is described by an Euler Equation that ties asset returns (water right returns in this case) to marginal rates of substitution for consumption at different points in time. This model implies that the current period reservation value of a water right is a function of the current value of the amount of water accorded to water rights in the spot market, the expected future water rights prices and the stochastic discount factor. Nevertheless, since most transfers of water rights take place among farmers that belong to the same WUA and such farmers are likely to have identical expectations, the primary basis for differences in reservation values and for water right transactions are the differences in their stochastic discount factors. Incomplete asset markets as well as heterogeneous risk preferences cause differences in the stochastic discount factors among farmers.

Because asset markets are not complete, farmers value water rights not only as a source of water for production but also as a means to insure themselves against bad shocks. As a consequence, the future value of a water right is given by the expected discounted marginal rate of return to holding a water right from time t to time $t+1$ plus a risk premium that is greater than zero. The latter implies that the reservation value of a water right for the more risk-averse farmer is greater than that for the less risk-averse farmer. This produces transfers of water rights from those farmers who are least risk averse to the most risk-averse farmers. This approach also emphasizes that water right transactions solve differences in attitudes towards risk among farmers, whereas differences in water marginal return among farmers are solved in the spot market.

The theoretical analysis provides the foundation for a case study of water transfers for irrigation in the Limarí Basin, an important agricultural region in the northern part of Chile, which has one of the most active Chilean irrigation water markets. With micro level data from that basin I estimate a system of equations that describes farmers' optimal decisions over the number of water right to be held and input quantities. The estimation of that system assumes that a farmer's utility from consumption is represented by a negative exponential utility function, and that the production technology is described by a Just-Pope Cobb-Douglas production function. The use of a negative exponential utility function imposes severe restrictions in the model and the results are conditional to that specific functional form. Nevertheless, that utility function allows me to characterize the absolute risk aversion coefficient for each farmer as a function of his observable characteristics and to develop a promising approach to jointly estimate the parameters that describe farmers´ preferences and production technology considering farmers investment decisions. This approach can be extended to more general utility functions although that will require more advance methods of estimation.

The results of the estimation procedure indicate that the hypothesis of heterogeneous risk preferences among farmers can not be rejected. Moreover, better educated farmers and with more experience are less risk-averse. On the production side, water, labor and fertilizers have positive impact on output mean per hectare. The analysis of inputs on yield variability showed that those inputs are risk increasing.

Up to now, research on agriculture finance has been characterized by the dominance of real estate among the farmers' assets. But now, due to the increasing interest in establishing transferable water rights not married to land rights, research on agriculture finance should move from considering land as the main asset to water rights as a dominant asset in dry areas. Due to the special characteristics of water resources, this new challenge offers a significant opportunity for future research. That future research may include the analysis of the robustness of the conclusions regarding farmers' heterogeneous risk preferences to alternative functional forms of the utility function. A suitable candidate is a *linex* utility function (Bell and Fishburn, 2001), consisting of a utility function that is the sum of an exponential function and a linear function. This function has the important property of decreasing absolute risk aversion while retaining some of the convenience of the exponential form. Moreover, that functional form allows a closed form solution to the farmer decision problem that I analyze in this dissertation.

Another possible extension would be to develop alternative ways of dealing with the missing data problems that might allow me to use more of the data that I have collected among farmers in the Limarí Valley.

The analysis of the role of risk differences, due to different types of crops or distance from the reservoirs, on the reservation values for a water right is another interesting extension of this work. The presence of speculative bubbles in water right market prices, as suggested by Person and Michelsen (1994), is an appealing area for future applied research on water price models. Other future research deals with improving the mechanism by which prices are formed in the permanent market. This could be done by the design of the right incentives to motivate farmers to reveal their private information on the reservation values[46]. The existence of this non-disclosed private information can reduce the number of transactions even when the reservation value of the buyer is greater than that of the seller, and this may impede the efficient

---

[46] Private information in reservation values for water rights includes information about the farmer's inter-seasonal discount rate and his attitude towards risk.

allocation of water. The formation of an options market in which farmers may obtain options to purchase water during a dry year could be quite useful in addressing this problem because an options market reveals the differences in attitude towards risk. One of the most interesting problems in the formation of an options market is the creation of an appropriate incentive framework for farmers who participate in such a market.

Annex: Survey instrument

Date of Survey ________________Name of interviewee ______________________________

Association that provides you with water ________________

1. Interviewee's home (either the tenant's or the landlord's)

Information about the tenant or landlord:

1.1 Age ______ Marital Status ______________

1.2 How many people live in your home? ________

1.3 Please give detailed information about each person living in your home

N°	Kinship with interviewee	¿Does he/she work in the farm?	Current Age	Experience in agriculture	Level of Education achieved
	Interviewee	yes	▨		
	Wife				
	Son/Daughter				
	Son/Daughter				
	Son/Daughter				
	Son/Daughter				

2. Property and management of the land and water

2.1 How many lots do you own in the valley? _________ (No)

2.2 Please describe your lots?

Lot N°	Location	Area	No. of water shares	Name of the Canal
Total				

2.3 Quality and use of the farms

Lot N°	Fertility*	Slope*	Erosion*	Niter*	Sown in 97/98	Sown in 98/99

Fertility*	(1) high fertility	(2) low fertility	(3) poor quality of land
Slope*	(1) flat	(2) hillside	(3) hill
Erosion*	(1) no problem	(2) some problem	(3) serious problem

2.4. Do you rent either part or all of your property to other persons? Yes ___ No____
Since when/for how long? _____
How many hectares? _________
How much do you charge per year? _________
With how many water shares? _______

2.5 Do you rent any land properties from other persons? Yes ____ No______
Since when/for how long? ______
How many hectares? _________
How much do you pay per year? _________
With how many water shares? _______

2.6 Do you work part or the whole of the land with any partners? Yes ____ No______.
How many partners? __________ Are they next of kin (relatives)? Yes ___ No____
How many hectares?_________ Since when/for how long?_________
Please describe the type of contract made with your partner(s) (i.e. crops grown, land distribution, water, labor and machinery each party supplies, etc.) and how you finance costs and production. ________________________

2.7 How did you purchase the farm?

Kind of Purchase	Area (hectares)	When did you purchase it?	How much was a hectare?
First purchase			
Second purchase			
Third purchase			
Inherited			
Due to agrarian reform			
Other			
Total (verify)			

2.8 Have you sold or divided your property so far? Yes___ No___
(If so, please fill in the chart below)

Type of operation	Area (Hectares)	When?	How much did you ask for each hectare?
First sale			
Second sale			
Third sale			
First partition			▨
Second partition			▨
Third partition			▨
Other			
Total			

2.9 How did you purchase your water shares and how much did you pay for them?

Type of acquisition	No. of water shares	When did you buy them?	With the land?	How much did you pay for each water share?	Whom did you buy it from?
First buy					
Second buy					
Third buy					
Inherited				▨	▨
Due to agrarian reform				▨	▨
Other					

2.10 Have you sold or distributed/divided part of you shares so far? Yes___ No___
(If so, please fill in the chart below)

Type of sale	No. of water shares	When did you sell them?	With the land?	What were you paid for each water share?	Whom did you sell it to?
First sale					
Second sale					
Partitions				▨	▨
Other					
Total					

3 Agricultural Production over the Past Two Seasons

3.1. How much land did you sow in the 98/99 season?_________
3.1.1. How much land did you sow with partners? _________

3.2. How much land did you sow in the 97/98 season? _________
3.2.1. How much land did you sow with partners? ___________

3.3 What did you sow in the 97/98 and 98/99 seasons?

Sowing	Hectares		Were there any losses due to drought?	
	97/98	98/99	97/98	98/99

3.4 What was your harvest production in the two seasons?

Crop	Total Production		Harvested Hectares		Unit of measure (sacks, boxes, kilos, etc.)	
▨	97/98	98/99	97/98	98/99	97/98	98/99

3.5 What were you paid for your products in the two seasons?

Name of Product	Price per unit in Pesos $		Weight unit	
▨	97/98	98/99	97/98	98/99

3.6 What sort of irrigation systems did you use for each crop in the 98/99 season? (Flooding, furrows, drip, etc)

Crop	Irrigated area	Type of irrigation system used in the crop

3.7 What sort of irrigation system did you use for each crop in the 97/98 season? (Flooding, furrows, drip, etc)

Crop	Irrigated area	Type of irrigation system used in the crop

3.8 Do you have grapevines? Yes___ No____
If so, please describe each of them

Grapevine N°	N° de hectares	N° of shrubs	Years	Type of grape	Yield in 98/99	Regular Yield

3.9 Do you have any other permanent crops? Yes____, No_____
(If so, please describe them)

Crop	N° de hectares	N° of shrubs	Years	Type of product	Yield in 98/99	Regular Yield

4. Use of Labor and Water

4.1 Do you have permanent workers in your farm? Yes____ No____
If so, how many? _______

4.2 How much labor did you use for each crop in the following activities over the past two seasons?

Grape 1 type) ________________No. hectares_______ No. shrubs________

Activity	Season 97/98				Season 98/99			
	Time span	Days	No. of people.	Salary	Time span	Days	No. of people.	Salary
Pruning/tying								
Applications								
Watering								
Clearing								
Harvest								
Other								

Grape 2 type) _____________No. hectares_______ No. shrubs___________

Activity	Season 97/98				Season 98/99			
	Time span	Days	No. of people.	Salary	Time span	Days	No. of people.	Salary
Pruning/tying								
Applications								
Watering								
Clearing								
Harvest								
Other								

Crop No. 1________________

Activity	Season 97/98				Season 98/99			
	Time span	Days	No. of people.	Salary	Time span	Days	No. of people.	Salary
Preparation of the land								
Seedbed								
Transplant								
Seed Sowing								
Applications								
Watering/irrigation								
Clearing								
Harvest								
Other								

Crop N° 2__________________

Activity	Season 97/98				Season 98/99			
	Time span	Days	No. of people.	Salary	Time span	Days	No. of people.	Salary
Preparation of the land								
Seedbed								
Transplant								
Seed Sowing								
Applications								
Watering/irrigation								
Clearing								
Harvest								
Other								

Crop N° 3_________________

Activity	Season 97/98				Season 98/99			
	Time span	Days	No. of people.	Salary	Time span	Days	No. of people.	Salary
Preparation of the land								
Seedbed								
Transplant								
Seed Sowing								
Applications								
Watering/irrigation								
Clearing								
Harvest								
Other								

4.3 Did you and your family take part in the pruning? Yes___ No____

4.4 Did you and your family take part in the sowings? Yes ___ No____

4.5 Did you and your family take part in the harvest? Yes ___ No____

4.6 Did your permanent workers take part in the pruning? Yes___ No____

4.7 Did your permanent workers take part in the sowings? Yes ___ No___

4.8 Did your permanent workers take part in the harvest? Yes ___ No___

4.9 How much do you pay your permanent workers? _______________

5 Use of Inputs and Other Expenses

5.1 Please state the amount/number and cost of inputs in the agricultural production in the last two seasons.

Grape Harvest 1_____________ hectares______ N° shrubs________

Input	Amount. 97/98	Unit	Total cost	Amount 98/99	Unit	Total cost
Fertilizers						
Pesticide/insecticide/fungicide						
Pumping		M/hr or days				
Freight						

Grape Harvest 2_____________ hectares______ N° shrubs________

Input	Amount. 97/98	Unit	Total cost	Amount 98/99	Unit	Total cost
Fertilizers						
Pesticide/insecticide/fungicide						
Pumping		M/hr or				
Freight						

Crop 1_____________ hectares______

Input	Amount 97/98	Unit	Total cost	Amount 98/99	Unit	Total cost
Seeds						
Fertilizers						
Pesticide/insecticide/fungicide						
Pumping		M/hr or days				
Freight						

Crop 2_____________hectares______________

Input	Amount 97/98	Unit	Total cost	Amount 98/99	Unit	Total cost
Seeds						
Fertilizers						
Pesticide/insecticide/fungicide						
Pumping		M/hr or days				
Freight						

5.2 Did you rent in a tractor in the last two seasons? Yes ___ No ___
If so, answer the questions below

Grape Harvest

	97/98		98/99	
	M/Hr	**Price**	**M/Hr**	**Price**
Preparation of land	______	______	_____	_____
Application	______	______	_____	_____
Crop	______	______	_____	_____

Other Harvests

	97/98		98/99	
	M/Hr	**Price**	**M/Hr**	**Price**
Preparation of land	______	______	_____	_____
Application	______	______	_____	_____
Crop	______	______	_____	_____

If not, please answer
Did you use your own tractor? Yes ____ No _____

5.3 How did you use your own tractor (or tractors) in your own land in the last to seasons?

Grape Harvest

	97/98	98/99
	M/Hr	**M/Hr**
Preparation of land	______	_____
Application	______	_____
Crop	______	_____

Other Harvests

	97/98 M/Hr	**98/99 M/Hr**
Preparation of land	______	_____
Application	______	_____
Crop	______	_____

5.4 Did you rent your tractor(s) to other farmers? Yes___ No____
If so, for how many hours _______ At what price? _______

5.5 Did you hire an accountant in the last two seasons? Yes_____, No_____
If so, how much did you pay him/her ______________

5.6 Did you buy **water** in the last two seasons? Yes ____ No _____
If so, please answer:

Amount purchased 97/98 _________ Price _______ ($ per m3)
Date of purchase __________
Name and address of salesman__________
How many salesmen did you deal with? __________
Did you use a middleman to negotiate the purchase? ___________
How did you contact the salesman? _________________
Why did you buy? _____________

Amount purchased 98/99 _________ Price _______ ($ per m3)
Date of purchase __________
Name and address of salesman __________
How many salesmen did you deal with? _____________
Did you use a middleman to negotiate the purchase? ___________
How did you contact the salesman? _________________
Why did you buy? _____________

5.7 Did you sell **water** in the last two seasons? Yes ____ No _____
If so, please answer:

Amount sold 97/98 _________ Price _______ ($ per m3)
Date of sale __________
Name and address of buyer __________
How many buyers did you deal with? _____________
Did you use a middleman to negotiate the sale? ___________
How did you contact the buyer?_______________
Why did you sell?_____________

Amount sold 98/99 _________ Price _______ ($ per m3)
Date of sale __________
Name and address of buyer __________
How many buyers did you deal with? _____________
Did you use a middleman to negotiate the sale? ___________
How did you contact the buyer? _______________
Why did you sell? _____________

5.8 Did you buy **water shares** in the last two seasons? Yes ____ No _____
If so, please answer the questions below

No. of shares bought 97/98 _________Price _______ ($ per share)
Date of purchase __________
Name and address of salesman __________
How many salesmen did you deal with?______________________
Did you use a middleman to negotiate the purchase? ___________
How did you contact the salesman? _________________
How much time passed since you decided to buy shares until you got hold of them?
Why did you buy?_____________

No. of shares bought 98/99 _________ Price _______ ($ per share)
Date of purchase __________
Name and address of salesman __________
How many salesmen did you deal with? ______________________
Did you use a middleman to negotiate the purchase? ___________
How did you contact the salesman? _________________
How much time passed since you decided to buy shares until you got hold of them? ___________
Why did you buy? _________________

5.9 Did you sell **water shares** in the last two seasons? Yes ____ No ________

No. Of shares sold in 97/98 _________Price _______ ($ per share)
Date of sale __________
Name and address of buyer __________
How many buyers did you deal with? _____________
Did you use a middleman to negotiate the sale? ___________
How did you contact the buyer? _______________
How much time passed since you decided to sell your shares until you transferred them?______________
Why did you sell? _____________

No. Of shares sold in 98/99 _________ Price _______ ($ per share)
Date of sale __________
Name and address of buyer __________
How many buyers did you deal with? _____________
Did you use a middleman to negotiate the sale? ___________
How did you contact the buyer? _______________
How much time passed since you decided to sell your shares until you transferred them? ______________
Why did you sell? _____________

5.10 Did you **rent in water shares** in the last two seasons? Yes ____ No _____
If so, please answer the questions below

Number of water shares leased in 97/98 _________Price _______ ($ per share)

Date of leasing __________
Duration of the leasing contract___________
Name and address of the renter__________
How many people did you negotiate the leasing with? __________
Did you use any middlemen to negotiate the leasing? __________
How did you contact the renter _________________
Why did you rent in water shares? _____________

Number of water shares leased in 98/99 _________Price _______ ($ per share)
Date of leasing __________
Duration of the leasing contract___________
Name and address of the renter__________
How many people did you negotiate the leasing with? __________
Did you use any middlemen to negotiate the leasing? __________
How did you contact the renter _________________
Why did you rent in water shares? _____________

5.11 Did you **rent out water shares** in the last two seasons? Yes ____ No _____
If so, please answer these questions below

Number of water shares leased in 97/98 _________ Price _______ ($ per share)
Date of leasing__________
Duration of the leasing contract___________
Name and address of the lessee__________
How many people did you negotiate the leasing with? __________
Did you use any middlemen to negotiate the leasing? __________
How did you contact the lessee__________?
Why did you leasing water shares? _________________

Number of water shares leased in 98/99_________ Price _______ ($ per share)
Date of leasing__________
Duration of the leasing contract___________
Name and address of the lessee__________

How many people did you negotiate the leasing with? __________
Did you use any middlemen to negotiate the leasing? __________
How did you contact the lessee__________?
Why did you rent out water shares?

6. Husbandry production in the last two seasons

6.1 Do you have livestock? Yes ____ , No_____ (If not, skip to the next section, if so, please describe your current stock of cattle)

Kind	Number	Breed	Approx. Total value in Pesos $

6.1.1 How much livestock have you had each year?
1999_______________
1998_______________
1997_______________

6.2 Have you sold livestock in the last two years? Yes ___, No____
(If so, please describe your sales)

Sales	Units	When?	Price per unit
1st sale			
2nd sale			
3rd sale			

6.3 Have you bought livestock in the last two years? Yes ___, No____
(If so, please describe your purchases)

Buys	Units	When?	Price per unit
1st buy			
2nd buy			
3rd buy			

6.4 Dou you produce milk or cheese for sale? Yes ____, No_____
(If so, what was your average productivity per animal over the last three years?)

Productivity in 1999 _____________	Price of milk in 1999 __________
Productivity in 1998 _____________	Price of milk in 1998 __________
Productivity in 1997 _____________	Price of milk in 1997 __________

6.5 What are the main expenses (in pesos) per animal monthly or yearly for the husbandry production of your farm?

	Expense per animal	Monthly or Yearly
Feeding costs	_____________	________
Healthcare costs	_____________	________
Labor	_____________	________
Other expenses	_____________	________

6.6 Have you lost animals because of drought? Yes ___, No____
How many? ___
When? ___________

7. Productive tools

7.1 What equipment of your own do you have for the agricultural production of your farm?

Type of equipment			
	Units	Years Old	Equipment description
Tractors			
Animals for labor			
Fumigation and application			
Equipment of the harvest			
Production Transportation			
Other equipment			

7.2 Do you have wells and pumping equipment? Yes ____ No _____(if so, what are their characteristics ?)

Well No.	Depth (meters)	Age	Pump No.	Pumping capacity	Age

7.3 How many hours have you used your pump (or pumps) to drain water from your well during each season?

97/98 __________ (Hours) 98/99 ___________ (Hours)

7.4 Do you have any storing system for surface water? (docks, tanks, etc.)?

Yes____ No _____ Type _______________

Age ___________.Covered area (m2) ________

Depth (meters) ___________.Capacity (m3) ___________

7.5 Do you have mechanized irrigation in your farm? Yes ____ No____
If so, please fill in the chart below

Irrigation Implements	Years	Detailed description

7.6 Do you have a contract with an export company or are you a member of a *Pisco* association? Yes ____, No ____
If so, please describe the contract:

7.6.1 Name of the company ____________________

7.6.2 Length of contract to date ____________________

7.6.3 Type of payment (monthly, bi-monthly, etc) _____________

7.7 Does the company provide you with one of these services?

7.7.1 Technical support (describe) ____

7.7.2 Credit assistance (describe) ____

7.7.3 Commercialization (describe) ____

7.8 Did you purchase harvest insurance in the 97/98 season?
Whom did you purchase it from? ___________________ How much did you pay for it? _________________

7.9 Did you hire purchase harvest insurance in the 98/99 season?
Whom did you purchase it from? __________________ How much did you pay for it? __________________

8 Participation in Lending Markets and Subsidies

8.1 Have you applied for any production loans in the last two seasons?
Yes ___ No____ (If not, skip to question 8.3)

8.2 Have you received any production loans in the last two seasons?
Yes ____No___ (If so, please fill in the following chart)

Source of the loan	Loan amount in Pesos $		Interest rate		Time span	
	97/98	98/99	97/98	98/99	97/98	98/99
Commercial Bank						
INDAP						
Other sources						

8.3 Have you applied to be granted a bonus or subsidy bonus to improve the irrigation system in your farm?
Yes ____ No_____ (If not, go to question 8.5)

8.4 Have you obtained any bonus from the government? Yes ___ No ____ (If not, go to question 8.5)
Did you already use the bonus? Yes ____ No____

Have you received or do you plan to receive any bank loans to complement the bonus or subsidy bonus? Yes ___ No____

What type of bonus did you apply for? For entrepreneurs ____, for farmers ____ both _____

Account for the money received in bonus or subsidy bonus ______ (Pesos)

8.5 If you have not applied for a bonus from the government, why is it so?
____

THANK YOU VERY MUCH.

References

Ajetomobi, J.O., S.O. Binuomote. (2006). "Risk Aversion among Poultry Egg Producers in Southwestern Nigeria**".** *International Journal of Poultry Science,* 5 (6): 562-565.

Alvarez, F., U. Jermann. (2005). "Using Asset Prices to Measure the Persistence of the Marginal Utility of Wealth". *Econometrica*, 73 (6): 1977-2016.

Antle, J.M. (1989). "Nonstructural Risk Attitude Estimation". *American Journal of Agricultural Economics*, 71 (3): 774-785.

——— (1987). "An Econometric Estimation of Producers Risk Attitudes." *American Journal of Agricultural Economics*, 69 (3): 509-522.

Arroyo, C.R. (1996). "Testing A Production-Based Asset-Pricing Model." *Economic Inquiry,* XXXIV (2)*:* 357-377.

Balgati, B.H. (2001). "Econometric Analysis of Panel Data." John Wiley & Sons, Inc.. Chishester, England.

Bar-Shira, Z., R.E. Just, D. Zilberman. (1997). "Estimation of farmers' risk attitude: an econometric approach." *Agricultural Economics,* 17 (2-3): 211-222.

Barry, P.J., L.J Robinson. (2001). "Agriculture Finance: Credit, Credit Constraints, and Consequences." Handbook of Agricultural Economics: Agricultural production. B.L. Gardner and G.C. Rausser, eds. Amsterdam: Elsevier Science B.V.

Bauer, C.J. (2004). "Siren Song: Chilean Water Law as a Model for international Reform." Resource for the Future, Washington, DC, USA.

——— (1995). "Against the Current? Privatization, Market and the State in Water Rights: Chile 1979-1993." Doctoral Dissertation, Jurisprudence and Social Policy Program, University of California-Berkeley.

Bell, D., E. Peter, C. Fishburn. (2001). "Strong One-Switch Utility." *Management Science*, 47 (4): 601-604.

Binswanger, H.P. (1980). "Attitudes towards risk: experimental measurements in rural India." *American Journal of Agricultural Economics*, 62 (3): 395-407.

Binswanger, H., M. Rosegrant. (1994). "Reforming Water Allocation Policy through Markets in Tradable Water Rights: lessons from Chile, Mexico and

California." Environmental and Production Technology Division. Discussion paper No 6. International food Policy Research Institute, Washington DC.

Bjornlund, H., J. McKay. (2002). "Aspects of water markets for developing countries: experiences from Australia, Chile, and the US." *Environment and Development Economics*, 2002, 7 (4): 769-795.

Bjornlund, H. (2004). "Formal and informal water markets: Drivers of sustainable rural communities?" *Water Resource Research*, 40, (9), WO9SO7.

——— (1998). "Factors affecting water prices in a rural water market: a South Australian perspective." *Water Resources Research,* 34 (6):1563-1570.

Blundell, R., M. Browning, C. Meghir. (1994). "Consumer demand and the Life-Cycle Allocation of Household Expenditures." *Review of Economic Studies*, 61 (1):57-80.

Bossaerts, P. (2002). "The Paradox of Asset Pricing." Princeton University Press.

Breusch, T., A. Pagan. (1980). "The LM Test and its Applications to Model Specification in Econometrics." *Review of Economics Studies*, 47 (1): 239-254.

Briscoe, J. (1996). "Water as an Economic Good: The idea and what it means in practice." Paper presented at the World Congress of the International Commission on Irrigation and Drainage. Cairo., September.

Brookshire, D.S., P.T. Ganderton. (2004). In Introduction to especial section on "Water Markets and Banking: Institutional Evolution and Empirical Perspectives". *Water Resource Research*, 40(9), WO9SO1.

Brown, L., B.J. Tyseling, C. DuMars. (1982). "Water Reallocation, Market Proficiency and Conflicting Social Values." Water and Agriculture in the Western U.S., Gary Weatherford ed. Boulder, Colo, Westview.

Bruns, B.R., R.S. Meinzen-Dick. (2000). In introduction to "Negotiating Water Rights." Edited by R.B. Bruns and R.S. Meinzen-Dick. International Food Policy Research Institute (IFPRI).

Burke, S.M., R.M. Adams, W.W. Wallender. (2004). "Water banks and environmental water demands: case of the Klamath Project." *Water Resource Research*, 40(9), WO9S02.

Cameron, A.C., P.K. Trivedi. (2005). "Microeconomics: Methods and Applications." Cambridge University Press, New York.

Campbell, J.Y., A.W. Lo, A.C. McKinley. (1997). "The Econometrics of Financial Markets." Princeton University Press.

Carroll, C.D. (1997). "Buffer-Stock Saving and the Life Cycle/Permanent Income Hypothesis." *Quarterly Journal of Economics*, CXII(1): 1-56.

Carter, H., W. Griffiths, G. Judge. (1997). "Introduction to Undergraduate econometrics." John Wiley & Sons, Inc.

Chavas, J.P., M.T. Holt. (1996). "Economic Behavior under Uncertainty: A Joint Analysis of Risk Preferences and Technology." *The Review of Economics and Statistics*, 78(2): 329-335.

Chavas, J.P. (2004). "Risk Analysis in Theory and Practice." Elsevier Academic Press.

Cochrane, J.H. (2005). "Asset Pricing." Princeton University Press, Princeton, New Jersey.

——— (1996). "A Cross-Sectional Test of an Investment-Based Asset pricing Model." *Journal of Political Economy*, 104(3): 572-621.

——— (1991). "Production-Based Asset Pricing and the Link Between Stock Returns and Economic Fluctuations." *The Journal of Finance*, 46(1): 209-237.

Colby, B.G., K. Crandall, D.B. Bush. (1993). "Water Right Transactions: Market Values and Price Dispersion." *Water Resource Research*, 29(6):1565-1572.

Constantinides, G., D. Duffie. (1996). "Asset Pricing with Heterogeneous Consumers." *The Journal of political Economy*, 104 (2): 219-240.

——— (1986). "Capital Market Equilibrium with Transaction Costs." *Journal of Political Economy*, 94(4): 842-862.

Cortés, Manuel. (1997). "Algunos problemas Jurídicos del Sistema Paloma." *Revista de Derecho de Aguas*, VIII: 9-18.

Coward, E. Walter Jr. (2000). In Preface to "Negotiating Water Rights." Edited by B.R. Bruns and R.S. Meinzen-Dick. International Food Policy Research Institute (IFPRI).

Crase, L., P. Pagan, B. Dollery. (2004). "Water Markets as a Vehicle for Reforming Water Resource Allocation in the Murray-Darling Basin." *Water Resources Research,* 40 (8), E08S05.

Crase, L., B. Dollery, M. Lockwood. (2003). "Watering Down Property Rights for the Sake of the Environment: A Consideration of the Environmental Benefits of Attenuated Water Rights in NSW." *Australasian Journal of Environmental Management*, 10 (1): 25-34.

Crase, L., L. O'Reilly, B. Dollery. (2000). "Water Markets as a Vehicle for Water Reform: The Case of New South Wales." *Australian Journal of Agricultural and Resource Economics*, 44(2): 299-321.

Cristi, O., A. Trapp. (2003). "Mercado de Agua para Irrigación y Uso Urbano: una Aplicación a la Cuenca del Río Elqui, Chile". World Bank-Netherlands Water Partnership Program (BNWPP), Water Rights System Window.

Cristi, O., L.G.T. de Azevedo, A. Baltar. S. Vicuña. (2002). "Markets for Water used for Irrigation: an Application to the Paloma System of the Limarí, Chile". World Bank-Netherlands Water Partnership Program (BNWPP), Water Rights System Window.

Crouter, J.P. (1987). "Water Rights Markets." *Land Economics* 63(3): 259-271.

Deaton, A. (1992). "Understanding Consumption." Clarendon Press, Oxford.

——— (1991). "Saving and Liquidity Constraints." *Econometrica,* 59(5):1221-1248

Di Falco, S., J.P. Chavas, S. Medina. (2006). "Farmer Managment of Production Risk on Degraded Lands: the Role of Wheat Genetic Diversity in Tigray Region, Ethiopia". *EPTD Discussion Paper*, 153, International Food Policy Research Institute (IFPRI).

Dinar, A., J. Latey. (1991). "Agricultural water marketing, allocative efficiency, and drainage reduction." *Journal of Environmental Economics and Management*, 20 (3): 210-223.

Dinar, A., R.E. Howitt, S.J. Rassenti, V.L. Smith. (1998). "Development of Water Markets Using Experimental Economics." Markets for Water Potential and Performance. Edited by K. William Easter, Mark W. Rosegrant and Ariel Dinar, Kluwer, Academic Publishers.

Dubois, P. (2001). "Consumption Insurance with Heterogeneous Preferences. Can Sharecropping Help Complete Markets?" Revised and resubmitted at the *Journal of Political Economy*.

Duffie, D., M. Schroder, C. Skiadas. (1997). "A Term Structure model whit Preferences for the Timing of Resolution of Uncertainty." *Economic Theory*, 9 (1): 3-22.

Easter, K.W., L McCann. (2004). “Estimating the Transaction Costs of Alternative Mechanisms for Water Exchange and Allocation.” *Water Resources Research,* 40(9).

Easter, K.W., A. Dinar, M.W. Rosegrant. (1998). “Water Markets: Transaction Costs and Institutional options.” Markets for water: Potential and Performance. Edited by K. William Easter, Mark W. Rosegrant and Ariel Dinar, Kluwer Academic Publishers.

Epstein, L., G. Stanley, E. Zin. (1989). “Substitution, Risk Aversion, and The Temporal Behavior of Consumption and Asset Returns: A Theoretical Framework ” *Econometrica*, 57(4): 937-969.

Gleeson, T. (2003). “Have the scientists got it right this time?” *Connections Farm Food Resource,* Issues, 3(1): 1 – 3.

Gollier, C. (2001). “Wealth inequality and asset pricing.*”* *Review of Economic Studies*, 68 (1): 181-203.

Gregory, D. (1978). “Multiplicative risk premiums." *Journal of Financial and Quantitative Analysis*, 13 (5): 947-963.

Hadjigeorgalis, E. (2000). “Private Water Markets in Agriculture and the effects of Risk, Uncertainty, and Institutional Constraints.” Doctoral Dissertation, Agriculture and Resource and Economics Department, University of California, Davis.

Hammond, J.S. (1974). “Simplification of Choice under Uncertainty.” *Management*, *Science*, 20: 1047-1072.

Hausman, J. (1978) “Specification Test in Econometrics.” *Econometrica*, 46 (6): 1251-1271.

He, H. and D. Modest. (1995). "Market frictions and Consumption-Based Asset Pricing.” *Journal of Political Economy*, 103: 94-117.

Hearne, R., K.W. Easter. (1995). "Water Allocation and Water Markets: An Analysis of Gains-From-Trade in Chile." World Bank Technical Paper, Number 315.

——— (1997). "Water Allocation and Water Markets: An Analysis of Gains-From-Trade in Chile." *Agricultural Economics,* 15(3):187-99.

Heaton, J., D.J. Lucas. (1996). “Evaluating the Effects of Incomplete Markets on Risk Sharing and Asset Pricing.” *Journal of Political Economy*, 104 (3): 443-487.

Holden, P. and M. Thobani. (1995). "Tradable Water Rights: A Property Rights Approach To Improving Water Use and Promoting Investment." *Cuadernos de Economía*, 32(97): 263-289.

Howitt, R.E. (1998). "Initiating Spot prices, option prices, and water markets: an analysis of emerging markets in California." Markets for water: Potential and Performance, edited by K. William Easter, Mark W. Rosegrant and Ariel Dinar,Kluwer Academic Publishers.

Israel, M., J.R. Lund. (1995). "Recent California Water Transfers: Implications for Water Management." *Natural Resources Journal,* 35 (1):1-32.

Just, R.E. (2000). "Some Guiding Principles for Empirical Production Research in Agriculture." *Agricultural and Resource Economics Review*, 29 (2): 138-158.

Just, R.E., R.D. Pope. (2003). "Agricultural Risk analysis: adequacy of models, data and issues." *American Journal of Agricultural Economics*, 85(5): 1249-1256.

——— (1979). "Production Function Estimation and Related Risk Considerations." *American Journal of Agricultural Economics*, 61: 276-284.

——— (1978) "Stochastic Representation of Production Functions and Econometric Implications" *Journal of Econometrics*, 7 (1): 67-86.

Kapetanios , G. (2004). "Testing for Exogeneity in Nonlinear Threshold Models." Working Papers No 515, Queen Mary, University of London, Department of Economics.

Keeney R., H. Raffia. (1976). "Decisions with Multiple Objectives" Cambridge University Press, Cambridge.

Knight, J., S. Weir, T. Wolehanna. (2003). "The role of education in facilitating risk-taking and innovation in agriculture". *The Journal of Development Studies*, 39 (6): 1-22.

Kumbhakar, S. (2002). "Specification and Estimation of Production Risk, Risk Preferences and Technical Efficiency." *American Journal of Agricultural Economics* 84(1): 8-22.

Langemeier, M.R., G.F. Patrick. (1993). "Farm Consumption and Liquidity Constraints." *American Journal of Agricultural Economy*, 75: 479-84.

Love, H.A., S.T., Buccola. (1991). "Joint Risk Preference-Technology Estimation with a Primal System." *American Journal of Agricultural Economics*, 73: 765-774.

Luttmer, E.G. (1996). “Asset Pricing in Economies with Frictions.” *Econometrica*, 64(6): 1439-1467.

Lynne, G.D., P. Saarinen. (1993). "Melding Private and Public Interests in Water Rights Markets." *Journal of Agricultural and Applied Economics,* 25(1): 69-83.

Meinzen-Dick, R.S. (1998). "Groundwater Markets in Pakistan: Institutional Development and Productivity Impacts." Markets for water: Potential and Performance. Edited by K. William Easter, Mark W. Rosegrant and Ariel Dinar. Kluwer Academic Publishers.

Michelsen, A.M., R.A. Young. (1993). "Optioning Agricultural Water Rights for Urban Water Supplies during Drought." *American Journal of Agricultural Economics*, 75(4): 1010-1020.

Michelsen, A.M. (1994). "Administrative, Institutional, and Structural Characteristics of an Active Water Market." *Water Resources Bulletin* 30(6): 971-982.

Moscardi, E., A. de Janvry. (1997). “Attitudes toward Risk among Peasants: An Econometric Approach.” *American Journal of Agricultural Economics* 59 (4): 710-716.

Moschini, G., D.A. Hennessy. (2001). "Uncertainty, risk aversion, and risk management for agricultural producers." Handbook of Agricultural Economics. Edited by B. L. Gardner & G. C. Rausser, Elsevier, volume 1A, Chapter 2: 88-153.

Murphy, J.J., A. Dinar, R.E. Howitt, .S.J Rassenti, V.L. Smith. (2000). "The Design of Smart Water Market Institutions Using Laboratory Experiments." *Environmental and Resource Economics*, 17(4): 375-394.

Myers, R.J. (1989). “Econometric Testing for Risk Averse Behavior in Agriculture" *Applied Economics*, 21 (4): 541-52.

Niehaus, F. (2001). “The influence of Heterogeneous Preferences on Asset Prices in an Incomplete Market Model.” Discussion Paper 234, University of Hanover, Hanover.

Nieuwoudt, W.L., R.M. Armitage. (2004). “Water market transfers in South Africa: Two case studies”. *Water Resource Research*, 40(9), WO9S02.

Person, P., A. Michelsen. (1994). “Determinants and Trends in Water Right Prices: an Econometric Analysis”. Technical Report Submitted to Department of the

Interior, U.S. Geological Survey, and Wyoming Water Resources Center, University of Wyoming, Laramie, Wyoming.

Phimister, E. (1995). “Farm Consumption Behavior in the Presence of Uncertainty and Restrictions on Credit.” *American Journal of Agricultural Economy*, 77 (4): 952-959.

Pinyck, R.S., D.L. Rubinfeld. (1998). “Econometric Models and Economic Forecasts.” Irwin/McGraw-Hill.

Pope, R.D., R.E. Just. (2003). “Distinguishing Errors in Measurement from Errors in Optimization.” *American Journal of Agricultural Economics*, 85 (2):348-358

Pope, R.D. (1988). "A New Parametric Test for the Structure of Risk Preferences," *Economics Letters*, 27 (2): 117-21.

Pratt, J.W. (1964). "Risk aversion in the small and in the large.” *Econometrica*, 32(1/2):122-136.

Rios, M.A., J.A. Quiroz. (1995). "The Market of Water Rights in Chile: Major Issues." *Cuadernos de Economía* 32(97): 317-45.

Rosegrant, M.W., M.A. Sombilla. (1997). “Critical issues suggested by trends in food, population, and the environment to the year 2020”. *American Journal of Agricultural Economics*, 79(5): 1467-14701.

Rosenzweig, M.R., K. Wolpin. (1993). “Credit Market Constraints, Consumption Smoothing, and the Accumulation of Durable Production Assets in Low-Income Countries: Investments in Bullocks in India”. *The Journal of Political Economy* 101(21): 223-244.

Saha, A., C.R. Shumway, H. Talpaz. (1998). “Joint Estimation of Risk Preference Structure and Technology Using Expo-Power Utility.” *American Journal of Agricultural Economics*, 76 (2): 173-184.

Saleth, R.M. (2004). Introduction to special section on River Basin Management: Economics, Management, and Policy. *Water Resource Research*, 40 (8), W08S01.

——— (1998). “Water Markets in India: Economic and Institutional Aspects” in Markets for Water: Potential and Performance”, edited by K. W. Easter, M. W. Rosegrant and A. Dinar. Kluwer Academic Publishers.

Saleth, R.M., A. Dinar. (2004). “The Institutional economic of water: a cross-country analysis of institutions and performance”. Edward Elgar Publishing Limited, Inc, a co-publication with the World Bank.

Saleth, R.M., J.B. Braden, W.J. Eheart. (1991). "Bargaining Rules for a Thin Spot Water Market." *Land Economics*, 67(3): 326-339.

Saliba, B.C. (1987). "Do Water Markets "Work"? Market Transfers and Trade-Offs in the Southwestern States." *Water Resources Research*, 23(7): 1113-1122.

Shatanawi, Al-J., G.A. Orabi. (1994). "Water rights in Jordan" Mimeo, Amman, Jordan: University Jordan, Water and Environmental Research Study Center.

Tisdell, J.G., J.R. Ward, T. Capon. (2004). "Impact of communication and information on a complex heterogeneous closed water catchment environment." *Water Resource Research,* 40, (9), W09S03.

Tsur, Y. (2004). Introduction to special section on Irrigation Water Pricing. *Water Resource Research*, 40, W07S01.

Vayanos, D., J-L. Vila. (1999). "Equilibrium interest rate and liquidity premium with transaction costs." *Economic Theory*,13 (3): 509-539.

Vermillion, Douglas L. (2000) : " Water Rights in the State of Nature: Emergent expectations in an Indonesian Settlement" in Negotiating Water Rights. Edited by B.R. Bruns and R.S. Meinzen-Dick. International Food Policy Research Institute (IFPRI).

Vicuña, S. (2000). "Mercados de agua en la cuenca del Maipo y el Sistema Paloma." Tesis de Grado, Pontificia Universidad Católica de Chile, Santiago de Chile.

Wooldridge, J.M. (2002). "Econometric Analysis of Cross Section and Panel Data." The MIT Press, Cambridge, Massachusetts.

World Bank. (1993). "Water Policy Document."

Zegarra, E. (2002)."Water Market and Coordination Failures: The Case of the Limarí Valley in Chile" Doctoral Dissertation, Agricultural and Applied Economics, University of Wisconsin-Madison.

Zeldes, S.P. (1989). "Consumption and Liquidity Constraints: An Empirical Investigation" *Journal of political Economy*, 97 (2): 305-46.