WATER MARKET AND COORDINATION FAILURES:

THE CASE OF THE LIMARI VALLEY IN CHILE

By

Eduardo Zegarra

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A Liliana, Tadeo y Danilo, mi familia....

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Table of Contents

Abstract

Despite the claim that water markets enhance agricultural performance, there is relatively little evidence on their actual operation. This thesis explores the operation of the spot water market in the Limarí Valley in Chile. Data were collected from this valley in 1996-1997, a period of severe drought. Escalating water prices, high price volatility and increasing market uncertainty during this period led a significant proportion of Limarí Valley producers to question the value of water markets.

Beginning with a micro-theoretic model, this thesis explores the hypothesis that water market instability is a systematic feature of agriculture characterized by fixed cost investment and permanent crops. In such a world, an investment coordination failure occurs as permanent crops make water demand rigid, resulting in price volatility when water supply shocks occur. In the case of the Limarí Valley, the model implies that the investment in permanent crops that fueled economic development also rendered the water market less effective. Econometric estimates of water market participation confirm the general outlines of the model and give quantitative dimension to the range of prices over which the water market is rigid.

Chapter 1: Introduction

The ideas for this thesis were developed in three stages. In the first stage, previously to writing my dissertation proposal, I was mainly interested in issues related to the debate about a new water legislation in Perú in the 1992-1994 period. Almost half of Peruvian agriculture is irrigated, all the Coast region and part of the Andean region. A new water legislation was considered a very important reform affecting the future of Peruvian agriculture.

At that time, the Peruvian government wanted to change the 1969 Water Code introducing legislation similar to the Chilean Water Code of 1981. The Chilean Code privatized water rights and promoted the functioning of water markets for allocating water among alternative uses both inside agriculture and among different sectors. It ended most of the State capacity for allocating and regulating the supply of water resources.

With a Tinker Foundation scholarship for pre-dissertators I visited Chile in 1994 to gather information on the Chilean Water Code and the functioning of agricultural water markets. I found an ongoing debate about the problems with the existent water legislation, mainly the extreme accumulation of water rights by hydropower firms and the Code's inability to cope with the complex conflicts among agriculture, electricity and mining sectors. In terms of agriculture water markets themselves (i.e. water trade among farmers in irrigated areas), the evidence was showing that these markets were very thin or nonexistent, except for specific areas in the drier northern region.

I learned that of one of these areas, in which an agriculture water market was active, was the Limarí Valley in the IV Region (400 Km from Santiago), where one of the country's largest reservoirs (Paloma Reservoir, with 700 million m3) irrigates about 30,000 Has. Farmers traded water both in permanent rights as well as in seasonal quantities (rental market). The functioning of this market was not very well known in Chile at that time, although a first study was started focusing on exchanges between agriculture and the urban sector.

I visited the Limarí area and interviewed personnel in charge of the reservoir as well as representatives of the six irrigation organizations. At that point they had a very positive opinion on the operation of water markets (both rental and permanent). The water market became increasingly active during the late 1980s and especially in the 1991-1992 dry period. The valley had passed through a structural transformation since the mid 1980s, with the increasing presence of permanent crops (grapes) and agribusiness (pisco industry and agro-exports) in the area. The possibility of using water markets for facing water allocation problems was seen as a crucial factor facilitating this structural transformation which had made this valley a prosperous area.

At that point I was interested not only in the water market itself but in the whole institutional set up in which water was managed in the Limarí valley. My main idea was to contribute to the discussion on a new Water Code in Perú (in which water markets are an important issue but not the main issue) and I imagined a comparative study between an irrigated area in Peru with non-market institutions and the Limarí valley operating with market institutions. With these insights I started writing the dissertation proposal.

Thus, the second stage of the ideas for this thesis were developed around the dissertation proposal. I intended to carry out a comparative study of water institutions looking at two irrigated areas in Perú and Chile. I researched on the general literature on irrigation institutions across many different setups and environments. In this stage I broadened my aspirations thinking that for a comparative study I needed an ample view on irrigation problems and water institutions, locating the water market as one institutional option among others. Issues of efficiency, equity and sustainability were to be considered in the analysis, trying to find a framework that makes the comparison meaningful and insightful for policy analysis.

Most of the dissertation proposal was written along these lines and it was defended in 1996. I applied for financial support for the field work and got partial support from Mac Arthur Foundation and the Social Science Research Council (SSRC) for starting up my study in Chile in 1997. I went to Chile in September-November of 1997 and visited the Limarí Valley in November of that year. I found a very peculiar situation. The valley was passing through a severe drought that was lasting almost three years. The water rental market had been very active during the whole year but the week in which I visited it had almost collapsed with prices escalating to 15 times their maximum value in the last dry season in 1994. Farmers were under a lot of stress and some of them complained that the rental market "was only working for rich farmers". Many farmers, especially those with permanent crops, feared total loss of their plantations if they could not buy (or dig) water as soon as possible (many wells were tried out that year, with not very good results).

With this intriguing situation in mind I had to travel to Lima and could not return to the Limarí Valley until April 1998 to carry out my field survey. At that point the agricultural season had ended and it was raining copiously in the highlands of the Limarí, so the three reservoirs (Paloma works together with other two smaller reservoirs) started to get filled up and farmers were less worried about loosing their plantations. However, they still had a lot of complains about the way in which the water market had worked in the previous season, especially the extreme prices and the lack of water supply when it was more needed. This situation contrasted markedly with what I had found in my first visit in 1994: the market was not working as expected by most farmers.

At that point I also noticed that I would not have financing support for carrying out a similar study in Perú so I had to focus my research on the Limarí valley. With my adviser's encouragement, I decided to focus my research on the operation of the rental water market in Limarí in the face of an extremely negative shock. I wondered how this may limit the advantages of water market institutions, a situation that is also common in other imperfect rural markets like labor and land.

Because of my previous plan, I did not have yet a precise framework for analyzing all the relevant issues on the rental water market. I designed my field survey to gather both production and institutional information and I had to redesign it to focus more on assets, production and technological choices which may influence participation in the water market. Although without a totally clear economic model in mind, I gathered most of the variables which are generally considered for market participation.

The third stage of the thesis is based on the interaction which I had with my adviser, the data I gathered and with a micro-economic model I started to build to analyze the water rental market. The main motivation for working out the model was to assess analytically how does the presence of permanent crops (a source of water demand rigidities) reduce the effectiveness of the rental water market. The building of the model was crucial to re-assess the data and organize the econometric estimations of demand and supply functions.

For the empirical part I used two main strategies. The first was to simulate the operation of a water market with the model using the real distribution of the total water supply in Limarí (which includes two important negative shocks as the one in 1995-97) and calibrated parameters.

The second strategy was to use econometric estimations of water market participation decisions by farmers based on the micro-economic data gathered in my field work. In both cases, the intent was to consider how rigidities in the demand of water for individual farmers may affect the workings of the rental water market, and how this may hinder investment and economic development in the long run.

Another important part of this third stage was the final interaction with my thesis committee. It allowed me to identify important aspects of my work which I did not pay attention or even that I did not considered before, especially in thinking alternatives to improve the workings of the rental water market. This interaction was also extremely useful to put together a work that was finished almost four years after the gathering of the data and seven years after the first visit to Chile.

The final result presented here is a study of a peculiar market that is a very valuable institution for farmers, but that requires specific policies both in the area of collective action and in the design of more flexible rules, in order to improve farmer's well being in a sustainable way. Water markets are far from being an extended institution for water allocations around the world. However, it is likely that in the near future water markets play a bigger role even if it does not seem advisable to leave water to the sole forces of markets. It is in this context that understanding how a real water market operates is important, as a form to better inform and support water reform. Having a coherent theoretical approach to it is crucially important. It is the only way to give policy makers a rigorous basis about what can be gained and lost with the use of water markets, and about the contexts in which these markets may be able to function well for the achievement of legitimate social goals.

The rest of the thesis is organized as follows. In Chapter 2 there is a relatively brief overview of theoretical and empirical literature devoted to water markets. I found very few studies dealing directly with the operation of agricultural water markets. Chapter 3 introduces the institutions and infrastructure behind the operation of the water market in the Limarí valley, starting with a description of the general water legislation in Chile.

Chapter 4 is devoted to analyze in more detail the production structure and the functioning of factor markets in the Limarí valley. Special attention is given to water market participation and its relationship to crop decisions by farmers.

In Chapter 5 the theoretical model is presented. This is used to simulate the operation of the water market in a long period of time. These results are compared to the observed water price distribution as estimated by non-parametric techniques. Chapter 6 presents the econometric estimations on water market participation decisions. Finally, Chapter 7 is devoted to explore policy alternatives for improving the rental water market in the Limarí valley.

Chapter 2: Water allocation problems in the Economics Literature

In this Chapter I present the intellectual context surrounding the analysis and policy debate on water management and irrigation problems. I give special attention to literature's contributions with respect to the (actual and potential) role of water markets in solving allocation problems in water resources. The Chapter combines analytical and policy debates surrounding water issues, which are closely related to the complex and specific features of the resource.

First I present some stylized features of water as a scarce resource for human use. These features impose restrictions on water institutions with respect to private appropriation, water transfers and social stability. These also imply that water management is a complex and multidisciplinary task.

The next sections summarize the economic literature on irrigation and water markets. Different issues and conceptual frameworks have been used by economists to try to understand and improve water allocation systems. Water pricing models for large irrigation systems are considered of limited use if these do not discuss the own restrictions on water tariffs as effective rationing mechanisms (given low exclusion) in a context of imperfect information and strategic behavior.

Understanding irrigation problems as part of the general literature on collective action problems appears as a promising avenue for theoretical and applied analysis. Recent research has focused on how water markets may work, shedding light on the complexities surrounding transaction costs, which are closely related to the information environment in which water must be allocated.

The Chapter finishes suggesting that it is necessary to adopt a more general and coherent economic paradigm for the research of irrigation problems, especially regarding the potential role of water markets. The information-based paradigm which has been developing in the last decade by Stiglitz and others appears as the most promising track to follow. In this dissertation I will apply concepts of this paradigm to the concrete case of an agricultural water market in the Limarí Valley (Chile).

2.1. Special features of water

Any serious economic analysis of water for irrigation must start by recognizing its very specific features. For economists this means to consider if water, as an scarce recourse, can be privately appropriated (at a reasonable cost), or whether it can be easily traded, or whether it generates external effects in use and distribution. All these considerations affect economic institutions designed to allocate the resource among alternative uses and users.

Unfortunately (or fortunately!) water is not a resource like others which can be easily appropriated, traded and used without affecting others. The list of water's "market imperfections" is as long as it can be. This makes water a fascinating resource for economics (and also points out the limitations of a too narrow economic analysis).

Thus, it is important to determine the specific features of water which may affect how the "irrigation problem" appears in real situations and how it can be approached by economic theory. I list what I consider the main special features of water in an irrigation system context:

> *Randomness*: total water supply for each cropping season is a <u>random variable</u>, which depends on environmental conditions. Reducing this variability is one of the most

important goals of designing and building irrigation facilities (dams, reservoirs, canals, ditches, etc.).

Mobility: water is a mobile resource, which in its liquid form tends to flow, seep, evaporate and transpire (Young, 1986). Its mobility generates multiple types of physical interdependence among users located in different areas of the same irrigation system.

Imperfect divisibility: water flows can seldom be divided into discrete units for individual use and thus is an imperfectly excludable commodity (Randall, 1988). In some systems--especially were use is highly valued--there are devices for volumetric measurement and greater division (like piped water for urban consumption). In general, however, these devices are not affordable in most irrigation systems, especially in developing countries.

Rivalry: most irrigation systems have a maximum capacity of flow, which generally falls bellow the total demands at some point in time; the rest of the season the capacity may be underutilized (LeBaron and Keller, 1986). As the irrigation system gets congested in the peak season, water is demanded as a rival good, as ones' consumption reduce others' utilities (Randall, 1988). This is also why irrigation systems have important degrees of conflict among irrigators, affecting the allocation process.

All these features may have different configurations which will affect and be affected by alternative institutional settings for water allocation. In fact, there has been a wide variation in institutional responses to these special features around the world and through time.

These specific features suggest some of the directions economists have taken when analyzing water allocation and irrigation problems. Economic approaches can be differentiated by their analytical underpinnings or by the type of problem these intend to tackle. I will use both criteria for presenting the reviewed literature.

2.2. Water allocation as a collective action problem

An effective way to start the analysis of water allocation issues is to consider it as a collective action problem (Saleth et al, 1991; Bardhan, 1994; Sengupta, 1993). A collective action problem refers to individual behavior *vis a vis* some accepted social goal: a situation where individual rationality can lead to "a strictly Pareto-inferior outcome (...) which is strictly less preferred by every individual than at least one other outcome" (Taylor, 1992, p. 19). A more Pareto-efficient allocation cannot be reached based only on individual rationality, as some form of cooperation (or coordination) among individuals may be needed.

The possibilities of collective action problems in water allocations inside an irrigated area are multiple and generally related to the fact that irrigation systems cannot perfectly accommodate individual preferences when exclusion is not perfect and the resource is not totally observable and measurable. Large-scale canal systems generally require high levels of management and collective action for obtaining (at least second best) optimal outcomes.

Thus, the general collective action problem in irrigation appears when designed (or legitimized) operational and allocation rules collide with individual “rationality”. Managerial and allocation strategies are designed to aggregate and restrict individual choices according to some operational principles under imperfect exclusion. However, individual irrigators may try to influence those rules or simply to break them up if that is possible and could benefit them. It is out of this delicate balance that many large-scale irrigation systems end up in severe managerial stress and low production performance at the same time (Chambers, 1988).

An important type of collective failure is presented by Sparling (1990), in the allocation mechanism itself. In his model of “cumulative externality”, farmers located upstream simply take extralegal (or "steal") amounts of water, affecting all the farmers down in the stream. As these water losses are cumulative, the effect will rise exponentially with location, severely affecting those located downstream. And although downstream farmers expected profits will be severely affected, it will be very difficult to blame and sanction individual farmers because actions are not easily observed. This type of problem has been extensively observed in real life situations in which poorer farmers have problems to effectively protect their water rights.

Another type of collective action problem that has been analyzed by economists is related to water transfers (which can be associated to water commercial trading or not). The fact that removing water from an irrigation system has complex effects on the water rights of those not participating in the operation is an important argument for farmers' reluctance to introduce unregulated water markets in irrigation systems. Miller (1987), for instance, uses a simple model of a fixed cost in the administration and maintenance of the canal system to show this point. As water is taken out of the canal system, all remaining users will have to pay the same fixed cost for less water, increasing the average cost of production. Miller argues and tries to show empirically that the observed opposition of farmers and water associations to non-regulated water markets may be an efficient response to the problem of distributing gains and losses among interdependent irrigators (a collective action problem).

2.3. Water subsidies and irrigation problems

The issue of water pricing has taken a lot of space in the economics of irrigation literature (Sampath, 1988). The models of water pricing are popular among economists because they can give very clear policy prescriptions respect to what is the "right thing" to do to improve water efficiency and equity when there is a centralized water authority that can enforce water rights.

Thus, water pricing theory in the irrigation context (and in urban contexts as well) is referred to the search for the optimal water tariff (of alternatives) that a monopolistic water authority must charge in order to obtain the highest social benefit (or other social goal) from individual water users. The formal models that are common in the water pricing literature are those of the monopolistic pricing and principal-agent types, not the auctioneer price-equilibrium models.

One of such typical models of water pricing is that of Rhodes and Sampath (1988). In their model,

> "(...) Six alternative methods[1] of allocating and pricing irrigation water used in developing countries are compared and ranked on the bases of efficiency in production, equity in the distribution of income, and cost recovery to the provisioning authority" (p. 103)

The authors built the model using a Cobb-Douglas production function in which water is a factor of production. Water supply is fixed and the authority's problem is how to allocate efficiently this water to two types of profit maximizing farmers: large and small (in terms of land), which have the same production technology. Using this model, the authors are able to find the six algebraic solutions to the problem and rank the analytical results in terms of efficiency, equity and cost recovery.

As can be expected from the outset, both the benevolent dictator's allocation and an efficient volumetric pricing system achieve the optimal allocation (the equity question is irrelevant, as

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[1] The alternative methods are: Pareto optimal distribution by a benevolent dictator; proportional water distribution regulatory system (proportion according to share in irrigated land); volumetric pricing system; acreage pricing system (a fixed fee according to irrigated land); tax on output produced; and tax on inputs purchased.

only reflects the initial endowments). The other four systems are restricted versions of the maximizing problem, so it is obvious that those would not render the optimal allocation.

The Rhodes and Sampath model is too simple to answer some of the important questions of irrigation problems. The two optimal mechanisms are not viable in almost any real-life situation because the high transaction costs, externalities and information processing those would require. The equity issue, also, is trivialized, in the sense that the results are driven by perfect markets reflecting the initial allocation of assets, something that would change dramatically if transaction costs and externalities of each allocation method were included.

More efficient water pricing models are probably a valuable analytical tool for water management but, in general, these need to include considerations about strategic behavior by water users; the transaction costs (enforcement and administration) of different water pricing systems; differing and conflicting social goals from water users and other actors, and the limited information that water authorities have regarding individual water demands and potential water conflicts. Incorporating some of these complications would make these models more realistic and useful for policy action.

The most troublesome assumption of these simple pricing models is that of non-exclusion (or zero transaction costs assumption), which is related to the possibilities of strategic behavior by users.

This heavily limit the effectiveness of almost any pricing mechanism as a zero-transaction cost allocation system. In fact, water bureaucracies seldom can exclude users on the basis of water payments, and almost never can organize auctions due to rampant strategic behavior (some farmers may have a location-specific strategic advantage due to conveyance losses which make them a sort of a grouped monopsonist).

More important, economic models of water pricing as allocation guides are generally of scarce usefulness for policy recommendations as the complicated problems of water management and investments in maintenance are not directly considered. In this direction, other approaches have focused attention on analyzing how water management is carried on in real life with more realistic assessment of the resource's features as discussed in the next section.

2.4. Irrigation management and the "syndrome of anarchy"

The limitations of using prices as allocation mechanism for water are self-evident to any manager of surface irrigation in developed and developing countries. Generally, water fees are collected ex-ante or ex-post, but seldom affect water demands by farmers (Lebaron and Keller, 1986). Indeed, the normal case is one where water allocations are supply-oriented, and farmers receive the amount to which they are entitled to. Water fees may be collected but those are to cover maintenance and administrative costs, not to rationing water consumption. Thus, analyzing in more detail these supply-oriented managerial practices becomes crucial to understand many irrigation problems.

Managerial principles generally are designed to distribute water in an orderly manner, respecting the parameters of the already built distribution system and according to some established schedule of allocation based on water requirements by crops (seldom according to real farmers' preferences; see Chamber, 1988). The main managerial problem is that actual water use by farmers is not technologically given (related to fixed crop coefficients). Water consumption is part of farmers decision-making both on-farm and above the outlet.

These actions may be too diverse and unpredictable to be accommodated by the designed system and the rigid managerial practices, and managers are faced with situations in which water do not reach farmers with recognized rights, or situations in which the planned allocation has nothing to do with the real allocation. This situation makes water management a very complicated activity, for which special skills of authority, persuasion and information processing is required.

The procedures of water management have been studied in many parts of the world, but with particular intensity in South Asia (especially India). Two important volumes (Coward, 1980; Freeman, 1989) have covered the most important issues surrounding water management in irrigated areas of South Asia. Freeman, for instance, recognizes that the main managerial problem is to reconcile main system supply with farmers demand:

> "The fundamental problem is that main system managers cannot control the strategic variables that determine water demand and water productivity farm by farm and field by field: site specific variations in soil moisture capacity, soil moisture availability, planting times, crop variety, root zone depth, daily crop moisture depletion.... Such matters are known to main system managers as general tendencies, not as field-by-field particularities" (p. 13)

These gaps between general tendencies and specific conditions (which for Freeman remain technological, but which can be extended to individuals economic motivations) is the basis of many irrigation problems. Freeman considers that farmers have better knowledge about these specifics, but are limited with respect to knowledge about the systemic logic of main canal irrigation. To fill this gap, most of this literature has proposed the development of <u>intermediate institutions</u> (for example: users associations) that can facilitate and smooth information transmission among dissonant spheres.

Other authors who have studied managerial problems in great detail are Botrall (1985) and Wade (1988). Botrall focused his work on "above the outlet" management as a leading source of irrigation problems. Wade called "syndrome of anarchy" to the type of situation which characterizes irrigation management in countries like India. In India, designed structures were built to maximize irrigated extension and minimize administrative costs. The result has been extremely extensive systems with permanent flows that are extremely vulnerable to managerial problems and strategic behavior.

Comparing Indian canals with more compact systems of Taiwan and Korea, Wade finds that the former allow a very low intensity of managerial control over the distribution process. The lack of effective control over water by the authority starts a cumulative process of rule-breaking by farmers, who do not see any benefit in restraining from stealing water. High levels of conflict and increasing inequality in the distribution of water are features of the "syndrome of anarchy".

Related to the literature on managerial problems, inefficiency has been associated to the notion of rent-seeking behavior, especially by Repetto (1986). Rent-seeking activities are those that can lead economic agents to obtain profits due to manipulation of the decision process by which some quantity or price of some good is determined by the government or the judicial system. In the case of irrigation management, the good is water, and farmers can bribe water officials or representatives in order to obtain more water than that legally authorized.

The effects of rent-seeking behavior can be daunting for irrigation performance in developing countries such as India (Wade, 1984). This “strategic behavior” not only affects any ordered allocation process but also alters the necessary mutual trust among irrigators and between irrigators and any type of water authority. Farmers start to break the rules and bribe officials, and the high rank officers tend to manage the water increasingly in bulkier units, in order to reduce the problem.

The rent-seeking behavior approach has been considered favorably by some analysts (Moore, 1989) as a simple and coherent diagnostic that accounts for a lot of observed trends and problems in large irrigation systems around the world. Perhaps Wade (1984) has the most telling analysis of rent-seeking behavior in Indian canals, where interest groups and populist coalitions have taken strategic positions in the whole bureaucratic apparatus to extract wealth using rent-seeking strategies of diverse type.

The rent-seeking approach to all irrigation problems, however, has its own limitations. Wade (1989) explains how the successful Taiwanese experience in irrigation management is based on the active role of Irrigation Associations (IA's) but under a clear and centralized hierarchy ruled by a disciplined water bureaucracy that seems isolated from rent-seeking behavior. In this case, the theory should explain why this can happen in one context and not in other.

Other important limitations of Repetto' s approach are the prescriptions. According to Repetto, the necessary reforms in water management should be oriented to increase the use of price and commercial criteria for allocating the resource, under the assumption that those are less vulnerable to rent-taking and rent-seeking activities. This idea, however, seems of little use if it is very hard to enforce commercial mechanisms in large irrigation systems. In general, the problem seems more one of lack of authority and discipline in enforcing the rules of allocation than one of using the price as an alternative mechanism (Moore, 1989). The successful Taiwanese water management is a system in which rules of allocation are based on bureaucratic management, not commercial principles (idem).

2.5. Local management of irrigation

There are many systems in which farmers organize water institutions themselves in order to enforce allocation rules. In Tang's (1992) comparative analysis of diverse irrigation systems in terms of institutional variables, he coded 49 case studies about irrigation communities, from which 41 are located in Asia. The size of systems ranged from 3 to 628,000 hectares.

The systems were classified as "community managed" and "bureaucratically managed", and three basic outcomes are evaluated: a) adequacy of water supply (to users); b) degree of rule conformance; c) maintenance and distribution of costs and benefits. The "explanatory" variables were physical attributes of the system (size, number of users, alternative sources); community attributes (income differentials, ethnic or cultural differences); and institutional arrangements (operational rules, collective choice entities).

The coding of these qualitative variables allows Tang to explore relationships between the explanatory variables and the observed outcomes. He also constructed scales ranking the degree of difficulty in obtaining some outcomes, for which one can see that if some outcome is not achieved (like adequacy of water supply), it is very unlikely that other outcomes are obtained as well (like maintenance and rule conformance).

Tang' s analysis is mainly qualitative and tends to confirm the better performance of autonomous irrigation communities versus bureaucratically managed systems. However, the fact that it is not possible to control for size and complexity of the systems, makes many of these two type of management systems non-comparable. Other problem is that most of the variables are too general and not connected to a clear behavioral model. An additional limitation is that most of the information is second-hand, taken from studies with different methodologies and criteria for outcome evaluation. The framework, however, looks promising as an initial approach to insightful comparative analysis.

One of the leading studies on autonomous water institutions was that by Maass and Anderson (1979) that dealt with six irrigation communities, three in Spain and three in the arid western U.S. These authors carried out a detailed field work describing the complex functioning procedures of autonomous irrigation organizations aimed to achieve "low conflict, equity, fairness and efficiency". They found that these communities indeed put a great weight to minimizing conflict, even if some efficiency gains may not be realized by the imposed rigidities in allocation. They also found that these communities were highly effective in reducing conflict and enforcing operating rules, in contrast to bureaucratic management.

They gave special attention on the extent and limitations of voluntary water transfers independently of land (the basis for a water market). They found that in Alicante (Spain) a market for water rights was actually operating for very long time, although this was subject to some mechanisms of communal control and limits to water transfers. Water transactions have occurred in Alicante since the thirteen century. One important feature of Alicante was the early construction of a large dam that allowed a high degree of regulation of the water supply before irrigation communal control was strong. Maass and Anderson describe a long history of unsuccessful intents to link water to land, promoted by the owners of "old" water rights who do not want to see their rights permanently challenged by "new" rights.

In the other two Spanish communities they studied (Valencia and Murcia-Orihuela) water was virtually "married to land", since water transactions were not permitted at all, and were even considered as evil or sinful activities:

> "...But the sale of water or of the rights to water is anathema to Valencians, where water is married to land and cannot be divorced from it. Spanish communities that

> allow divorce are both benighted and immoral in their view. The farmers attach considerable importance also to their claim that water is 'free' in their huerta, compared to other 'less fortunate' areas where water is sold. Valencians, in other words, prefer elaborate administrative procedures in the short run and prohibitions against water transfers in the long run to an efficiency-oriented market" (p 41).

The reasons that the authors put forward for this resistance to market transactions of water are some "fears of market manipulations", especially by "moneyed men who are not resident farmers (and) could buy sufficient water to be able to control its price and the destinies of irrigators" (p. 42). My own interpretation is that water markets may not have been feasible in these areas due to the low level of control and imperfect measurement over the scarce resource.

2.6. Functioning of water markets and the formation of water prices

In the face of emerging water markets as allocation institutions, economic analysis has been increasingly focusing its attention on how these may operate, what type of market is likely to appear and how water prices may be formed. Economic models of water markets are either oriented to consider the actual functioning of water markets in some areas of the world, or to predict possible outcomes in the case that water markets are introduced.

A model applied to actual functioning was developed by Crouter (1987). He wanted to test whether in Colorado—where water laws allowed trading water separately from land-- the functioning of the water market (in water rights, not in the spot market) was independent (separable) from the land sales market. One of the main efficiency gains from a water market is that it allows higher flexibility in the allocation of the resource, avoiding the traditional bundling of water and land rights.

Crouter used a hedonic price model to test for separability in water and land prices. If water and land markets are independent, a hedonic price function would be linear or additive separable in both prices. Otherwise both resources are really traded as a bundle in the market (like houses with bundled attributes). Analyzing 107 land/water transactions in 1970, he estimated a hedonic price function which was not separable in both prices. Therefore he concluded that in this particular setting, the water market has not evolved as an independent market (yet).

He hypothesized that this may be caused by significant transaction costs in the water market. Search and negotiation costs, identification of water rights attributes and other informational and legal costs may be high enough to make the water market too thin to operate independently from the land market.

A similar study but with a larger data set encompassing several irrigated areas in western U.S. states was carried out by Colby et al. (1993). In their study, these authors seek to find explanatory variables for water price dispersion. They proposed the following variables: priority of rights (or attributes of water), geographic flexibility, high-profile transactions, size and date of transactions. Using regression analysis they found that all of these factors and regional dummies explained water price dispersion, pointing out that these markets are very far from competitive markets (again, this due to high transaction costs).

In a recent analysis of water markets in Chile, Bauer (1995) finds no evidence of (independent from land) water transactions, despite the fact that the Water Law of 1981 created transferable water rights in that country (one of the few in the world). He argues that water transfers independent of land are not feasible in most of Chile because high transaction costs.

If the sales water market has received a lot of attention in the last two decades, especially for the U.S., the rental market not so. One of the few studies related to the water spot market is that of

Saleth et al. (1991). In their model, these authors simulate the operation of a "thin" rental water market in which transactions are restricted by minimum stream flow requirements (which are necessary to protect other water users in the same canal).

They are interested in the alternative types of markets which may appear, especially in terms of their efficiency and price formation. For this purpose they use a multi-agent bargaining model in which the bargaining power of agents depend on their current valuation of water and their gains (or losses) from trading water. The authors consider different bargaining rules and bargaining environments for the simulations. Bargaining rules are based on signal and settlement mechanisms, whereas the bargaining environment depends on market size (3 to 16 players), farm size distribution (identical versus skewed), property right systems (equal sharing and prioritized system) and information (complete versus incomplete).

In their simulations using estimated parameters of water crop use and yields (which affect bargaining power), they find that water prices are highly sensitive to the bargaining rules and environment. As the market size increases, efficiency losses are lower and price formation is more competitive (and efficient). Different water rights systems produce different outcomes, whereas farm size distribution appears as a central factor for increasing inefficiencies, especially in small size markets. In general, the simulated results are suggestive in the sense that thin rental water markets may be very sensitive to structural factors as assets distribution, information and market size.

2.7. Towards an information-based paradigm for water allocation problems

In an influential article by Young (1986) the following is stated about the role of economists regarding water allocations:

> "...it appears in too many cases that an overly large difference in the value of alternative uses is required in order to precipitate transactions as a solution to water supply problems. As economists, we can help to smooth the process of economic change by continuing to improve the empirical knowledge regarding the potential impacts of water transactions. In addition to the conventional economic analysis of direct, indirect and secondary impacts, economic tools can be usefully directed to assess the cost of achieving non-economic goals. We can also help devise exchange institutions with properties which permit the full range of social concerns to be reflected in the transactions..." (p 1150)

I think it reflects a correct standing on the role of economist for improving water institutions. From my perspective, the most promising paradigm for achieving this goal comes from the so called "information economics" as explained by Stiglitz (1994):

> "(...) During the past fifteen years, a new paradigm, sometimes referred to as the information-theoretic approach to economics (or, for short, information paradigm) has developed. This paradigm is explicitly concerned with these issues [problems that arise with the absence of perfect information and the costs of acquiring information, as well as the absence or imperfections in certain key risk and capital markets]. This paradigm has already provided us insights into development economics and macroeconomics. It has provided us a new welfare economics, a new theory of the firm and a new understanding of the role and functioning of financial markets. It has provided us new insights concerning traditional questions, such as the design of incentive structures" (pp 5)

I think that this emerging paradigm may be fruitfully applied to the economic analysis of water problems, in particular, to irrigation incentives and the role of water markets. Given the special features of water (especially its problems of exclusion), it is intuitive to think in a paradigm oriented mainly to understand how imperfect markets may operate in real terms is the most appropriate. The full power of this theory applies "...when markets are incomplete and information is imperfect, (so) the actions of individuals have externality-like effects on others, which they fail to take into account...” (idem, pp 29).

Returning to the quotation from Young, the challenge for economists analyzing water allocation problems may well go beyond measuring the expected impacts of those transactions to studying with a more appropriate model the efficiency of the market itself in a context of imperfect information and adverse incentives. As water markets become a real possibility for allocating the resource we can contribute to understand in which contexts these market are likely to be more efficient and stable, both decisive factors of economic development.

Chapter 3: The Limarí Valley: Irrigation Infrastructure and Water Institutions

Introduction

This chapter is divided in three main sections. The first section presents a general discussion on the Chilean Water Code of 1981, the code that opened the possibility of water markets in Chile. It also presents some evidence of the operation of water markets in Chilean territory.

The second section focuses on the history of the Limarí-Paloma irrigation system and its current situation in terms of the existing water infrastructure serving to agriculture. The third section discusses how water is managed in the regulated area, paying special attention to the organizational features of water distribution, definition/enforcement of water rights and alternatives for the reallocation of water (including the market).

3.1. The Chilean Water Code

Chile is one of the few countries in the world that has a water legislation based on the privatization of water rights and the full operation of water markets. This legislation was introduced by the military government in the early 1980s as part of radical liberal reforms in diverse areas of the Chilean economy. In this section I will analyze the most relevant features of this legislation and of the institutional framework for irrigation and water management in Chile.

The Water Code of 1981 (D.L. 1122) marked a radical change to the previous legislation (of 1967 and linked to the Agrarian Reform implemented in Chile in the 1960s). In the water law of 1967 the State was the only owner and administrator of water, giving authorizations of use to economic agents. Authorizations were based on a ranking of economic activities and pertained to achieve rational and efficient use of the resource through centralized planning. The legislation prior to 1967, however, had a more private approach as water rights were considered "real rights" (*derechos reales*), which gave owners high security and were registered in public registries (Bauer, 1995) .

Most of the planning procedures established by the 1967 legislation did not work in practice. The assumptions about water management were unrealistic with respect to the State's ability to control actions by individual users, especially of agricultural irrigators. Also, the Chilean tradition in agricultural water management was based on private ownership, so farmers did not accept the more centralized legislation. Regulatory aspects of this legislation were seldom enforced and in practice irrigation in Chile went on operating under the strong tradition of private control of the resource. Still, there were collective aspects within the private control of the resource which should not be overlooked.

The water law of 1967 was strongly criticized by the team that prepared the new water code during the second phase (1977-1982) of the government of General Pinochet (1973-1990). This team considered that the existing water law of 1967 was statist and an obstacle for private investment not only in irrigation but also in mining and hydroelectric energy, the main source of electric energy in Chile. Consistent with this critique, the Water Code of 1981 limited the possibility of State intervention in the management and administration of the resource. The water authority (*Dirección General de Aguas*, DGA) lost almost all its power and voice in issues of alteration of water infrastructure, intra and inter-sector transfers of water rights and about specific uses of the resource. All of these functions were, at least in theory, assigned to private owners of water who would have private and tradable water rights with almost not restrictions.

The tradability of water rights was one of the most controversial aspects of the 1981 Water Code. Private owners did not need any authorization to transfer water rights from one use to other or to sell it to other party. Although the Code said that negative externalities should be compensated, in practice it did not create any institutional mechanism for tackling externality-related problems. Water rights were to be registered in public registries and were separate and different from land rights.

Although the DGA was not assigned any important role in water management, it was in charge of the initial allocation of water rights. This was one of the most controversial aspects of the new code as the DGA was obliged to give water rights to anyone who would ask for it until the total consumptive use of the source was exhausted. There was no charge for assigning water rights. Although the Code established that if there were more than one claim to the same water rights these were to be allocated using public auctions, these auctions did not work and most water rights were allocated from two processes: non-competing claims from individuals and corporations, and bureaucratic programs for titling water rights in agricultural areas. It was estimated that at the end of the 1980s, only about 40 percent of water users had formal water rights in Chile (Rios and Quiroz, 1995). It seems that there were also acquisitions of water rights for speculative reasons, especially from firms in the hydroelectric area.

The Code created two types of water rights: consumptive and non-consumptive. The first type are typical of agriculture and urban consumption, the second of hydroelectric and recreational activities. Mining can be considered a consumptive activity as the quality of the resource is severely changed after use. The Code gave a certain priority to consumptive water rights over non-consumptive, although this interpretation was challenged by the powerful electric industry. Conflicts between electric firms and agriculture were not eliminated under this scheme (Bauer, idem).

In terms of conflicts resolution, the Code assumed that private bargaining was enough to solve these. Under the "Coase Theorem" type of logic of zero transaction costs, the Code assigned any water conflicts to the regular judicial system, considering these as standard problems of private ownership. At the same time, the Code did not create any institutional framework for the multi-sector use of water inside water basins. At the moment of the approval of the code in 1981 there were no much public and academic interest in water management at the basin level, situation which would change in the 1990s.

In the 1990s and after the change of government in Chile, the Water Code of 1981 started to be criticized both in political and academic circles. ECLA, an institution of the United Nations, started to evaluate some of the most important problems of this legislation which were associated to speculative practices in the acquisition of water rights, and to inter-sector conflicts between hydropower and agriculture. On the other hand, a group inside the World Bank also started to evaluate this legislation with a very different approach: stressing its impact on terms of efficiency and promotion of private investment in water supply infrastructure. Both institutions presented conflictive evidence about the advantages and disadvantages of the Chilean Water Code.

The newly elected Chilean government in 1990 also started to consider some changes to the 1981 Water Code in two crucial areas: to establish a mechanism to tax non-used water rights and reduce speculation, and to create an institutional framework for water management at the basin level. Both measures were strongly opposed by the conservative opposition in Congress—arguing that these affected the private property of water owners--and could not be passed.

In the 1990s the Chilean Water Code also served as model for adopting similar legislation in other countries in Latin America like Peru, Mexico and Bolivia. However in none of these cases the legislation became as liberal as in the Chilean model.

3.1. Some evidence about water markets in Chile

When considering the possibility of activating a water market it is necessary to evaluate the relative scarcity of the resource, which is strongly related to ecological conditions in different parts of the territory. Water scarcity is also affected by human control of the resource expressed in water storage and conveyance facilities. Only water under human control is considered as economically useful and thus reducing water scarcity. If water cannot be controlled, its abundance does not mean low scarcity in economic terms.

In the Chilean territory, water conditions are very different across the long strip. Only in two of the four main climatic formations is irrigation important: the Northern area (frontier with Peru to the Elqui Valley) and the North and Central Valley (from Limarí to Bio-Bio). Beyond that area, water supply (i.e. water under human control) is abundant and relative scarcity will not generate conditions for water markets to operate.

Besides relative scarcity, another factor must be considered: transaction costs. If a water market were to exist, these costs should be low enough to make transactions profitable for both parties. However, in most irrigated valleys of Chile, reallocating water faces important transaction costs. These are associated to "*marcos partidores*" which are rigid structures which assign water in fixed proportions to different areas inside the same system. This devices were designed previously to the market legislation and reflect the traditional practices of water allocation under fixed proportions. Altering "*marcos partidores*" involve significant costs which need to be paid by potential partners in a water transactions. This may also affect may other parties in the system who will need to be compensated.

The preliminary studies about water markets in Chile indicate that there are very few areas in which such markets have started to operate (Bauer, 1995). The Elqui and Limarí valleys are perhaps the most significant Chilean agricultural valleys in which active water markets appeared after the 1981 Water Code (Hearne, 1995, my own fieldwork in Limarí, 1997). In other agricultural areas with relative water scarcity there was very limited water market activity, whereas in some urban areas near Santiago there is evidence of some market activation (Rios and Quiroz, 1995).

3.2. Evolution and current status of the water infrastructure in the Limarí Valley

The Limarí river basin is located between latitudes 30°15' and 31°25' and is bordered by the Elqui River watershed to the north, and by the Choapa River watershed on the south. The basin's area basically coincides with the boundaries of the province of Limarí. The provincial capital is Ovalle which is the only major city in the area and the center of administrative, social and commercial flows. Ovalle is located 385 Km north of Santiago, and 86 Km from La Serena, the capital of the IV Region to which the Limarí Province belongs to. In general, the Limarí valley has good transportation and communications infrastructure which allows for a fluid commerce of its mainly agricultural products.

The Limarí basin is made up of several major rivers which have their source in the Andes and are filled by thawing snow from the mountains. The Hurtado river drains the northeastern part of the basin. Along its lengthy course it is joined by many small tributaries formed by diverse pluvial streams. Several rivers with a relatively heavy stream flow run from the Andes into the central part of the basin, eventually flowing into the main water resource of the basin, the Grande river. The other three important rivers in the basin are the Pama, Combarbalá and Cogotí rivers which originate in the southern area.

The whole Limarí valley has an extension of about 60,000 hectares. The upper part encompasses about 20,000 hectares in which there is not regulation of water resources. In this area agriculture is much more poorer than in the lower part, which has about 40,000 hectares and is currently devoted to highly commercial crops like *pisco* grapes, avocados, green peppers and artichokes.

3.2.1. Evolution of water infrastructure

The exploitation of water supplies in the Limarí Valley has a long (and conflictive) history in which extreme events like droughts and floods have played a central role. It seems that the hydrological sequence of this valley tends to produce three to four-year periods of severe water scarcity followed by long periods of relative abundance and even floods. For instance, in the 1880-1890 period there was one of these extreme scarcity situations which triggered the first formal register of private water rights in the valley.

In 1928 there was a more precise definition of water rights in which most of the current water rights (associated to land rights until 1981) were created. In the 1930s the State started the construction of two dams to regulate water in the lower part of the valley, as part of a nationwide public investment program oriented to create employment in the mid of the big world recession.

The initial goal of the construction of the two dams (Cogotí and Recoleta) was to give total regulation to the lower part of the valley. This means that the stored water must be enough to give a permanent and secure water supply to holders of water rights. The dams were built with a capacity of 150 million cubic meters for Cogotí (receiving water from the southern rivers) and 100 million cubic meters for Recoleta (receiving waters exclusively from the Hurtado river and tributaries). The estimations were totally off the mark in terms of assuring the regulation of water supplies for the lower part of the valley as engineers used very short hydrological series for their calculation and the functioning of the dams in the following decades showed that there was only a very imperfect regulation of the water supply. This meant that permanent crops were not viable in the valley.

In the late 1950s the Chilean government started to plan the construction of a much larger reservoir to give enough regulation to the valley. The financial support for this project (it estimated cost was US$ 300 million) was going to come from copper export surpluses. Technical studies showed that it was necessary to build that reservoir to generate an interconnected system which would give secure water regulation to the whole lower valley. The site for the reservoir was an area known as Paloma, so the project was named the Paloma system.

After an analysis of 50 years hydrological series, it was determined that the Paloma reservoir must have a capacity of 750 million cubic meters. This capacity was defined only to regulate the water supply of the existent agricultural area, not to increase it (although this was relaxed later under socio-political pressures). The interconnection of the three dams would allow to regulate 60 percent of the water received by Cogotí and Recoleta, and to supply an average of 300 million cubic meters per season to the lower valley.

It was planned that the Paloma system was going to start operations in 1968. However, that year was the beginning of a severe drought that lasted for three years and the interconnected system only could start working in 1970. The initial design of the project required a branch canal (canal *alimentador*) of 78 Km between Paloma and the Recoleta dam. Because of that extended drought this canal practically disappeared as the users of the Recoleta canal did not invest in its maintenance in the mid of the Agrarian Reform in the 1970s in Chile[2].

In 1978 the administration of the Paloma system (which is managed by the Ministry of Infrastructure and Public Works since then) made a hydrological study to determine the optimal annual supply of water from the whole system (which has a total capacity of 1,000 million cubic meters). The study determined that the annual supply must be of 320 million

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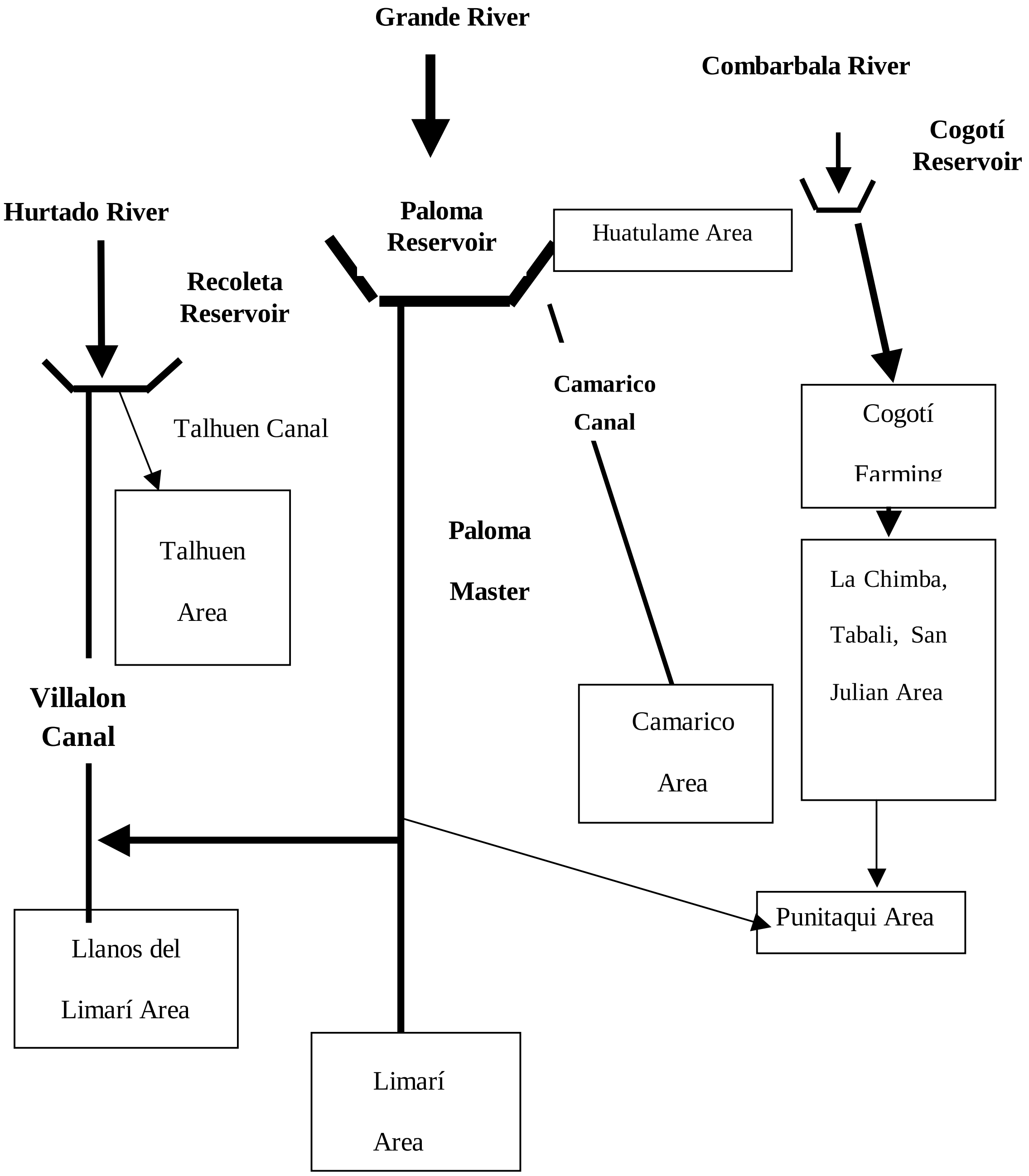
[2] In this period the whole agrarian structure in the valley changed by the redistribution of *haciendas* to permanent workers in the form of cooperatives. This change affected at least to 50 percent of the area, and in some cases even to 70 percent (for instance, in Camarico). A rapid process of parcelation of these cooperatives was going to change again the distribution of agricultural assets (land and water) among members, especially after 1975-1976 and the liberal reform of the Pinochet government.

cubic meters, although there are still difficulties to estimate the inter-annual distribution of rain. The supply of 320 million cubic meters was considered appropriate for agricultural production in the 32,000 hectares (of the 42,000 cultivable hectares that have water rights below the three dams). This means that in a normal year the whole regulating system supplies water to irrigate 32,000 hectares, with an average use of 10,000 cubic meters per hectare. This supply has allowed a massive adoption of permanent crops by local farmers since the 1980s.

Diagram 3.1.: The Paloma-Limarí Irrigation System



3.2.2. Current water infrastructure

The whole irrigation infrastructure in the valley is known as the Limarí-Paloma system regulating the waters for about 32,000 hectares. It includes reservoirs, riverbeds, canal systems and facilities (see Diagram 3.1.). The whole regulated system can be divided into three subsystems: Recoleta, Cogotí and Paloma subsystems. Inside each subsystem there are different water associations (see below about their functions). I will present a general description of each subsystem in turn.

The Recoleta sub-system

Includes the reservoir of the same name, six main canals and a secondary network of canals providing access to the farms. The storage infrastructure consists of an earth-fill 70 m high and 1,000 m long, which makes possible to store 100 million m3 of water. The Recoleta reservoir is the oldest of this type in Chile, and it was put into operation in 1934. At present it has a high embankment and considerable seepage, both in the dam and in the hills surrounding it.

The water is delivered through the bed of the Hurtado river and six main canals of which the Villalón and Talhuén canals are the most important. Both canals have significant seepage losses, estimated in an average of 40 percent of the delivered water[3]. The irrigated area is of about 14,000 hectares of which 9,000 are irrigated by the Villalón and 3,400 by the Talhuén.

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[3] Not all "lost" water is really lost, some or even most of it may reappear for agricultural use by other farmers located downstream or even in other sections of the valley. According to the local engineers, most of the percolated water is received by the Camarico canal, which was built in the deeper zone in the valley. This increases the water endowment of this area with a typical positive and uncompensated externality in water distribution.

The Villalón canal receives complementary water from the Paloma system in order to increase the water regulation capacity of the Recoleta sub-system.

The Cogotí Sub-system

The reservoir was built after the Recoleta, between 1935 and 1940. It consists mainly of a dam made of selected large loose rocks which had been previously washed in order to prevent settling. The dam is 90 m high and 400 m long and has a storage capacity of 150 million cubic meters. The reservoir is designed to store winter water and deliver it in the summer (December-March). The water is discharged directly into the natural bed of the former Huatulame river and 18 Km downstream starts the intake of the Cogotí master canal. From that a portion of the water is given to the Huatulame valley, which had permanent water rights before the dam was built, and the rest of water is delivered to the Cogotí farming area, which is properly the area that "owns" the reservoir.

Although Huatulame[4] farmers receive regulation from the Cogotí reservoir, they do not manage and pay for reservoir's use as they did not own water rights in it. This situation was generated in the 1930s when the dam was built because of Huatulame's strategic location in the system, from which their farmers were able to bargain with Cogotí users to receive regulation without payment or maintenance responsibilities. The Huatualame valley also receives water from the Grande river through the Semita canal.

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[4] The Huatulame valley, with an estimate of more than 2,000 hectares, is very special. It has an excellent climate and soils, which allows the production of high-quality table grapes. These ripen in mid-December and are exported mainly to the United States, at high prices, which makes the activity very attractive (the farmed area has increased steadily in this zone, raising water demand and conflicts with other areas as well).

The remaining water from the Cogotí reservoir is delivered using the extremely long Cogotí master canal (108 Km) from its intake in Chanaral Alto to Cruz Colorada, on the boundary between Ovalle and Punitaqui. This canal is very old and seepage looses are as high as 50 to 60 percent of delivered water, depending on the amount of water flowing in the canals[5].

The canal irrigates a large area of farmland west of the reservoir and south of Ovalle, consisting basically of three terraces which descend in altitude toward the west. Water is supplied to these serially. The first terrace, located in the intermediate zone, has an irrigated area of about 2,230 hectares, and is served exclusively with the water supplied by the Cogotí master canal. The surplus flow is used to irrigate the other terraces, which are complemented with water brought by the branch canal between Paloma and Cogotí.

A final terrace is located in the area of Punitaqui, which was not considered in the original area of the system. It seems that after the Paloma system was operating in the late 1970s there was a severe crisis in the very poor area (related to a mining sector which went bankrupt). In order to increase employment in the zone, the government decided to expand the agricultural area in 1,000 hectares, which were assigned to workers of the mines. The water assigned to Punitaqui comes directly from the Paloma reservoir but using at some points the Cogotí master canal.

The Paloma Sub-system

This system consists of a reservoir, plants and a network of branch canals, which were built in coordination. The wall is 85 m high and 900 m long; the flooded area covers 3,000 hectares,

[5] There are increasing returns in water delivery. This means that when canals deliver more water proportional water losses are lower. This effect implies that water losses are highly variable across years and months, and that water reallocations also affect negatively to those receiving less water in their canals.

and it has a storage capacity of 750 million cubic meters. The network of canals covers a total of 100 Km. The work was considered at the beginning of the 1990s the largest, most modern irrigation infrastructure of the country (this situation may have changed after new irrigation construction during this decade). It serves two main purposes: on one hand, it provides inter-annual regulation of surplus water produced during abundant years, which are then distributed during dry years, and, on the other hand, it backs up the seasonal regulation functions carried out by the Recoleta and Cogotí reservoirs, providing complementary resources.

The Paloma reservoir is in quite good condition. Seepage is minimal and it is inspected and maintained frequently. It is operated by a specialized staff of the Irrigation Bureau (Direccion de Riego) which is part of the Ministry of Infrastructure and Public Works. In recent years the government was trying to pass the administration to the local water associations.

The Paloma reservoir usually delivers about 200 million cubic meters which are assigned more or less in the following fashion: Paloma master canal, 115 million m3, Camarico canal, 35 million m3 and the remaining 50 million m3 are delivered downstream through the Grande and Limarí rivers.

The Paloma master canal is 25 Km long, is fully lined and has very low seepage losses. The canal eventually divides in the branch canals to Recoleta and to Cogotí. The branch to Recoleta is 8 Km long, whereas the one connecting Paloma to Cogotí is 25 Km long. There is still some discussions about who is the main responsible of maintaining and lining these two branches (there were not totally lined in the original project) between the irrigation bureau and the water associations.

The Camarico canal is an old privately owned canal which was built before the reservoir. It irrigates about 5,500 hectares in the southeastern terrace of the basin. The canal is 80 Km long and it is not lined, and losses an average 32 percent of if flows (in some sort of compensation, this canal receives water percolated from other areas in the valley).

The rest of the water from the Paloma reservoir is sent to the bed of the Grande River. This water is mainly used to irrigate 9,000 hectares in the central part of the intermediate and coastal zones. The Grande river joints the Hurtado river upstream of Ovalle, given origin to the Limarí river. The Limarí river is about 40 Km long and empties into the Pacific Ocean. The whole valley and province are known as Limarí from this river.

3.3. Water management and water institutions in the Paloma-Limarí System

The administration of the irrigation infrastructure is complex and is based on a mixture of private and public administration. At the time of my field work, the administration of the largest reservoir (Paloma) and its canals was still under the Irrigation Bureau. A group of about 10 people worked in this office, most of whom were highly trained civil engineers with a long experience in large reservoir administration. In general, the opinion of irrigators regarding this office was favorable, even in the context of a severe drought in which I carried out my research.

The main role of the office is to operate and maintain <u>the reservoir</u>. These services are not charged to farmers, situation which may change in the near future if the administration is passed to the water user associations. The office also provides a crucial function of coordination among the irrigation associations which use the reservoir. Each year around April the office must reach an agreement with all users on the total amount of water to be delivered from the Paloma and the other two reservoirs. Because the whole system is interconnected, water supply decisions must be closely coordinated. The general rules of water allocation were established in an operational accord signed in 1958 and which still today is subject to some conflicts, especially during extremely dry years.

Besides this office, there are six irrigation organizations in the regulated area which have important duties in managing and maintaining the rest of the system. These organizations are private and all users with water rights are required to be members (as in other systems, there is not the option of avoiding membership). In Chile these associations are of three types: Vigilance Bodies (*Juntas de Vigilancia*), Canal Associations (*Asociación de Canalistas*) and Irrigation Communities (*Comunidades de Riego*). Two of the three types of organizations exist in the Limarí valley. Both Limarí and Huatulame rivers are organized as Vigilance bodies, whereas the rest of the system is organized as canal associations (Recoleta, Cogotí, Camarico and Punitaqui).

Water rights in this valley are measured by water shares that endow their owners with a certain amount of water each year. The total volume to be supplied is decided each year for the whole system and each irrigation organization receives a fixed proportion of the total supply. The decision about total supply is based on a general coordination of the Irrigation Bureau and all the users' associations and a basic parameter is the projected water to be stored in the whole system. The proportional rules of allocation to each association were established in the 1958 accord.

Each irrigation organization also makes a projection of water losses due to percolation and seepage, and farmers are communicated of their projected water endowment for each year more or less with precision. Conveyance losses differ across organizations depending on maintenance of the canals and managerial decisions by the corresponding administrators.

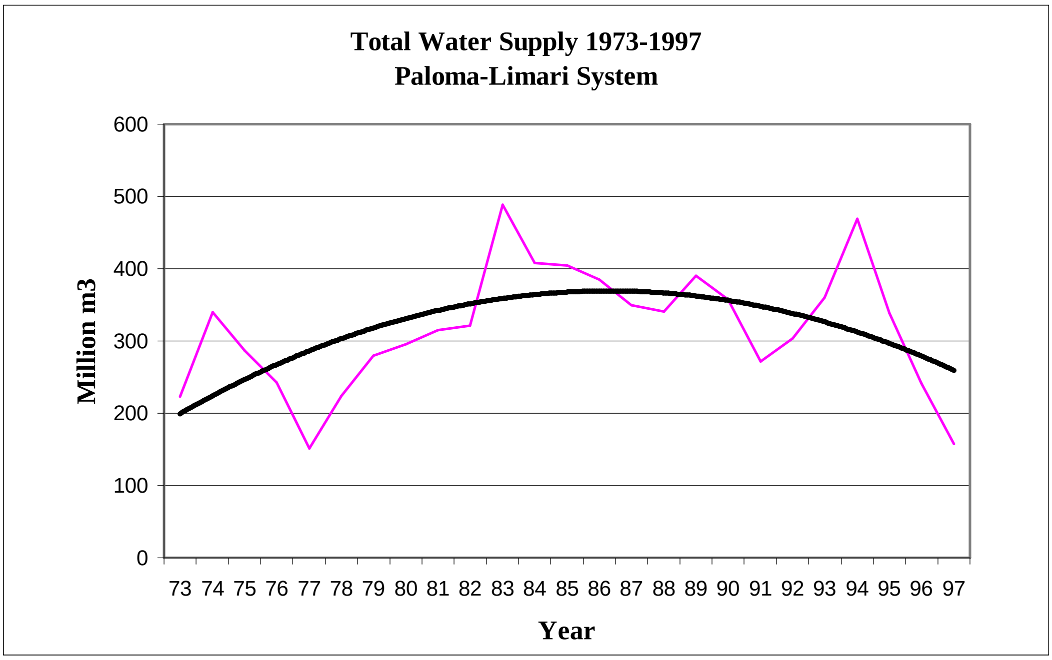
This system of water rights is the main basis for the existence of seasonal water transactions (i.e. the water rental market). Water shares can also be traded as permanent endowments although shares cannot be traded out of a given area (this is controversial as the Chilean Water Code of 1981 allows these transactions, see Chapter 2). Farmers can save water from one year to the next, but there is a penalty of 15 to 20 percent of the endowment due to projected evaporation losses, so this practice is seldom observed. Water savings can be accumulated for other years although this is not a common practice in this system.

Each irrigation association has an elected directorate, which generally is linked to different areas of the specific irrigated area. Each irrigator has voting power proportional to the number of water shares he or she has. This voting system links directly water ownership to representation in the directorate. Generally marginal and small farmers (with few water shares) are underrepresented or not represented at all in the directorate. Sometimes even whole areas are not represented in the respective directorate.

These directorates appoint an administrator to accomplish two main functions: orderly water distribution and canal maintenance. In some cases these administrators also take care of construction of new infrastructure or improvement of the existent. Farmers are charged a flat water tariff (per water share) to cover these administration costs. Failure to pay this tariff may end up in not delivering water to the farmer. Each administrator generally works with some administrative personnel and with a team of water guards (*celadores*) who are responsible for water distribution in different areas. Guards are also responsible for communicating any problems or break downs of the irrigation infrastructure or about complains or transgressions by farmers[6].

In graph 3.1 I displayed the evolution of the annual amount of water supplied to the regulated area since 1972.

Graph 3.1.

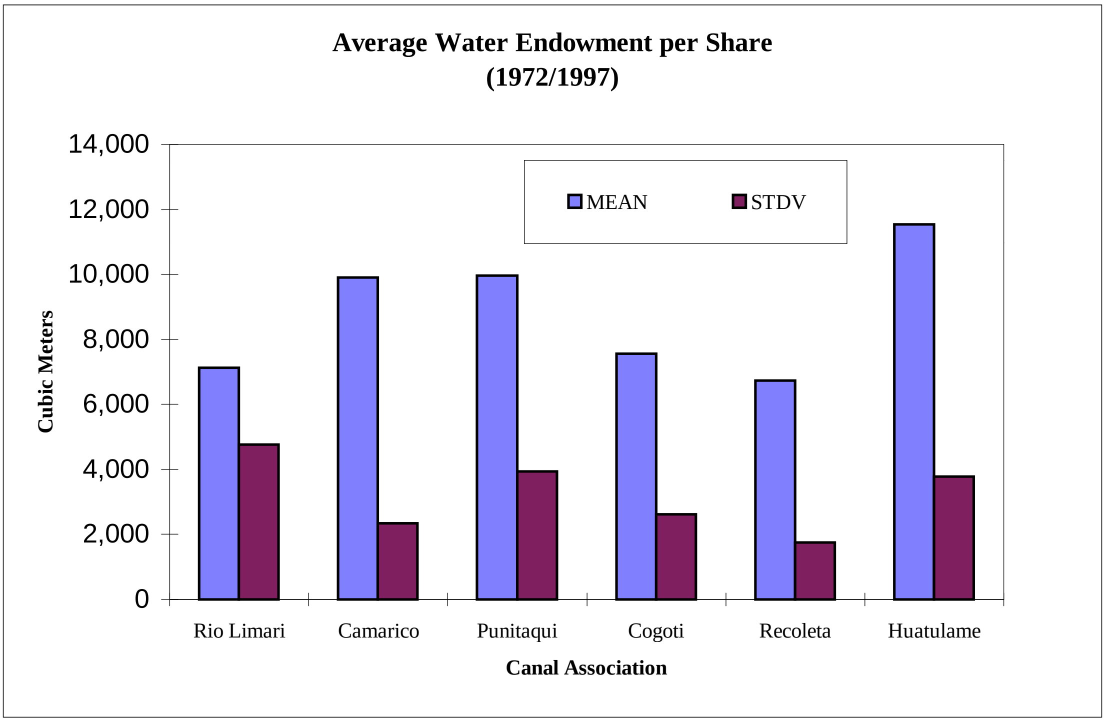


[6] In general, this system of private administration seems to work well and with strong legitimacy among farmers. Water stealing is not really an issue in this valley and I did not hear much about that when I was working there. Still I heard some complains about the administrators, especially from small/marginalized farmers and in the context of a three-year drought and severe water scarcity. Water tariffs, for instance, were also considered too high by poorer farmers, who claimed that even when receiving a minimal amount of water they have to pay the same or even a higher water tariffs in 1996 and 1997. This effect is common in irrigation system in which the administration costs are almost fixed although annual water supplies are highly variable.

It can be seen that the average annual water supply is indeed 300 million cubic meters, although with significant annual variability around this mean. It is important to note that the average supply of water in the 1970s was well below the average supply in the 1980s. In the 1990s, the supply seems to be higher than in the 1970s but below the supply in the 1980s. The severe drought 1995/97 explains most of the drop in average water supply in the 1990s.

Besides inter-annual variability in water supply, each canal association receives a different amount of water each year depending on their water rights and the management of the stored resource in the whole system. In graph 3.2 we see that the average endowment of water per share between 1972 and 1997 was of about 8,000 cubic meters, but with important variation both within and across water associations.

Graph 3.2.



In terms of mean water per share, Huatulame, Camarico and Punitaqui have a higher mean endowment, although with high standard deviation for the case of Punitaqui. Recoleta, Cogotí and J.V. Limarí show a lower mean water endowment with high standard deviation only for the case of J.V. Limarí. This implies that even in this highly regulated environment, there are important imperfections in the supply of water supply to each association.

Farmers have different water requirements each year depending on their crops choice, profitability, their relative endowments and specific ecological conditions (see Chapter 4, ahead). There are different short-term options (versus longer term options) that farmers can use to adjust their water endowments to their water demand. I describe some of the options most used in the Limarí-Paloma system:

Tubewells (pozos): this option is not very common in this valley but was heavily tried during the severe drought of 1995-97. Farmers dug wells using their own labor or hiring machinery hoping to find groundwater supplies which are of open access. In most cases, the obtained water was not sufficient to cover the requirements.

Intra-farmer water transfers: farmers with plots in different areas of the irrigation system are allowed to transfer water from one to other point. If there is a change of water association, the farmers transferring water must adjust their water losses according to the association in which the water will be delivered.

Water loans: some farmers (especially small) receive water from relatives in order to cover some shortages; reciprocity relations are important for some farmers although these practices are not very common in a increasingly commercialized environment.

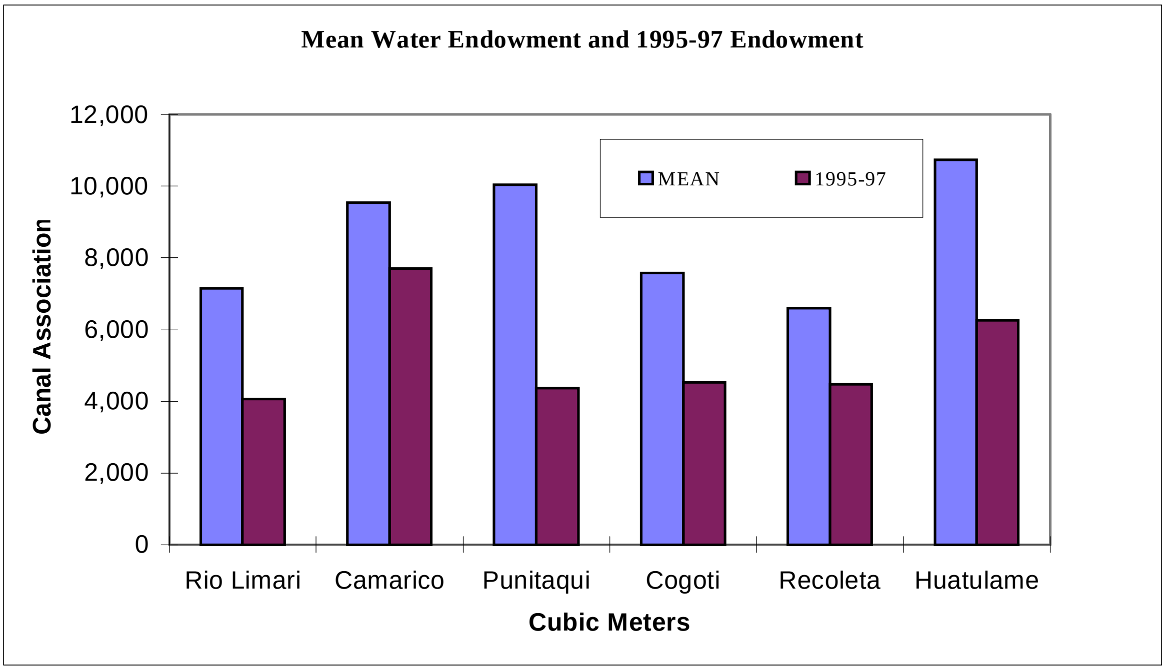
Water trading: farmers can buy or sell water from others in voluntary exchanges; farmers must find their own trading partners (some water offers or requests are posted in the water administration offices); the price is bargained by the parties and there is no intervention of any authority to regulate or tax these exchanges. When a deal is made, both parties sign a legal document (or in some cases a note of mutual agreement) which is sent to the corresponding irrigation organization. If two organizations are involved, both are notified of the exchange. The "water account" of each irrigator is adjusted to reflect the exchange. Water losses are adjusted when the exchange is among two water organizations[7].

There are two types of water markets in Limarí-Paloma: (a) trading of permanent water rights; (b) trading of annual water endowments (or spot market). High levels of regulation and clear definition of water rights makes the operation of both water markets possible in the area.

The permanent market started early in the 1980s when the Chilean water legislation made water trading a legal activity (see Chapter 2). Transactions of water shares among farmers and from farmers and other sectors (like urban or mining) have been common in this valley and

[7] It seems that water exchanges and water transfers do not affect negatively the administration of water resources in the valley. Given the large storing capacity of the system, water trades can be easily accommodated by administrators without affecting operational procedures. It should be noted that water exchanges in other environments may imply operational problems to administrators if water claims are important enough to affect or break the scheduled water distribution. In my field work, the administrators of each irrigation association did not find that the system of water exchanges and water transfers were burden to most of their planning and implementation procedures.

the price of water shares have increased constantly as economic development has been rapid in the area.



The water spot market operates with variable intensity in different years. In general, in years with abundant water supply (for instance, almost all the 1980s), the spot water market was not active at all. There were some transactions but which were marginal and at very low prices. During the severe drought of 1996/97 (see Grpah 3.3.) the spot water market operated very intensively. A deeper analysis of how does this market work is presented in the next chapter.

Chapter 4: The Limarí Valley: Crop structure and Water Market Operation

Introduction

In this chapter I approach the study area from two perspectives. The first one considers the changes in crop structure in the last two decades. Particularly, I am interested in the interplay between irrigation infrastructure and crop patterns. It is clear that the higher water control achieved in the valley after the construction of the Paloma reservoir has had important effects on the increasing presence of permanent crops in the Limarí Valley. This does not deny that other factors, including policies, have influenced the changes observed in the highly commercialized environment. Most of this analysis is presented in the first section.

The second perspective is more a cross section analysis. I analyze the current crop structure using survey information. In the second section I describe the main productive features of the Limarí Valley. In the third section I focus on how the spot water market works. A first issue there is how water prices have been behaving, particularly in the mid of the severe drought of 1996-97. Another issue analyzed is the potential role of transaction costs in the behavior of this market.

The fourth section focuses on the interaction between the water market and a crop structure of the Valley, in which permanent crops occupy a prevalent space. This interaction is the main issue to be analyzed with the theoretical model developed in the next chapter (Chapter 5) and the main basis for the estimations and results presented in chapter 6.

4.1. Recent Changes and the Current Crop Structure in the Limarí Valley

The crop structure in the Limarí valley changed dramatically during the 1980s and 1990s as farmers started to install permanent crops instead of the more traditional annual crops (mainly grains like wheat and maize) and livestock production. These changes are apparent in Table 3.1 comparing crop structure in 1985 and 1997 when the Agricultural Census was carried out in Chile.

Table 4.1.: Changes in Crop Structure 1985-1997

	1985(*)	% in total	1997(**)	% in total
Basic		19.2%	1,892	5.2%
Horticultur		3.9%	4,286	11.8%
Fruits		15.7%	16,074	44.3%
Pasture		61.2%	14,032	38.7%
Total		100.0%	36,284	100.0%

(*) Based on Cepal ,
(**) Agricultural Census

As can be seen, high value permanent crops (mainly grapes) increased their participation in the crop structure from 16 percent to 44 percent. Horticulture also acquired greater importance whereas basic grains and pasture decreased significantly. This dramatic change in crop structure was possible due to the higher regulation of water resource which made investment in permanent crops safer and more profitable.

Some policies also favored the proliferation of permanent crops in Limarí like the government subsidy to investment in drip irrigation since 1985. The presence of the *Pisco* industry also contributed to the ***boom*** in permanent crops in the Limarí valley. The resulting structure in this valley was one in which high value permanent crops became the most important assets for many farmers. I analyze the current structure in the following subsection.

4.2. Describing farmers, their production technologies and access to markets

Based on the producers' survey[8] I carried out in 1998 in the Limarí Valley (asking about the 1996-97 season) I classified farmers using a typology of activities (or crops) that, from my own observation, is a good representation of what farmers were actually producing in the 1996/97 agricultural season. In this highly commercialized area, most farmers tend to specialize in one or at most two types of crops. Therefore, the typology is based on the crop of highest proportion in total production value. Using this criterion I have distinguished six typical activities.

Livestock/traditional: this group encompasses an important group of cattle producers and a few farmers who were cropping traditional crops like maize, beans or potatoes. It seems that in

[8] The sample selection for the survey was made according to the following criteria. Inside each organization I did not take a random sample from a list of farmers due to financial limitations in term of finding each sampled individual. Instead, I simulated random sampling for farmers who were present at their farm at the moment I took the sample: starting a some point inside the irrigated area (stratum), I interviewed farmers using a systematic round skipping close neighbors. This gives 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 selection probability. The procedure also excludes farmers who, at the moment of the survey, have had abandoned production or were not living at their farms.

the past livestock was much more important in the Limarí Valley; in 1997 this activity was not very important due to diminished profitability and water shortages; however it still had some presence both as a specialized activity and as complement for some types of farmers

Horticulture/*Invernadero* production: these crops include mainly artichokes, *pepino dulce*, tomatoes, green peppers (*morrones*) and hot chili pepper (*aji*). In this group many farmers use "*invernaderos*", an option in which plants are covered with a plastic structure creating an artificially protected environment. When *invernaderos* are used generally the irrigation technique is drip and the size of the "plots" is small (the operated median size for farmers producing exclusively under *invernadero* is 0.2 has). There are few exceptions of large farmers using *invernaderos* in some small part of their land. Renting and sharecropping are important for this activity.

Pisco grapes and avocados: these are permanent crops (trees) which lives between 15 and 20 years (sometimes even for 30 years); farmers who choose this option face a high initial investment (trees start to produce after the second year) and a decision regarding the varieties and density of trees in their land; after that the main costs come from maintenance of the trees until these are no longer profitable. Most of the grapes produced by this sector are processed by local **pisco** industries, concentrated on two big private firms: **Pisco** Capel and **Pisco** Control. The **avocado**s, on the other hand, are sold in the local market.

Export grapes: these are also trees but of extremely high value (usually these trees are of shorter time span than **pisco** grapes, and can start production after the first year) which are almost exclusively exported to U.S. and Asian markets. Currently, large commercial firms are predominant in all the production process: cropping, packing and exporting the grapes.

4.2.1 Geographical distribution

The classification of farmers gives me the following distribution across irrigation associations:

Table 4.1: Typology of farmers by irrigation sector

	Traditional	Horticulture	Pisco Grape	Export Grape	Total
Recoleta	4 **8%**	26 **52%**	19 **38%**	1 **2%**	50 **100%**
Camarico	6 **20%**	5 **17%**	12 **40%**	7 **23%**	30 **100%**
Cogoti	1 **3%**	9 **25%**	26 **72%**	**0%**	36 **100%**
Limari	3 **11%**	10 **37%**	13 **48%**	1 **4%**	27 **100%**
Huatulame	**0%**	12 **39%**	3 **10%**	16 **52%**	31 **100%**
Punitaqui	10 **56%**	1 **6%**	7 **39%**	**0%**	18 **100%**
Other	**0%**	2 **67%**	1 **33%**	**0%**	3 **100%**
Total	24 **12%**	65 **33%**	81 **42%**	25 **13%**	195 **100%**

Source: 1997 Survey in Limari Valley

As can be seen, the different sectors have alternative degrees of specialization in the activities. Cogotí, for instance, is highly oriented to pisco grapes production, whereas Huatulame has a clear orientation to export grapes. On the other hand, Recoleta is a sector in which horticulture leads farmers' options, whereas Camarico tends to have the more diversified structure in the irrigated area. The poorest Punitaqui area keeps producing more traditional activities as expected, although pisco grapes are important for some larger producers entering this small zone recently.

4.2.2. Farmers' features

If we observe the differences across our four "types" of farmers in some of their specific features (like education, experience, family size), we can see that there are not dramatic differences:

Table 4.2: Farmers' features and assets

	Traditional	Horticulture	Pisco Grape	Export Grape	Total
Age (years)	57	51.7	55	57.9	54.3
Years of Education	5.4	7	8.1	7.5	7.3
Experience (years)	35.9	29.9	34.7	37.7	33.4
Family size	6	4.84	5.22	4.93	5.16
Corporation	0%	2%	10%	36%	9%
Rent in land	17%	26%	7%	8%	15%
Rent out land	8%	6%	4%	0%	5%
Operated land (Has)	17.1	17.2	41.4	40.1	30.2
Owned land (Has)	15.8	11.3	38.7	39.9	26.9
Water endowment (m3/Ha)	2122.7	1616.7	2543	1662.5	2059.9
Family labor endowment	2.5	2	2	1.7	2
Livestock value (,000 Pesos)	1485.3	465.5	779.7	0	665.3
Tractors	1.33	1.18	1.8	2.59	1.8
Animals	1.4	1.89	1.78	1.33	1.77
Pumps	1.11	1.17	1.3	2.14	1.41
Wells	1	1.1	1.17	1.54	1.19
Water storage	29%	42%	54%	56%	47%
Drip irrigation	1%	19%	16%	84%	24%
Invernadero	0%	22%	5%	12%	11%

Source: 1997 Survey in Limari Valley

Perhaps the most important fact is that corporations are important only in the case of **export grapes.** In this activity there is still some family farming, but it has lost a lot of presence (in terms of area) to corporations which entered the valley first in the processing and exporting business and which have aggressively moved to farm production more recently. In most of all other cases we observe the predominance of the family farm or of the medium/large farmer living and managing his own farm. This is why farmers' features tend to be not very different.

In terms of the farmers' years of education, we observe that traditional farmers have the lowest level (with an average of 5.7 years, below the seven years of primary education). In terms of experience and family size (which are generally correlated), we see that **horticulture** producers show significantly fewer years of experience and smaller family size than the rest of producers. The smaller family size of this group reflects the higher presence of sharecroppers/renters in this activity, which tend to be younger. Precisely, Table 4.2. also shows that renting and sharecropping appear to be much more important for horticulture production. Pure renting is also important for some small **livestock** producers, who are landless but rent land with pasture for the season.

4.2.3. Production assets

More clear differences among our types of farmers appear in productive assets (those which are under their control and/or ownership). In terms of the mean operated and mean owned land, there is an increasing relationship (in the means) among activities.

The ownership of water per operated hectare does not seem to be highly different across farmers. Farmers with the lowest per hectare water endowment were those who did not have any production that year (with a mean well below the rest). Also, we see that both **traditional** and **pisco**/**avocado** producers have a relatively higher water endowment than the rest.

In terms of tractors, **export grapes** producers have the higher level for these assets. Animal traction has the reverse presence across the types. Livestock value is important for **traditional** farmers and complementary for the other types except **export grapes** producers.

4.2.4. Irrigation assets and techniques

Regarding irrigation assets and technique, Table 4.2. shows that the ownership of pumps, wells and small private water storage devices (estanques) are highly correlated to drip irrigation. According to the Table, 24 per cent of the surveyed area was under drip irrigation (this technique assures an efficiency above 90 per cent in application, i.e. plants receive 9 from 10 units of water applied, and a very efficient use of fertilizers and pesticides as well). In the case of **export grapes**, the proportion of land under drip irrigation was 87 per cent, with 19 per cent in the **horticulture** group and only 16 per cent for **pisco/avocados**. It is clear that drip irrigation is highly correlated to crop value and profitability. Access to long term capital is crucial for adoption as this technique requires a large initial investment. In the case of farmers with *invernadero*, who also show an intensive use of drip irrigation, it was observed that their use of drip irrigation tends to be manual instead of computerized as is the case of **export grapes** producers.

Drip irrigation seems to be so crucial in the Chilean context that the government implemented a program of subsidies to those farmers investing in this technique in the mid 1980s. The government offered between 45-55 per cent of the cost of investment, and farmers had to cover the rest. The system was based on annuals contests in which farmers offering to finance more of the project got more points in the general score. At the beginning of the 1990s the program was extended to include also small farmers which were previously excluded from the program (in practice the program excluded small farmers as they could not finance much of the projects and because they could not cover the cost of the technical research required by the government). More discussion about this program below when I analyze access to credit and subsidies.

In all the rest of activities the irrigation technique used by farmers was farrow ("surcos" or "melgas" in Spanish) and in the case of livestock, flooding irrigation ("tendido") and the least efficient is also important for pasture. The estimated efficiency in water application of farrow irrigation is between 40 and 50 percent, whereas for flooding is as low as 15-20 percent. It is necessary to mention that the costs of these alternative irrigation techniques are very different. Computerized drip irrigation can cost about US$ 2,500 to US$ 3,000 per hectare. Manual drip will require a much lesser amount (although I do not have the figure), whereas farrow irrigation only requires labor or machinery to build the farrows at the beginning of the season. In many cases this cost per hectare is low. The same for flooding, which basically is applied to pasture (pasture can hardly be farrowed).

As I said, the ownership of other irrigation assets is highly related to irrigation technique. For instance, it is very likely that a farmer using computerized drip irrigation will have a water storage device ("*estanque*") and several water pumps. **Livestock** producers (especially large) are also very likely to have water storage which is crucial for cattle. The presence of groundwater wells ("*pozos*") was relatively new in the Limarí valley and was tried by many in order to improve their water endowment after several dry years. Most of these, however, had very low yields, and in many cases were not used at all. It seems that the area is not very rich in groundwater resources or that these are located too deep to be economically useable. Regarding the presence of invernadero, it is most important in the **horticulture** group.

4.2.5. Differences in Input use

Differences in per hectare input use across farmers may reflect differences in production techniques, skills, relative prices and relative non-marketable endowments of farmers in a context of imperfect markets. It is likely that a combination of all these may explain the large dispersion observed in factor use in our sample from the Limarí Valley (see Table 4.3.)

Table 4.3. Input use and access to credit by type of farmer

	Traditional	Horticulture	Pisco Grape	Export Grape	Total
Cropped area 1997 (Has)	4.8	5.2	13.7	29.8	11.9
Cropped area 1996 (Has)	11.7	6.7	14.1	29	13.3
Lost area 1997 (Has)	0.2	0.6	0.4	0.4	0.5
Lost area 1996 (Has)	7.7	0.3	1.2	0.6	1.6
% cropped area 1997	**58.9**	**45.3**	**55.7**	**80.5**	**56**
Applied m3/Ha	4165.1	8509.1	7366.2	2877.3	6786.9
Tractor Hours/Ha	2.7	1.1	8	23.5	7.2
Input expenditure/Ha	56.5	209	66.4	199.8	129.8
Contract farming	0.04	0.12	0.72	0.64	0.42
Applief for credit	0.33	0.52	0.3	0.12	0.36
Got credit	0.29	0.43	0.25	0.12	0.3
Credit from INDAP	0.21	0.34	0.06	0.04	0.17
Applied for drip subsidy	0.08	0.14	0.24	0.28	0.19
Got drip subsidy	0.04	0.06	0.16	0.04	0.1

Source: 1997 Survey in Limari Valley

A first important observation (which related to water use below) is that there was significant differences in the ratio of cropped/operated land across types of farmers. **Horticulture** producers were those who used the smallest proportion of their total land (only 45 per cent) whereas **export grapes** producers cropped a 81 per cent of their operated land. It is clear that farmers are more able to adjust cropped land in the case of **horticulture** than in other activities, depending on different crop water requirements.

Regarding water use per hectare, we see that **horticulture** is the most demanding activity, followed by **pisco-avocado** production. **Export grapes** show an extremely low level of water use per hectare, explained by the high efficiency of drip irrigation. **Livestock/traditional** production, on the other hand, has a relatively high level of water use per hectare even if its profitability is low. These differences in water use per cropped hectare across groups can be contrasted with the relatively equal distribution of water per operated land endowment I mentioned before. This means that farmers are either adjusting land (reducing cropped land) to their water endowment or using the water market to complement their different crop water requirements. It seems that whereas an important part of the **horticulture** producers were doing the former (they showed a low ratio of cropped land to operated land), **pisco-avocado** producers were doing the latter (low adjustment but important use of the water market). I return to this point in the description of water market participation.

Regarding the use of machinery services and other inputs (fertilizers, seeds, pesticides) both **pisco-avocado**s and **export grapes** are the most intensive users of machinery, showing that these crops are capital intensive activities. In terms of expenditure on chemical inputs, besides the expected high use by **export grapes**, **horticulture** demands a high expenditure of these.

Pisco-avocado producers, on the other hand, show a relatively low level of input use per cropped area.

In general, more than differences in market factor prices (which are minimal for this localized cross-section survey), what seems to be driving the heterogeneity in input use are differences in crop production technologies, skills and water/labor endowments in a context of imperfect labor and capital markets. I discuss a little more on the credit market next.

4.2.6. Access to credit and subsidies

Farmers can get liquidity for production from three alternative sources: contract farming, financial institutions and their own resources. In the Limarí Valley we observed that different types of farmers have different patterns of access to liquidity. In terms of farm contracting, it is observed that practically all or most of the producers of **pisco-avocado** have a contract with the local processing industry (see Table 4.3). The *pisqueras* firms started to operate about 15 years ago basically promoting the installation of **pisco** grapes offering contracts to buy the grapes at pre-season negotiated prices each year. Farmers only need to find the start up capital for the trees and wait the third year in which grapes start to produce.

It seems that in the last years these contracts have become less attractive to farmers as the relative price of **pisco** grapes has dropped and some costs (especially water) have increased steadily. In any case, the income stream that these type of contracts assures the farmers seems to be enough for them to avoid the use of financial credit in most cases. Only 30 percent of these producers applied for credit in 1996/97 (Tale 4.3.). The same is true for **export grapes**, in which only 12 percent applied for financial credit. In this case, most commercial firms operating in this activities (some of them international corporations) have their own sources of financing both domestic and foreign. In most cases we did not have access to the information regarding credit operations from these firms.

A very important observation is that access to financial credit seems to be crucial for **horticulture** producers. In these alternatives (in which farm contracting is not common), a 52 percent of farmers applied for financial credit and 43 received it. In this activity INDAP (the government credit agency for small producers) has played a central role in providing credit, as in the case of **Livestock/traditional** producers (29 percent of them applied for credit and 21 percent of them received credit).

In terms of access to the irrigation subsidy promoted by the government, the most important observation is that the **pisco**/**avocado** group was by far the most benefited by this subsidy. 16 percent of farmers in this numerous group received this subsidy, which seem to be the only way these farmers can invest in drip irrigation.

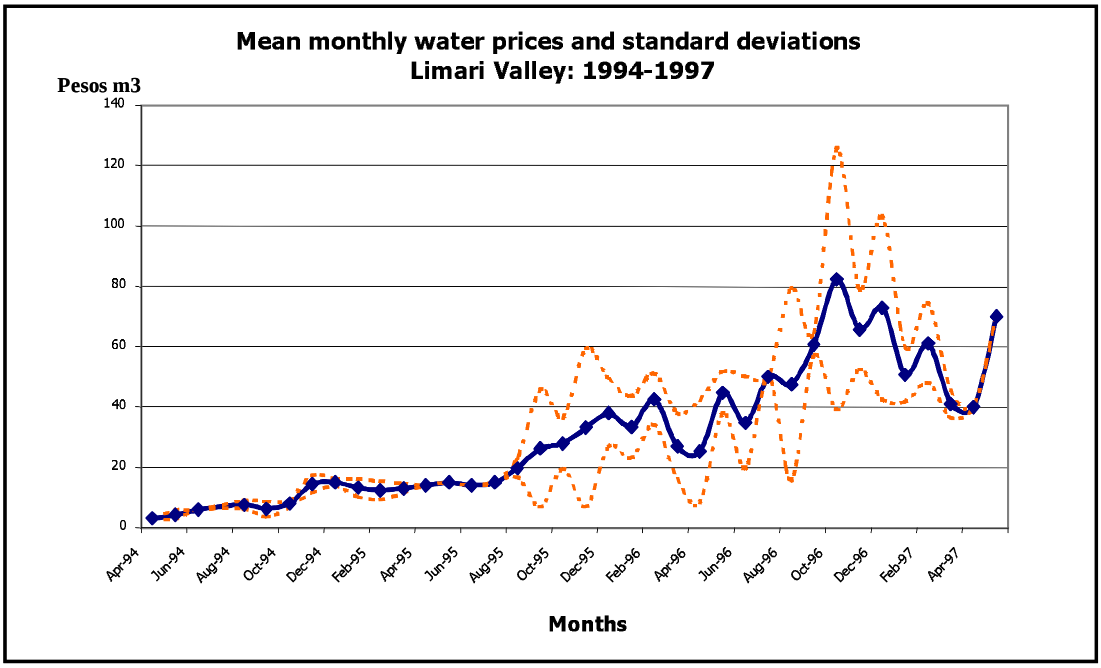
4.3. The workings of the spot water market in the Limarí Valley

I already mentioned in Chapter 3 that a very active (spot) rental market operates in the Limarí Valley, especially during dry years. This market has been active since the 1980s, but started to become more important in the 1990s, after the Valley accommodated much more valuable and commercial crops like pisco and export grapes. It also contributed to this increasing importance the fact that the 1990s were drier than the 1980s (see Chapter 3).

4.3.1. Price behavior

Water associations keep a record of water transactions. These records basically account for the quantity of water traded. In many cases the records also includes the price set by the two involved parties. I used this information to build a time series of water prices since April 1994 to May 1997. In Graph 4.1. it is displayed the monthly evolution of the mean price for water and its standard deviation in the Limarí Valley taken from records of three water associations: Camarico, Recoleta and Cogotí.

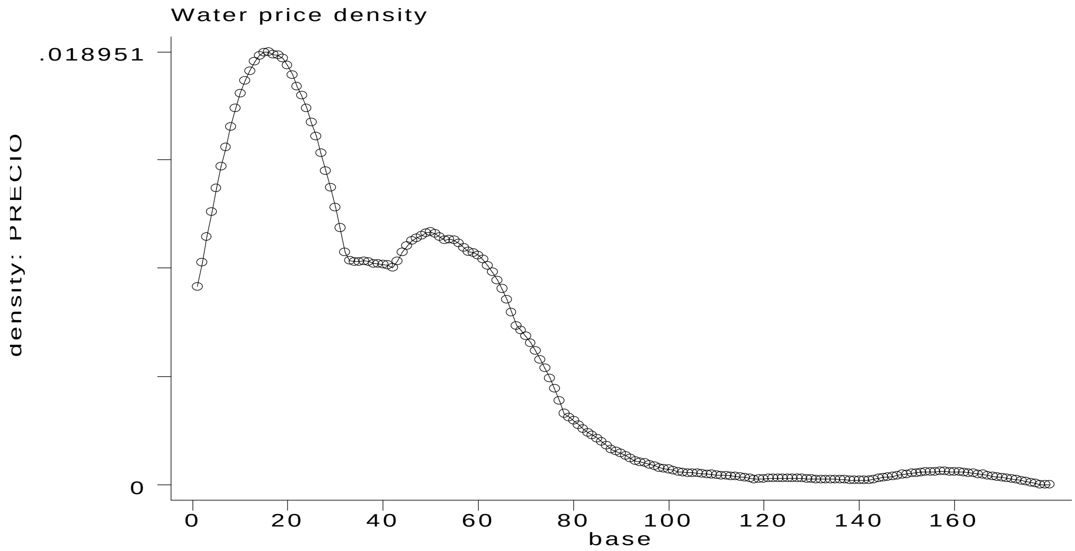
Graph 4.1.



As can be seen, there was a significant rise in prices in 1995, but this trend accelerated during 1996 until its had a peak in October 1996, in which average water prices were about 80 pesos per m3, a price never seen by farmers in this area (inflation was very low in Chile during these years, about 5% annualy).

In Graph 4.2. I estimated non-parametrically the implicit density function for the price series depicted in Graph 4.1. It can be seen that the price distribution tends to be bimodal, i.e. that spot market prices tend to be highly volatile going from low to high prices as one can expect from rigid water demand schedules.

Graph 4.2.



It is important to be cautious about the non-parametric estimation. It must be considered that I used a short time series of prices for the estimation, accruing to no more than four agricultural seasons, from which two had a severe drought affecting the water market. Thus, we cannot make strong inferences about the stability of this estimated distribution in the long run. In any case, the estimation suggests that based on this short term period the farmers in Limarí face a water market with volatile prices. This market behavior will be analyzed in detail in more in the last part of this Chapter, and it will become the main object of study for this dissertation (see Chapters 5 and 6). Despite this high variability in water prices, I am also interested in discussing how well this market may work in terms of transaction costs.

4.3.2. Water market and transaction costs

In my field work I heard a lot about the problems small farmers faced in terms of accessing the water market (be as sellers or buyers) during 1996, especially amidst the driest months of October-December. Graph 4.1. also indicated high variance in water prices, especially when prices started to escalate in 1996. This may be taken as evidence of high transaction costs in this market, as water is a highly homogenous resource for which one would not expect significant differences in quality or other attributes affecting prices.

In order to inquire more about transaction costs, I took the price series and ran a regression of the log of water prices on the log of the quantity of water traded, as well as other variables like time and time squared and association dummies. The results are shown in Table 4.4.

The significant coefficient on quantity of traded water indicates that sellers supplying higher volume of water can get higher prices with an elasticity of 3.2%. This is consistent with the presence of fixed costs in water transactions which tend to promote more bulkier transactions. This implies that in order for small farmers to buy water, they need to coordinate to find a large seller. In one case, the administrator of Camarico was trying to organize one of these transactions but he could not make the operation as there were collective action problems among the many small buyers.

Table 4.4.: Regression of prices on traded water

Number of obs	271
F(5, 265)	217.3
Prob > F	0
R-squared	0.80
Adj R-squared	0.80
Root MSE	0.36

	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
log(volume m3)	0.0324	0.0177	1.83	0.07	-0.002	0.067
time	0.1206	0.0110	10.97	0.00	0.099	0.142
time2	-0.0012	0.0003	-4.49	0.00	-0.002	-0.001
Camarico	-0.0047	0.0775	-0.06	0.95	-0.157	0.148
Recoleta	-0.2215	0.0869	-2.55	0.01	-0.393	-0.050
Constant	1.1485	0.2003	5.73	0.00	0.754	1.543

4.3.3. Water market participation and farmers´ type

One of the limitations of the producers survey I applied is that it was based on farmers who were engaged in some form of production in 1996/97 (see footnote 1 in this Chapter). Farmers who sold out all their water endowment do not appear systematically in our sample (with few exceptions) and we do not have much information about them. Although this will not affect much the information about the demand, this will bias the view of the supply side of the water market as the sellers that we observe are those who stayed in production. Even considering this limitation, we had a good level of market activity in both demand and supply sides in our sample (see Table 4.5.).

Table 4.5: Water market participation by types and associations

	Traditional		Horticulture		Pisco grapes		Export grapes		Total	
	seller	buyer	seller	buyer	seller	buyer	seller	buyer	seller	buyer
Recoleta	0%	0%	19%	31%	5%	42%	0%	0%	12%	32%
Camarico	0%	67%	0%	20%	8%	67%	14%	43%	7%	53%
Cogoti	0%	0%	22%	44%	19%	35%			19%	36%
Limari	0%	0%	0%	20%	8%	23%	0%	0%	4%	19%
Huatulame	0%	0%	0%	0%	0%	0%	0%	19%	0%	10%
Punitaqui	0%	10%	0%	0%	14%	0%			6%	6%
Total	0%	21%	11%	23%	11%	35%	4%	24%	9%	28%

Source: 1997 Survey in Limari Valley

For instance, 9 % of the surveyed farmers were net sellers of water in 1996/97, whereas 28% were net buyers during the season. The mean net purchase water was of 9,632 cubic meters. The mean water price paid or received by farmers in the valley was of 53.2 Pesos per cubic meter. There was significant variation across the different farmers, depending on transaction costs and other production-related variables.

The highest level of water demand was observed in **pisco-avocado** farmers (with the highest number of buyers, 35%). All other groups had a similar participation in the demand side with an average of 23% of farmers buying water in 1996/97. In the case of **export grapes**, the average size of water purchases was much larger than for the rest, purchases made basically by large agro-export corporations at very high water prices (about 80 Pesos per cubic meter).

4.4. Main features of the water market in the Limarí Valley: motivating a micro-economic analysis

In this section I will relate this information focusing on economic variables that I think are crucial to understanding the functioning of the water market.

4.4.1. Profitability and sunk costs

In Table 4.1 to 4.3. we observed a lot of heterogeneity among farmers and across alternative crop technologies (input use, production assets and access to markets). The fact that the data was taken at the end of a severe drought gives me a unique opportunity to observe different "reactions" to extreme water shortage. The following table describes different strategies to this situation:

Table 4.6: Main changes in 1996/1997

Producers	Mean Has in 1996	Mean Has in 1997	Change 96/97	Net Buyers
Livestock	11.9	4.9	- 60%	24%
Horticulture	9.7	7.2	- 26%	25%
Artichoke/pepino	12.2	7.2	- 41%	25%
Pisco grapes/avocado	12.8	13	+ 2%	38%
Export grapes	33.5	34.2	+ 2%	24%

Source: Survey 1997

It is clear that producers of pisco grapes/avocados and export grapes did not find profitable to reduce the cropped area in the mid of the severe drought. In contrast, the rest of producers had a drastic adjustment in their cropping area under the expected water scarcity in 1997. This is also confirmed by the participation in the water market. Whereas pisco/avocado producers had the highest proportion of net water buyers in the sample the other groups have much lower participation in the demand side of the market.

This indicates that the group of pisco grapes/avocado producers had to sacrifice their short-term profits (i.e. lower productivity and accept lower prices from the local Pisco industry) when faced with the drought. This was not the case of the export grapes producers, who were able to keep the same cropping area and profitability given their superior irrigation technology (drip irrigation) and exogenous (foreign) market demand. The rest of farmers (and crop technologies) were able to adjust more their cropping area to avoid loosing short-term profitability.

These observations suggest that pisco grape/avocado producers faced a situation in which the long run losses from water shortages were higher than the short-run losses in profitability. This behavior by pisco/avocado producers can be explained (if we keep the assumption of economically rational behavior) by the presence of significant sunk costs in the crop technology and some sort of minimium water requirement that the trees need for being viable in the long run[9].

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[9] If trees can be irrigated with any little amount of water and still be alive, we would observe less water demand from their owners. The observed rigidity in water demand of *pisco/avocado* producers suggest that they have a crop technology with some sort of "discontinuity". Below some minimum water requirement per hectare they may loose their whole plantation (I think this "discontinuity" is a feature of any living being, including trees, consuming energy from the environment).

Now the question to explore is how this situation may affect the functioning of the water market in the Limarí Valley. From an introductory textbook like Varian (1992) we know that in a "world" in which the input requirement set is convex and the production function has all the necessary niceties like constant returns to scale and no externalities we can expect that market exchanges in a non-produced but essential input (like labor or water in this case) will generate a Pareto efficient allocation (by the way, equilibrium prices are completely independent of preferences and endowments, see pp. 354-355). The observed situation suggests that the input requirement set for pisco/avocado producers is not convex, and one of the main assumptions is broken. One wonders how the water market may work if this assumption does not hold.

4.4.2. Water price distribution and non-convexities

If sunk costs and non-convexities are important in the crop structure in which the water market operates we can expect that these features readily affect how the water price is formed, especially when water supply is binding for many producers (or when their water endowment is below the minimum requirement). This situation was observed in the Limarí Valley during the drought of 1995-97 (see graph 4.1.) which triggered an activation of the spot water market that was not seen in the valley since this market appeared in the early 1980s. The bimodal sort of water price distribution seen in Graph 4.2. also confirms this peculiar behavior for this market.

In 1997 most farmers did not imagine that the price of water was going to end up that high (between 50 and 120 Pesos per cubic meter, depending on the area and period) as they were used to 3 to at most 10 Pesos per cubic meter (as I said before, in Chile inflation was very low for the whole decade, less than 5 percent per year at most).

The escalation of water prices in 1996-97 observed in graph 4.1. reflected the fact that the supply of water for that season was about 200 million cubic meters (see Chapter 3) , i.e. almost one third less than the normal amount. This situation was even more complicated by the fact that water losses due to conveyance are a fixed quantity (sort of a fixed cost), so the available water to farmers was even lower[10].

What we saw was that the price of water was extremely volatile in the October 96-March 97 period. This is the part of the year (summer) in which water demand is higher and farmers face the decision of keeping production or loosing it altogether. I hypothesize that the main cause of this water price[11] behavior is related to the role of pisco/avocado producers and their non-convex crop technology. Their willingness to pay for water was very large when faced with the possibility of loosing their plantations altogether. Alternatively, I hypothesize that if pisco/avocado production were not so important in the valley (41 percent of producers in my

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[10] For instance, in Recoleta and Cogotí, where generally a water share in a dry year gives farmers an endowment of about 2,500 to 3,000 cubic meters, for the 1996/97 season these were below 1,000 cubic meters. Most farmers were severely affected by water shortages, especially in Recoleta, Cogotí and Punitaqui.

[11] The operation of the water market in Limarí-Paloma in 1996-97 was not free of externality-related problems (see Chapter 1 for a discussion of these problems in the literature). For instance, the J.V. Limarí was the association which more water sold out to irrigators in other associations. However, the J.V. Limarí farmers who did not participate in the exchanges complained that they were affected as a lower flow was delivered in their section. Water transfers from Limarí were banned by the directorate of this association in September 1996 (although there was no legal basis for this ban), but the restriction was lifted in November of that year in the mid of increasing pressure from powerful sellers and buyers. It seems that this restriction in the J.V Limarí was also a cause of the huge price increase between October and November of that year (see graph 4.1).

sample a more than 40 percent of area in the recent Agricultural Census), we would not observe this extreme variability in the price of water.

The other important question that arises from this initial exploration is what may be the implications of this "odd" behavior of the water market in the allocation decisions of farmers in the long run.

4.4.3. Water market, coordination failures and allocation efficiency

I propose that farmers in the Limarí Valley face a coordination problem in their decisions to install permanent crops like pisco grapes. The importance of this type of problem was already suggested as promising area of research at the end of Chapter 1 when I discussed the theoretical contributions of the "economics of information" to irrigation problems.

In a world without this problem, farmers' decision to install permanent crops would not affect the distribution of water prices in a way that have allocation implications (in a general equilibrium framework individuals' decision always affect prices, but these effects do not have any interesting allocation implications). In the case under study, it seems that more farmers installing permanent crops have already generated a price distribution with too high variance. This type of price distribution may not be conducive to more investment in permanent crops in the future, reducing the prospects for economic development.

Chapter 5: A Micro-economic Model of Coordination Failures and Water Market Dynamics

Introduction

In this Chapter I will focus on a particular case of coordination failure in the context of decentralized action in which a water market relies. This is not a central limitation for the functioning of a water markets *per se*, but can reduce its efficiency gains versus other alternatives. I will analyze the problem arising from the covariate nature of water supply shocks across farmers sharing the same irrigation system, which are transmitted in specific ways to the market water price distribution in the context of specific crop technology.

The basis of the coordination failure is informational and technological: farmers must decide the type of crop (and technology) they install based on a given water price distribution which is changed over time by those decisions. As farmers are unable to internalize the social costs of those decisions, we have coordination failure regarding crop choice and investment. In particular, I explore this type of problem when farmers decide to install permanent crops with non-convexities in the production technology. A permanent crop is generally more profitable than a non-permanent crop but also riskier with respect to water shortages as the lost of the crop is very costly.

The Chapter is divided into four sections, conclusions and two appendixes. The first section describes the main components and assumptions as well as basic notation of the two-period model. The second solves the maximization problem of risk neutral farmers in the second period, which gives the basis for getting individual net water supply functions (these are used to simulate water operation dynamics in Appendix V.1.).

The third section goes back to the first period decision problem to see how farmers may fail to consider the impact of their decisions on the distribution of water prices. Also, I consider how specific shifts in the price distribution may affect the incentives for land use and for crop choice.

The fourth section compares aggregate output and profits in four allocation alternatives: (a) no water market and no non-convexities in crop production; (b) no water market and convexities in production; (c) water market and no non-convexities in crop production, and (d) water market with convexities in crop production.

5.1. Model's fundamentals

In this section I describe the main features of the model: type of decisions involve; the timing of these decisions; the information and preferences farmers have as well as the technology for crop production.

5.1.1. The time framework for decisions

There are two periods characterizing one agricultural season. In the first period farmers decide about the crop to install (or to keep if it is permanent) and the total water and land endowment to assign to it given an exogenous market price or opportunity cost for each resource. When taking these decisions in the first period, farmers know their water and land endowments but not the water price in the second period.

At the onset of the second period water price is realized. Then farmers decide the amount of water to use in production and water is the only variable input of production, so total output is determined. Land does not have rental market value during the second period but it has sales value at the end of the period.

5.1.2. Crop choice, risk preferences and technology

Crops will differ in three parameters: (a) minimum water/land requirement (θ); (b) crop price (P); (c) land value at the end of second period (h). The crop mix choice set, C, will be defined as C = {s in R1+, such that $0 \leq s \leq 1$}. The continuous decision variable "s" in [0,1] will characterize the crop mix the farmer will put into production. A farmer with s=1 will install only permanent crops, whereas a farmer with s=0 will install only seasonal crops. Different crop mixes will set "s" between 0 and 1.

The value of "s" (i.e., crop mix) will be mapped onto output price, minimum water requirement and per hectare land value by the monotonically increasing functions P(s), $\theta(s)$ and h(s); $P'(s)>0$, $P''(s)<0$; $\theta'(s)>0$, $\theta''(s)<0$; $h'(s)>0$, $h''(s)<0$. This notation implies that it is possible to index crop mixes so that increasing "s" implies increasing output prices, higher minimum water requirement and larger land value all at a decreasing rate.

The function h(.), per hectare value of land, is related to specific features of the crop mix. In the case of a permanent crops (like fruit trees) the land value will be the present value of the expected income stream in its relevant time horizon. If a permanent crop dies due to water failure, the farmer will not receive that income stream or would not be able to sell his land with that embedded return, with a large drop in land value. For non-permanent crops, there are also some losses in land value when the farmer decides to leave production at all during one season but these are much lower than with permanent crops.

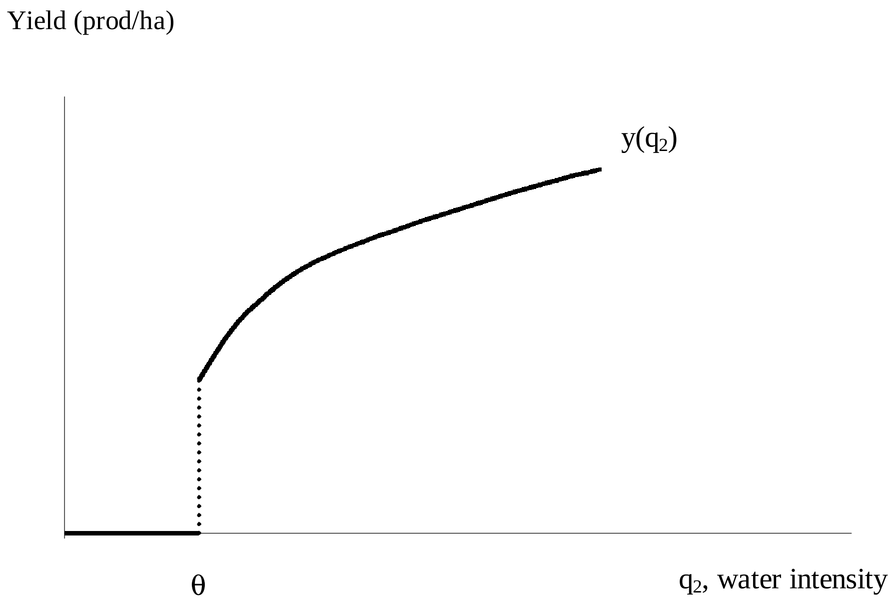
With respect to risk preferences, farmers are assumed to be risk neutral, so they only care about expected returns from water and expected land value in the second period. Farmers cannot save water for the future so their are constrained to consume what they have for this period[12].

The main feature of the technology for crop mix production is a minimum water requirement constraint. If a farmer is not able to apply enough water for his chosen crop mix in the second period (i.e. to meet the minimum requirement), he looses all the crop and production is zero for the season. Beyond the "minimum requirement" threshold, the production function for crop mix displays standard properties of a constant returns to scale (CRS) production function with diminishing returns to water for the fixed (in second period) amount of land. Thus, for the nonnegative water intensity variable "q_2" (water/land) and the minimum requirement parameter θ the yield function y(.) is defined as (see Graph 5.1):

$$(1) \quad y(q_2) = \begin{cases} g(q_2) \quad \text{with} \quad \partial g/\partial q_2 > 0; \partial^2 g/\partial {q_2}^2 \le 0; \text{if } q_2 \ge \theta \\ 0 \quad \text{otherwise} \end{cases}$$

[12] As I mentioned in Chapter 3, farmers could save water for next season in the Limarí Valley if they wanted, but the penalty for this was between 15 to 20%, depending on the association, so this practice was very limited. This high penalty was associated to estimated evaporation losses and managerial complications regarding the allocation of savings. This topic will be addressed when I discuss alternatives to improve the workings of the spot water market in Chapter 7.

<u>Graph 5.1.</u>: Production Technology



This function is discontinuous and right-differentiable at the minimum water per hectare (m3/ha) requirement point θ.

Risk neutral farmers seek to maximize expected profits. As the first period requires that farmers form a water price expectation, I start describing decision making in the second period in the following section. Afterwards I will develop decisions on the first period.

5.2. Second period optimal decisions

Consider the second period water use decision for a farmer who has installed a crop mix "s_1" (in the first period) assigning positive amounts of land (T_1) and water (A_1) for it. The decision problem in the second period is to maximize total profits plus land value h(.) at the end of the season. Due to the minimum water requirement, there are two alternative regimes for profit maximization, depending on whether the farmer exits production in the second period or not. Denote profits by the following function:

$$\pi(.) = \begin{cases} \text{Max}_{\{q2\}} [P(s_1)T_1 g(q_2)] + p_2^w (A_1 - q_2 T_1) + h(s_1)T_1 \text{ s.t. } q_2 \geq \theta(s_1) \text{ if not exit} \\ p_2^w A_1 + h(0)T_1 \text{ if farmer exits production.} \end{cases}$$

In the notation, $h(0) < h(s_1)$ for all $s_1>0$ indicates that by loosing the crop, the value of land is equal to the case in which there is no permanent crop at all. In order to evaluate whether it is optimal for a farmer to exit production and loose the crop in the second period we need to know the maximum profit he can get from production given the parameters and the water restriction. Denote $\pi^*_{\text{non-exit}}$ to the maximum profit value function when the farmer does not exit production. The farmer exits production if and only if $\pi^*_{\text{non-exit}} \leq p_2^w A_1 + h(0)T_1$. This condition will determine an "exit threshold" for the farmer.

Now for calculating the profit value function I look at the optimal conditions using the following Lagrangian function:

$$L = [p(s_1)T_1 g(q_2)] + p_2^w (A_1 - q_2 T_1) + h(s_1)T_1 + \lambda(q_2 - \theta(s_1))$$

where λ is the nonnegative Lagrange multiplier of the minimum requirement constraint. The conditions for optimality (assuming second order conditions are met) are:

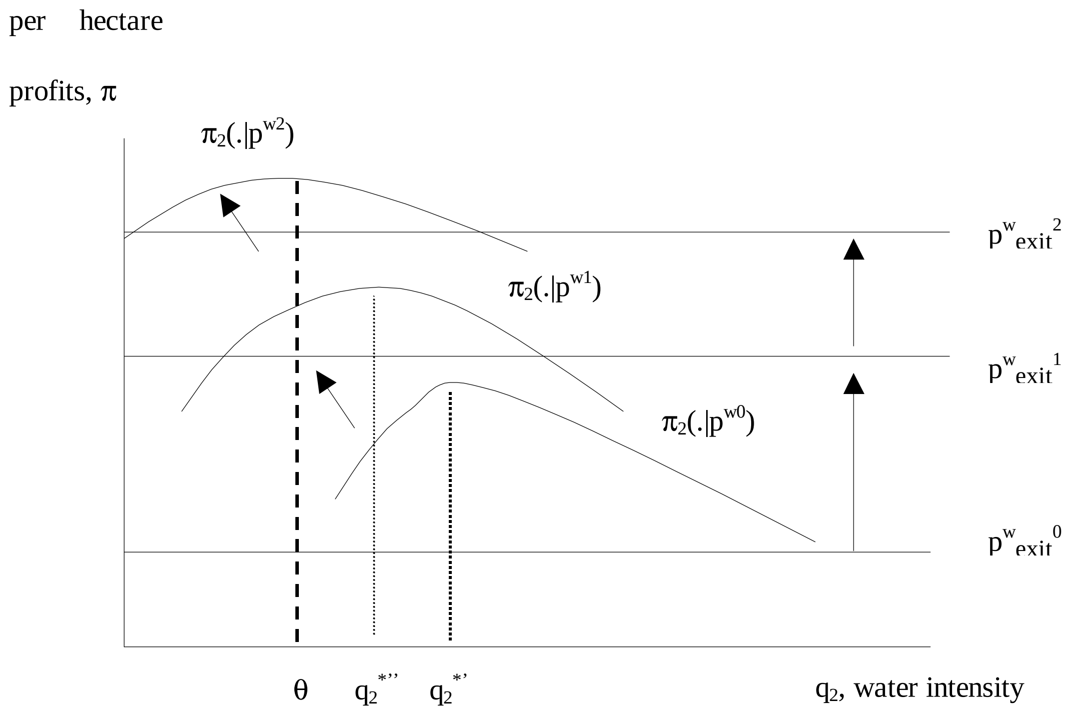
(2.1)	$[p(s_1)\partial g/\partial q_2 - p_2^w] + \mu$	≤ 0
(2.2)	$\{[p(s_1)\partial g/\partial q_2 - p_2^w] + \mu\}q_2$	$= 0$
(2.3)	$q_2 - \theta(.)$	≥ 0
(2.4)	$[q_2 - \theta(.)]\mu$	$= 0$

where $\mu = \lambda/T_1$, the per hectare shadow cost of the minimum water intensity constraint. Conditions (2.1)-(2.4) describe the economic rules maximizing farmers will follow when they do not exit production (i.e. conditional on the non-exit regime). The first two conditions describe the trade-off the farmer faces between generating profits from production and meeting the minimum water constraint.

For a farmer for whom the minimum water constraint is not binding ($\mu^*=0$), the maximization condition requires equalization of water intensity marginal product to the market price for the resource. In contrast, a farmer for whom the minimum water constraint is binding ($\mu^*>0$) has two options; (i) keep producing even if the marginal value product of water intensity (set at the minimum) is lower than the water market price (the positive shadow cost of the water constraint is $\mu^* = - p_2^w + P(s_1)\partial g/\partial q_2$); or (ii) exit production assuming a loss in land value of $-k(s_1)T_1$ with $k(s_1)=-[h(s_1)-h(0)]$ and $k'<0$, $k''>0$.

These conditions are depicted in graph 5.2 for per hectare direct profit function $\pi_2(q_2,p_2^w) = p(s_1)\partial g/\partial q_2 - p_2^w$; as a function of water intensity and for three hypothetical and increasing water prices. As water price increases, this function moves up in the north-west direction (higher per hectare profits). At some point it becomes optimal for the farmer to set water intensity equal to the minimum water constraint. In that case the farmer must consider if he wants to continue producing with negative marginal returns from water intensity or abandon production.

Graph 5.2: Profit Function



The exit decision depends on the net returns from exiting, which are represented by the three straight horizontal lines in the graph. As water price increases, exit net returns also increase. At some point, the exit option is more attractive to the farmer, and he will prefer to sell his overall water endowment and exit production.

Now for deriving the conditions under which a farmer optimally sets water intensity at the minimum requirement (call it the "binding" threshold) we need that $\partial\pi/\partial q_2|_{q2=\theta} < 0$ i.e. when the marginal return from water intensity (evaluated at the minimum requirement) is negative[13]. Developing this condition we have:

$$\partial\pi/\partial q_2|_{q2=\theta} = p(s_1)g'(\theta(s_1)) - p_2^w \leq 0 \rightarrow p_2^w \geq p(s_1)g'(\theta(s_1))$$

Now for the exit condition (call it the "exit" threshold) it is required that profits from exiting must be higher than profits from staying in production at the minimum requirement. This condition is given by:

$$p_2^w A_1 + k(s_1)T_1 > p(s_1)T_1 g(\theta(s_1)) + p_2^w(A_1-\theta(s_1)T_1)$$

$$\rightarrow p_2^w \geq [p(s_1)g(\theta(s_1)) + k(s_1)]/\theta(s_1)$$

So, the following two thresholds are defined :

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[13] A farmer for whom $\partial\pi/\partial q_2|_{q2=\theta} > 0$ will never set the optimal use of water equal to the constraint as he can get more profits from increasing water intensity.

(3) $\mathbf{p_2{}^w{}_{bind}(s_1)} = p(s_1)g'(\theta(s_1))$

(4) $\mathbf{p_2{}^w{}_{exit}(s_1)} = [p(s_1)g(\theta(s_1)) + k(s_1)]/\theta(s_1)$

As can be seen, under CRS both thresholds depend only upon s_1, the crop mix chosen by farmers. The differentials of these two thresholds with respect to s_1 also depend upon s_1 and the curvature of the functions p(.), k(.) and θ(.). It is time to return to the first period decision process in which farmers set the crop mix.

5.3. The first period decision problem

In the first period farmers seek to maximize expected profits (including land value) choosing the amount of land and water endowment they want to devote to production as well as the crop mix for the season:

(5) $\text{Max}_{\{A1,T1,s1\}}\ E[\pi_2^*(A_1,T_1,s_1,\tilde{p}_2^w)|\ \text{information}] - p_1^w A_1 - r_1 T_1$

s.t. $0 \le A_1;\ 0 \le T_1;\ 1 \ge s_1 \ge 0;$

where $\tilde{p}_2^w$ is the random price of water. I assume that the random variable $\tilde{p}_2^w$ in [0,M] is generated by the probability density function $f(\tilde{p}_2^w\,|\phi(s_1^i;\varphi))$, where the conditioning function

$\phi(.)$ denotes shifts on the density function which in turn depends on all individual decisions regarding crop choice that affect water market price.

Note that in this first period farmers are not restricted by their initial endowments of water or land (from above) because they can buy land or water at the market prices if that is optimal for them. Only nonnegative constraints apply to these variables. Using integrals, the maximization problem becomes:

$$\underset{\{A1,T1,s1\}}{Max} \int_0^b \pi_2^*(.) f(\tilde{p}_2^w;\phi) d\tilde{p}_2^w + \int_b^e \pi_2^*(.) f(\tilde{p}_2^w;\phi) d\tilde{p}_2^w$$

$$+ \int_e^M [\tilde{p}_2^w A_1 + h(0)T_1] f(\tilde{p}_2^w;\phi) d\tilde{p}_2^w - p_1^w A_1 - r_1 T_1$$

$$\text{s.t.} \qquad 0 \le A_1;\ 0 \le T_1;\ 1 \ge s \ge 0;$$

where "b" and "e" are the binding and exit price thresholds respectively. The Kuhn-Tucker conditions for this problem are:

$$(6.1) \qquad \int_0^b \partial\pi_2^*(.)/\partial T_1\ f(\tilde{p}_2^w;\phi)\, d\tilde{p}_2^w + \int_b^e \partial\pi_2^*(.)/\partial T_1\ f(\tilde{p}_2^w;\phi) d\tilde{p}_2^w$$

$$+ \int_e^M h(0)\ f(\tilde{p}_2^w;\phi) d\tilde{p}_2^w - r_1 \qquad \le 0$$

$$(6.2)\quad \int_0^b \partial\pi_2^*(.)/\partial s_1 f(\tilde{p}_2^w;\phi)d\tilde{p}_2^w + \int_b^e \partial\pi_2^*(.)/\partial s_1 f(\tilde{p}_2^w;\phi)d\tilde{p}_2^w \leq 0$$

$$(6.3)\quad M^2/2 - p_1^w \leq 0$$

with $(6.1)^*T_1=0$; $(6.2)^*s_1=0$; $(6.3)^*A_1=0$.

Expressions for the derivatives of the indirect profit function $\pi^*(.)$ with respect to each choice variable are developed in Appendix 5.2. As can be seen in (6.2), when individual farmers decide about crop choice they will take the distribution of prices as given and thus fail to consider the impact of their own decisions on the function $\phi(s_1,.)$ which shifts the price distribution in specific ways.

As more farmers install permanent crops, the water price distribution becomes more volatile, i.e., it has a higher variance and likely a higher mean.

5.4. Comparing aggregate output and profits in alternative "worlds"

In the previous two sections I showed how a crop structure in which permanent crops become predominant may affect investment incentives for potential entrants and even block agricultural development for a long period of time. In this section the approach to the same phenomenon is different, I look at how our model of water market compares to other alternative models in terms of aggregate output and welfare (expected income). In particular, it is interesting to compare how well the market does compared to an autarchy situation, in which each farmer is restricted to use their water endowment.

The crucial assumptions of our model are the non-convexity of the production technology and the coordination failure or externality problem in individual decisions, and we are interested in comparing market and autarchy situations, thus we have four models to compare:

Model	Non-convexity	Coordination Problem	Market
A	No	--	No
B	Yes	--	No
C	No	No	Yes
D	Yes	Yes	Yes

Model A: autarchy in a perfect world

In this case we have that farmers cannot trade their water endowment (so information problems are not relevant for price formation). Also, we have that the production technology does nos show non-convexities, and so the production function is concave.

In this situation we have that value fo production per hectare and profits per hectare are given by:

$$z(s_1,A_1) = p(s_1)g(A_1) \qquad (A.1)$$

$$\pi(s_1,A_1)= y(s_1,A_1) + h(s_1) \qquad (A.2)$$

Model B: autarchy in an imperfect world

In this case we have that the production technology have a non-convexity (again, information problems are not relevant) and farmers cannot trade their water endowment. The output value and profits per hectare are given by:

$$z(s_1,A_1) = \begin{cases} p(s_1)g(A_1) & \text{if } A_1 \geq \theta \\ 0 & \text{if } A_1 < \theta \end{cases} \qquad (B.1)$$

$$\pi(s_1,A_1)= \begin{cases} p(s_1)g(A_1) + h(s_1) & \text{if } A_1 \geq \theta \\ h(0) & \text{if } A_1 < \theta \end{cases} \qquad (B.2)$$

Model C: Trade in a perfect world

In this case a water market exists and farmers are no longer constrained to consume their water endowments; also, the production technology does not show non-convexities and there is no coordination problem. This mean that although individual crop choices do affect the water price distribution as price is an endogenous variable, there are no amplifying effects related to non-convexities when many farmers do the same thing and install permanent crops. The resulting output and profits per hectare are:

$$z(.) = p(s_1)g(q_2^*) \qquad (C.1)$$

$$\pi(.) = p(s_1)g(q_2^*) + p_2^w (A_1/T_1 - q_2^*) + h(s_1) \qquad (C.2)$$

In this case, $q_2^*(.)$ is a function of the water equilibrium price and other exogenous variables. This means that optimal production and profits depend upon how the water market works.

Model D: Trade in an imperfect world

This corresponds to the model developed in sections (1)-(4). The output and profit per hectare that we have already used are:

$$z() = \begin{cases} p(s_1)g(q_2^*) & \text{if } q_2^* \geq \theta \\ 0 & \text{if } q_2^* < \theta \end{cases} \qquad (D.1)$$

$$\pi() = \begin{cases} p(s_1)g(q_2^*) + p_2^w(A_1/T_1 - q_2^*) + h(s_1) & \text{if } q_2^* \geq \theta \\ p_2^w(A_1/T_1) + h(0) & \text{if } q_2^* < \theta \end{cases} \qquad \text{(D.2)}$$

5.5. Simulation routine and results

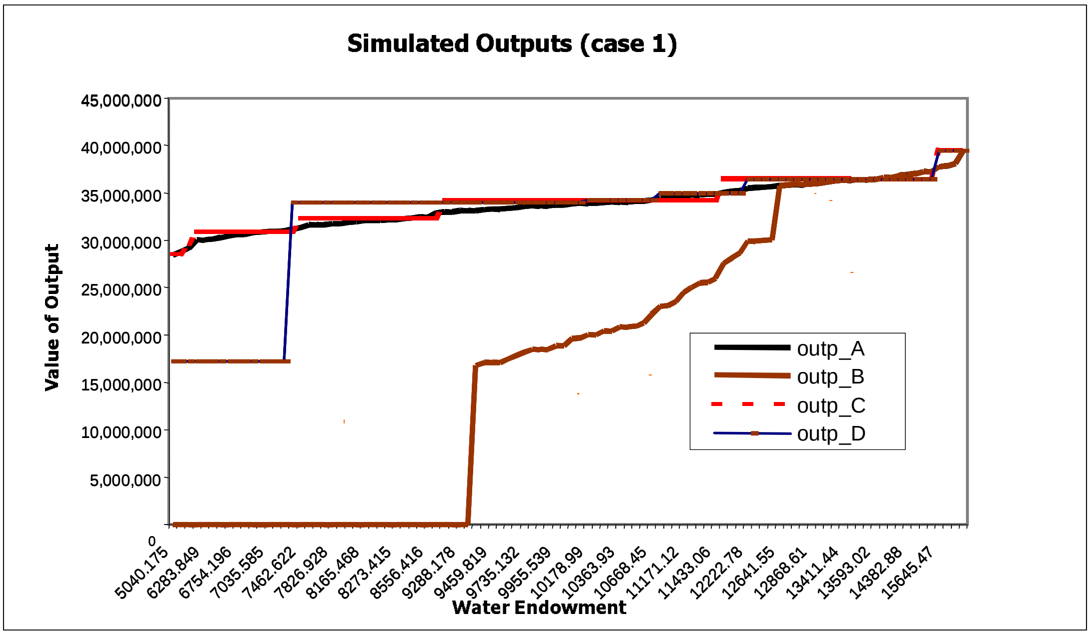
In order to compare the four models I used again the same simulation exercise described in Appendix 5.1. In this context I was interested in comparing aggregate output, profits and the resulting price distribution in the case of models C and D. In the case of models C and D, the routine gives equilibrium water prices (at market clearing point) and I use these prices to calculate expressions C.1-C.2 and D.1-D.2. The simulation calculates output and profits for each farmer and aggregates for the whole system at each simulated year (I used 100 years for this simulation). I ran the four models for two cases: a) when non-permanent are predominant (case 1 in Appendix 5.1) and when permanent crops are predominant (case 3 in Appendix 5.1).

Some results are presented in graphs 5.5 to 5.7. In graph 5.5 (case 1) we see that model C gives the higher total output and profits, as expected.

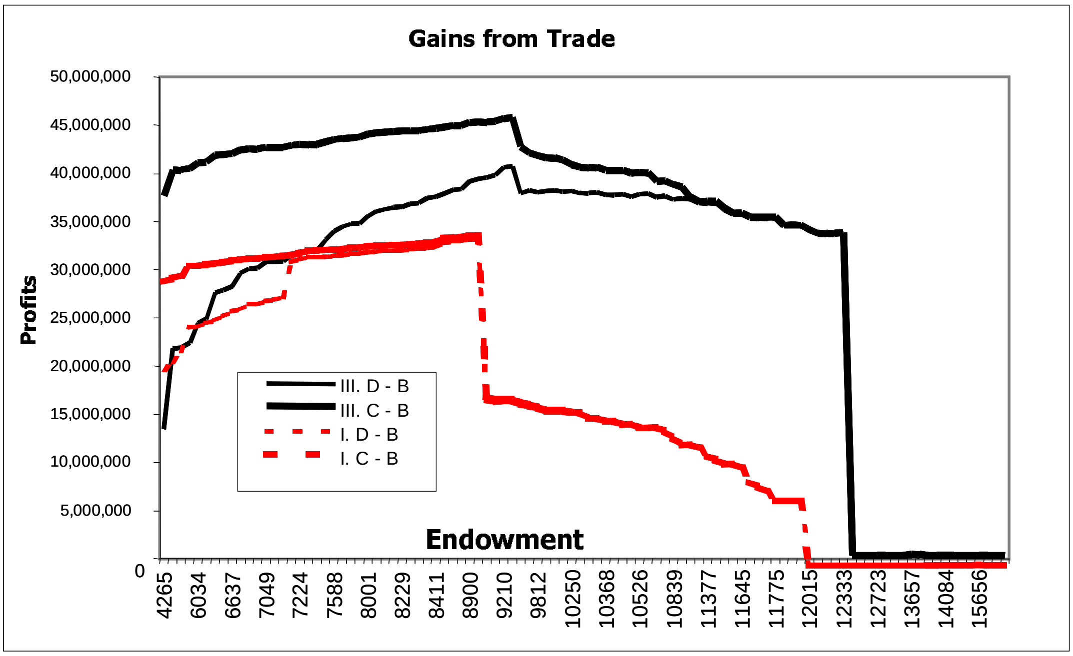
We also see that model A (the autarchic but perfect world) is not very far from the most efficient model C, which implies that gains from trade are not very high when there are no non-convexities.

In graph 5.6 I compared gains from trade (i.e. aggregate profits between models with market versus model with no market) using model B as the no trade case. We see that model A gives larger gains from trade than model D. This means that the assumption regarding non-convexities clearly affects gains from trade or that the gains from trade from market activity are highly sensitive to our assumptions regarding technology, individual behavior and how the water market works.

Graph 5.5:

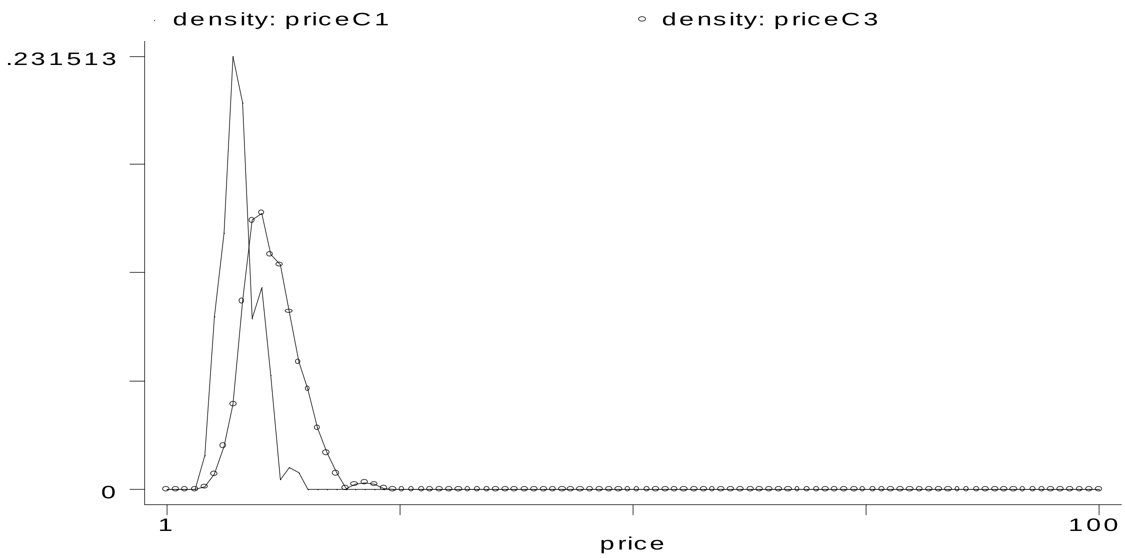


Graph 5.6.

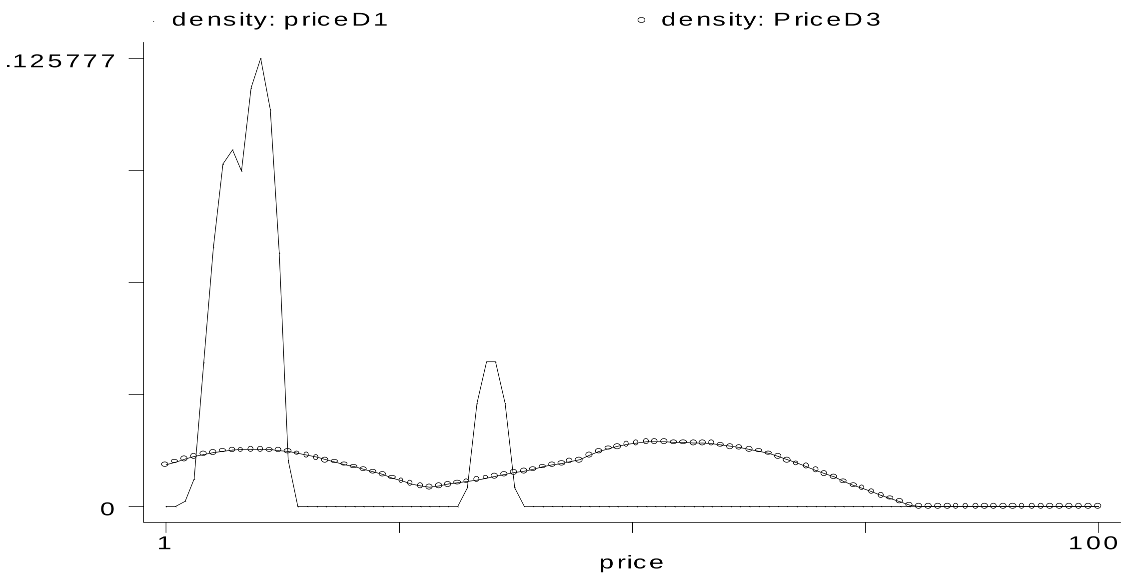


In graphs 5.7 and 5.8 I compared the price distribution generated by models C and D for both crop structures. One limitation of our simulation model is that crop choice and investment decisions are not endogenous (the crop structure is given). The simulation is still useful to see how the externality in model D may affect those decisions. A price distribution with higher mean and variance will reduce the incentives for installing permanent crops and expanding investment. In this context, we can argue that the price distribution generated by model D will generate less incentives for investments than model C for any given crop structure. In case 3 (permanent crops are dominant) we see that the impact of this externality is very high, as the resulting price distribution shows very large variance and expected water price. The dynamic effect of the negative externality is to reduce investment in high value permanent crops than in the case where there no externality (model C).

Graph 5.7.



Graph 5.8.



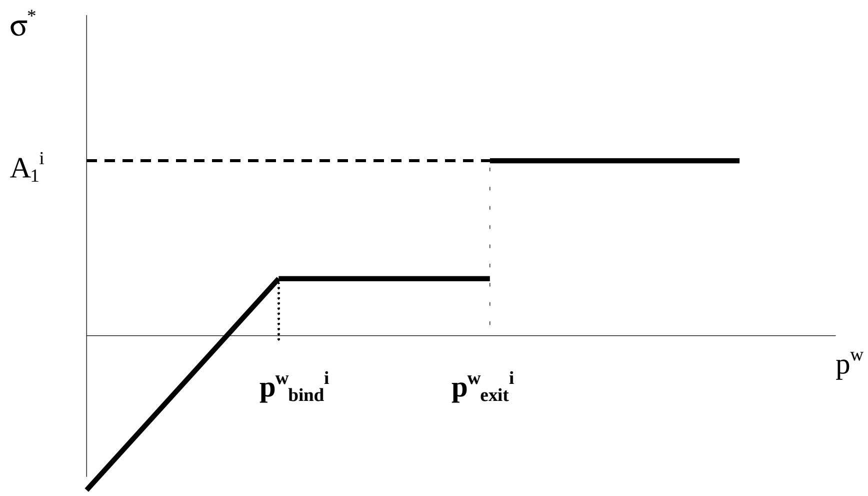
Appendix V51: Net Water Supply and Market dynamics simulation

From the maximization problem in the second period (section 2), denote for a farmer "i" the net water supply function $\sigma^{i*}(p^w,T_1^i,A_1^i,s_1^i)$ as:

$$\sigma^{i*}(p^w,T_1^i,A_1^i,s_1^i) = \begin{cases} A_1^i - q_2^*(p^w,T_1^i,A_1^i,s_1^i) > \theta^i; & p_2^w < p_2{}^w{}_{bind}^i; \\ A_1^i - \theta^i & p_2{}^w{}_{bind}^i \geq p_2^w \geq p_2{}^w{}_{exit}^i \\ A_1^i; & p_2^w > p_2{}^w{}_{exit}^i \end{cases}$$

One of these functions, for a farmer with $A_1^i - \theta^i > 0$, is drawn in Graph 4.3.

Graph 5.3.: Net demand Function



The function is non-continuous and non-differentiable at the exit threshold, and continuous and non-differentiable at the binding price threshold. Thus, there are three different regions of this function, each divided by the binding and exit thresholds. Note that for each farmer there is only one point at which $\sigma^{i*}=0$ (non-market participation). This result changes if we introduce transaction costs in the water market. Transaction costs will generate a larger range on non-participants as is observed in real world (see Chapter 4).

Now in order to consider water market dynamics we need to think in terms of different individual values for the variables determining individual net water supply functions. Differences in any of these variables will create gains from trade and generate market transactions. Assume first that all farmers have the same amount of land $T_1^i=T_1$, and water $A_1^i=A_1$ for all i, but that they have different crop mixes distributed by $\phi(s_1^i;\varphi)$, where the φ parameter shifts the distribution.

There are three potential market participation regimes inside each one of the net water supply's sections (net sellers, net buyers and non-participants). It is clear that after the exit threshold $\sigma*>0$, only net sellers are present in this section. Now in the $[0\ ,\ p_2^w{}_{exit}]$ range, the net position of each farmer depends upon its individual value for s_1^i. Define the following two critical values for s_1^i at which a net seller becomes a net buyer in each section of the net water supply function:

$$A_1 - q_2*(s_1^i) \leq 0;\ s_1^i = q_2*^{-1}(A_1); \qquad p_2^w < p_2^w{}_{bind}{}^i$$

$A_1 - \theta(\underline{\underline{s}}_1^i) \leq 0, \rightarrow \underline{\underline{s}}_1^i = \theta^{-1}(A_1);$ $\qquad$ $p_2{}^{w}{}_{bind}{}^{i} \geq p_2{}^{w} \geq p_2{}^{w}{}_{exit}{}^{i}$

Aggregating these expressions across farmers we have the following expected total water supply and demand schedules:

$$S(.) = \int_0^b \int_0^{\underline{s}} [\underline{A_1} - q_2^*(s_1^i)]\, \phi(s_1^i;\varphi) ds \;\; f(\tilde{p}_2^w) d\tilde{p}_2^w + \int_b^e \int_0^{\underline{\underline{s}}} [\underline{A_1} - \theta(s_1^i)]\, \phi(s_1^i;\varphi) ds \;\; f(\tilde{p}_2^w) d\tilde{p}_2^w$$
$$+ \int_e^M \underline{A_1}\, f(\tilde{p}_2^w) d\tilde{p}_2^w$$

$$D(.) = \int_0^b \int_{\underline{s}}^1 -[\underline{A_1} - q_2^*(s_1^i)]\, \phi(s_1^i;\varphi) ds \;\; f(\tilde{p}_2^w) d\tilde{p}_2^w + \int_b^e \int_{\underline{\underline{s}}}^1 -[\underline{A_1} - \theta(s_1^i)]\, \phi(s_1^i;\varphi) ds \;\; f(\tilde{p}_2^w) d\tilde{p}_2^w$$

The interaction between water endowment distribution and the supply-demand schedules will determine how the water market works every year. Due to the increasing analytical complexity of these supply-demand schedules I will use simulation techniques to see how this market may work for many periods. The simulation will be based on the actual annual water endowment distribution of the Paloma System in Limarí (Chile) but will assume that all farmers have the same endowments of land and water. For a water market to exist, I also assume in the simulation that there is a given distribution of crops (s_1) and that this distribution is changing over time by individuals' actions.

The Simulation routine and its results

For simulation pursposes I used expressions (4) and (5), and gave parametric content to the CRS production function, output price and land sale value functions. All these are functions of s_1, the crop mixing. Each farmer was equal (in terms of endowments and parameters) except for their crop mix, which is the only source of heterogeneity among farmers which makes a water market feasible.

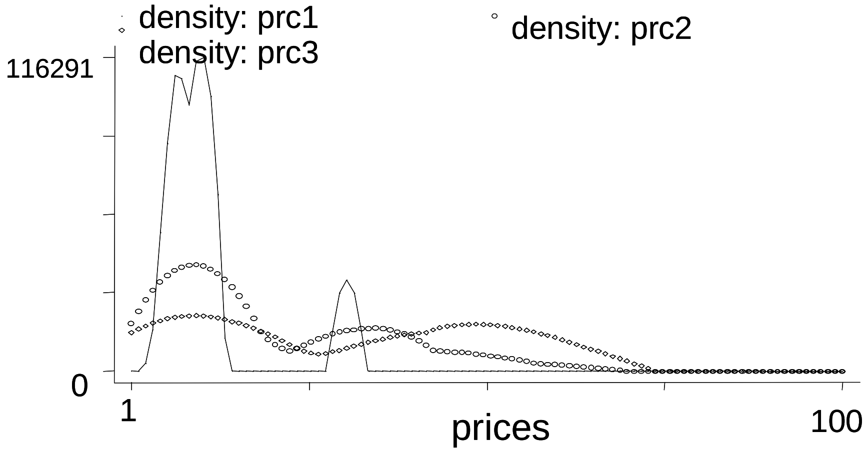
For the evolution of the total (and individual) water endowment over time I parametrically estimated the distribution of water supply in Limarí using actual data on total water supply in the last 25 years using a beta distribution which is highly flexible. Also, for the minimum requirement parameter I used actual data to check at which points agricultural production starts to fall drastically due to water shortages. These are only approximations which give the simulation a degree of similarity with a real situation.

The routine I used for simulating the water market basically builds individual net water supplies as a function of water prices. Aggregating these function the routine check if the market clears (supply near demand); if there is excess demand the water price increases, if there excess demand it falls. The equilibrium price is that at which the market clears with some degree of approximation. The routine randomly extract a water supply from the estimated water distribution function (beta distribution) for each year, and runs the water market routine giving an equilibrium price for each simulated year. The same procedure was repeated 100 times giving 100 equilibrium water prices. Using the beta distribution again we estimated the distribution of these 100 water prices.

Finally, in order to see how changes in the distribution of s_1 affect the distribution of water prices, I simulated the model in three cases: non-permanent crops are predominant, an intermediate case with similar importance for permanent and non-permanent crops in the structure, and a case in which permanent crops are predominant in the crop structure.

The simulation results are shown in graph 5.9. The simulation was able to pick up the bimodal structure observed in the real water price distribution (see Chapter 4, Graphs 4.1 and 4.2). As can be seen, as the crop structure becomes more concentrated in permanent crops, the price distribution not only becomes more disperse (higher variance) but its bimodal structure tends to take a more extreme form. Also, water prices tend to be higher in average. In general, this implies that under these assumptions (and the highly covariate nature of water shocks in an interdependent water system), individual decisions regarding crop choice will have a predictable impact on the distribution of water prices. This is the source of the externality problem or coordination failure in the model.

Graph 4.4



Appendix 5.2: Indirect Profit function and the first period decision problem

Define the indirect profit function for each farmer as:

$$\pi_2^*(p^w,T_1,A_1,s_1)= \begin{cases} P(s_1)T_1g(q_2^*) + p_2^w(A_1 – q_2^*T_1) + h(s_1)T_1 & \text{if } p_2^w < p_2{}^w{}_{bind}; \\ P(s_1)T_1g(\theta) + p_2^w(A_1 – \theta T_1) + h(s_1)T_1 & \text{if } p_2{}^w{}_{bind} \geq p_2^w \geq p_2{}^w{}_{exit} \\ p_2^wA_1 + h(0)T_1 & \text{if } p_2^w > p_2{}^w{}_{exit} \end{cases}$$

Using the envelope theorem (Hotelling´s Lemma) the corresponding first and second partial derivatives of the profit function with respect to water price are:

(X.1.1) $\partial\pi_2^*(.)/\partial p_2^w = A_1 - q_2^*(p^w,T_1,A_1,s_1) > \theta$; for $p_2^w < p_2{}^w{}_{bind}$;

(X.1.2) $\partial\pi_2^*(.)/\partial p_2^w = A_1 - \theta$; for $p_2{}^w{}_{bind} \geq p_2^w \geq p_2{}^w{}_{exit}$;

(X.1.3) $\partial\pi_2^*(.)/\partial p_2^w = A_1$; for $p_2^w > p_2{}^w{}_{exit}$

and

(X.1.1’) $\partial^2\pi_2^*(.)/(\partial p_2^w)^2 = \partial q_2*(.)/\partial p_2^w < 0$; for $p_2^w < p_2{}^w{}_{bind}$;

(X.1.2’) $\partial^2\pi_2^*(.)/(\partial p_2^w)^2 = 0$; for $p_2{}^w{}_{bind} \geq p_2^w \geq p_2{}^w{}_{exit}$;

(X.1.3’) $\partial^2\pi_2^*(.)/(\partial p_2^w)^2 = 0$; for $p_2^w > p_2{}^w{}_{exit}$

In (X.1.1), before the binding threshold is reached, the profit function is increasing in realized water prices at a decreasing rate $\partial q_2^*(.)/\partial p_2^w$; in (X.1.2) between both thresholds it is increasing at the constant rate A_1-θ, and in (X.1.3) after the exit threshold it is increasing at the constant rate A_1. In graph 3 one of these profit functions is depicted for a water price range [0,M]. Notice that (X.1.1)-(X.1.3) also traces the net water supply function of the representative farmer. The net water supply function is responsive to price changes only in the $[0,p_2^w{}_{bind}]$ range (X.1.1'), whereas it is constant for higher realized prices (X.1.2')-(X.1.3').

Also, we need to derive the first partial derivatives for the profit function with respect to the first period used land and crop choice decision variables:

(X.2.1) $\partial\pi_2^*(.)/\partial T_1 = - p_2^w q_2^*(p_2^w,T_1,A_1,s_1) + h(s_1)$; for $p_2^w < p_2^w{}_{bind}$;

(X.2.2) $\partial\pi_2^*(.)/\partial T_1 = P(s_1)g(\theta) - p_2^w\theta + h(s_1)$; for $p_2^w{}_{bind} \geq p_2^w \geq p_2^w{}_{exit}$

(X.2.3) $\partial\pi_2^*(.)/\partial T_1 = h(0)$; for $p_2^w > p_2^w{}_{exit}$

and

(X.3.1) $\partial\pi_2^*(.)/\partial s_1 = T_1[P'(s_1)g(q_2^*(p_2^w,T_1,A_1,s_1))+h'(s_1)]>0$;for $p_2^w< p_2^w{}_{bind}$;

(X.3.2) $\partial\pi_2^*(.)/\partial s_1 = T_1[P'(s_1)g(\theta) + h'(s_1)]$; for $p_2^w{}_{bind} \geq p_2^w \geq p_2^w{}_{exit}$;

(X.3.3) $\partial\pi_2^*(.)/\partial s_1 = 0$; for $p_2^w > p_2^w{}_{exit}$

In general, the marginals (X.2.1)-(X.2.3) and (X.3.1)-(X.3.2) are functions of the realized water prices. This implies that these decisions are affected by how the water market functions, which is the main channel for the negative externality under analysis.

Chapter 6: Econometric estimations of Water Net Supply Functions

Introduction

In this chapter I use survey data to estimate some of the parameters related to the model developed in the previous chapter. In the model I emphasized the impact of discontinuous (or "jumpy") individual water net supply functions on water price volatility, i.e. on the formation of wider bimodal price distributions. These distributions became wider as the presence of permanent crops increases in the irrigated area. It is the main interest of this chapter to estimate a model of the water market participation decisions by farmers and relate it to both individual and aggregate net supply functions as postulated by the theoretical model.

Section 6.1. returns to the main relationships established in the theoretical model to develop a stochastic version that can be estimated using the survey data. One of main variables of the theoretical model was the crop decision "s_1", that is not directly observable in the data. Indexed between 0 and 1, this variable is increasing in minimum water requirement , profitability and sunk costs. As I do not directly observe this variable, I will approximate its measurement using frontier techniques similar to those used to estimated unobserved technical efficiency among farmers. This procedure is developed in Section 6.2.

In Section 6.3. I estimate the econometric model in which the categorical dependent variable on water market participation is compatible with an ordered-response specification called ordered probit. For this estimation I use the individual-specific measure of "s"$_1$ taken from the previous section. I also construct individual and aggregate net water supply functions to evaluate the price range in which there is no water supply to the market. For this I build up an expected aggregate water supply under the assumption that farmers sell water proportionally to their probability of being a seller. This aggregate "potential water supply" function shows a flat portion for a large range of water prices.

Finally, Section 6.4. presents a more direct estimation of water demand and supply functions using censored regression analysis (tobit models). The results again show a supply function with a large range of no supply below a specific water price confirming the ordered-response results.

6.1. Modeling water market participation

In this section I extract some of the relationships established in the previous chapter for explaining water market participation decisions in order to build an econometric model to empirically estimate some of those relationships. In the two-period model, a net water supply function was established and it was the driving force of farmers' water market participation decisions. The net water supply function depended upon realized water prices, land and water endowments and crop decision taken in the first period. More important, a farmer could be at one of three alternative regimes regarding net water supply: (i) he will exit production and sell all of his water endowment: (ii) he will produce at the minimum water requirement in order to not loose the crops (especially high value permanent crops): or (iii) he can be in the well behaved function equalizing marginal value of water to water price. In regime (i) the farmer will be a net seller of water; in regime(ii) he will be likely a buyer or a non-participant: and in (iii) he can be at any of the three possible options: buyer, seller or non-participant.

The most important variable in the model for any of these situations to occur is s_1 in [0,1] the crop decision taken in the first period, in which farmers with high value permanent crops are represented by higher values (close to 1) and farmers with no permanent crops with values close to 0. For farmers with high s_1, the model assumed high water requirement parameter $\theta(s_1)$ and especially a high loss function $k(s_1)$ when they decide to exit production. The model identified two individual-specific thresholds for which farmers may pass from one regime to other[14]: (a) an exit threshold, for farmers selling all their water endowment: (b) a minimum water requirement threshold, for farmers producing at the water constraint with marginal productivity of water different (likely higher) than market price for water. Both thresholds depended only on the crop decision variable (s_1) and on the realized water price. Thus, the net water supply to the market decision for an individual farmer "i" can be expressed as $z^i(.|p_2^{wi};s_1^i)$, assuming that farmers located in different areas may face different individual-specific water prices.

In a stochastic specification and assuming a linear relationship with exogenous variables, the net water supply function can be cast as:

$$z^i(.|p_2^{wi};s_1^i) = \alpha + \beta_1 p_2^{wi} + \beta_2\, s_1^i + v_i = \beta' x_i + v_i \quad \text{(i)}$$

where $\beta' x_i$ represents the non-stochastic part of the relationship and $v_i \sim N(0,\sigma_v^2)$.

---

[14] This type of model has important similarities with the household models developed by de Janvry, Fafchamps and Sadoulet (1992) in which "endowment sensitive" shadow prices affect farmers' participation decisions on input of output markets under market failure conditions.

My econometric approach to expression (i) will be based on ordered-response models (Maddala, 1997). In these models, some specific decisions taken by economic agents are classified in a given number of categories and a categorical variable if defined for these alternatives. In the case of the market participation decision I have an ordered decision variable with three possible situations: (a) being a seller: (b) do not participate (autarchic) or (c) being a buyer. Returning to expression (i), I have:

"i" is a seller if $z^i(.|p_2^{wi};s_1^i) > 0$;

"i" is non-participant if $z^i(.|p_2^{wi};s_1^i) = 0$;

"i" is a buyer if $z^i(.|p_2^{wi};s_1^i) < 0$.

Before estimating this model I will explain how did I approximate variable "s_1" using stochastic frontier methods.

6.2. Measuring unobserved variable "s_1"

In the theoretical model variable "s_1" plays a central role in defining net water supply functions. This variable is not directly observable by the researcher as it involves past investments and future returns not easily measured by cross-sectional data. Thus, in this case I retorted to "production frontier analysis" to get an individual-specific measure of this variable. In the frontier approach, technical efficiency by economic agents is not directly observed and it is approximated building a stochastic frontier which gives the benchmark for efficiency. Distance to this frontier is the measure of technical inefficiency.

The case of "s_1" in my model has strong similarities with the technical efficiency measurement. This variable is not observable but it increases observed income and output from higher sunk investments. In the theoretical model I propose that farmers can be indexed by such a variable measuring differences in crop decisions embedding different past sunk investments and future returns. It should be noticed, however, that according to this, the non-observable parameter to be estimated will be a mix of technical efficiency and embedded past crop decisions. It is not possible to distinguish between these two effects in the estimation with the available information.

For the frontier specification I will be using a standard Cobb-Douglas function with constant elasticity of substitution between inputs. The econometric specification of the relationship between output and inputs for a farmer indexed as "i" takes the following form:

$$Y_i = A * T_i^{\gamma} * L_i^{\alpha} * W_i^{\beta} \exp(u_i + v_i) \qquad \text{(ii)}$$

where Y_i: value of production by i; A is a constant; T_i is land used by i, L_i is labor by i and W_i is water used in production by farmer i. The random variable v_i, has normal distribution with $v \sim N(0,\sigma_v^2)$. Production parameters are γ, α and β, which are directly related to the marginal productivity of the these factors. Random variable $u_i \leq 0$ measures deviations of current crop structure by farmer "i" from maximum possible sunk cost-technical efficiency in crop structure in the sample. The measure of "s_1" for each farmer is given by $\exp(u_i)$, so if u_i is equal to zero, this takes a value of 1 and the farmer is at the highest possible value of sunk cost-technical efficiency.

Taking logs to both sides of (ii) gives:

$$\log(Y_i) = \log(A) + \gamma*\log(T_i) + \alpha*\log(L_i) + \beta*\log(W_i) + u_i + v_i \qquad \text{(iii)}$$

The frontier approach to the standard production function analysis is based on alternative assumptions regarding the distribution of u_i, that becomes the main object of interest. Assuming the standard option of a half-normal distribution for u_i, the compounded disturbance in (iii) is $\varepsilon_i = u_i + v_i$, which is asymmetrically distributed but with known distribution.

Using maximum-likelihood estimation for this model I get estimates of the variances for u and v, which are needed for getting the conditional expectation of u given u+v. This expectation is evaluated for each farmer getting individual-specific s_{1i} parameters. Before the estimation, I present some specific features of the used data.

Some features of the data

The survey was designed to take production data during the 1996/97 agricultural season in the irrigated area of the Limarí valley (see Annex IV.1 in Chapter 4 for the sampling procedures and survey design). A total of 195 farmers were surveyed from a stratified sample (strata were defined as irrigation organizations, so I had six strata, see footnote 1 in Chapter 4). Table 6.1. presents farmers who declared not to have production or to used some inputs in the 1996/97 season. A first important point is that 11% (about 21 farmers) of the sample did not have any production in the 1996/97 season. These farmers will need to be excluded from the logarithmic form of the Cobb-Douglas specification (and other log specifications as well) as it requires positive production.

In the case of water used by farmers in 1996/97 production season, I calculated indirectly--for each of the 195 farmers--how much water did they use during the season. This information was not taken from the survey but from administrative records on farmers' water endowments, water delivered for that season (discounting seepage losses) to the area and water trade and transfers among farmers.

Many farmers (42%) declared that they did not expend anything on inputs (chemicals and fertilizer) for that season, and that ratio was quite stable across farmers' types (Table 6.1.).

Table 6.1.: No use of inputs by type of farmers

	No production	No land	No labor	No input
Traditional	22%	9%	26%	48%
Horticulture	18%	3%	5%	40%
Pisco grapes	4%	0%	1%	43%
Export grapes	4%	0%	0%	40%
Total	11%	2%	5%	42%

Source: Field survey

A part of this high figure for no input use might be simply related to the fact that some farmers could not recall the detailed information asked by the surveyors. In many cases I have missing values instead of zero values. In any case, given this high presence of zeros and missing values, I would not use inputs in the production function specification. Farmers with no declared use of labor (5%) were also dropped from this initial analysis. It left 164 farmers for the production function regressions. Table 6.2. presents summary statistics of the variables used in the production function estimation.

Table 6.2.: Summary statistics of regression variables

	Unit	N	Mean	Stdv	Min	Max
Log(production)	Pesos	164	8.039	2.125	2.079	13.576
Log(land)	Has	164	1.627	1.364	-1.715	5.298
Log(labor)	Days	164	6.325	1.509	2.773	11.212
Log(water)	Cubic meters	164	10.273	1.361	6.763	13.271
Grape age	Years	164	4.653	5.586	0.000	24.200
Grape age2	Years2	164	52.660	96.673	0.000	585.640
% land with drip	Ratio	164	0.218	0.394	0.000	1.000

Source: Field Survey

Maximum-likelihood estimations

The results of the maximum-likelihood estimation of (ii) are presented in Table 6.3. along simple OLS estimates. As can be seen, the estimated variance of u is much higher than the estimated variance of v, the random normally distributed error term. This implies that differences in crop structure by among farmers is important in explaining output variation.

Table 6.3.: Production Frontier estimation

	OLS Estimation			Frontier Estimation		
Variable	Estimate	Std error	t-value	Estimate	Asym error	z-value
Constant	**4.949**	1.089	4.545	**7.1287**	1.1935	5.97
log(land)	**0.528**	0.131	4.041	**0.6187**	0.1444	4.28
log(labor)	**0.699**	0.101	6.905	**0.5569**	0.105	5.3
log(water)	**-0.272**	0.116	-2.337	**-0.2044**	0.1286	-1.59
Years	**0.199**	0.050	4.016	**0.0783**	0.0683	1.15
Years2	**-0.008**	0.003	-2.889	**-0.0041**	0.004	-1.01
% with drip	0.441	0.295	1.494	**0.6821**	0.3033	2.25
σ_u				**3.0759**	0.2949	10.43
σ_v				**0.4243**	0.0866	4.9
log- lik value				-0.8910		
Observations	164			164		
R2	0.689					

(*) Coefficients in bold are different from zero at the 95% confidence level

The main interest of the estimation is to calculate the conditional expectation (for each farmer) of u_i given u_i+v_i, that will play the role of "s_1":

$$E(u_i \mid u_i + v_i) = \int_{-\infty}^{0} u_i f(u_i \mid u_i + V_i)\,du_i$$

Following Kalijaran (1990), this expectation is given by:

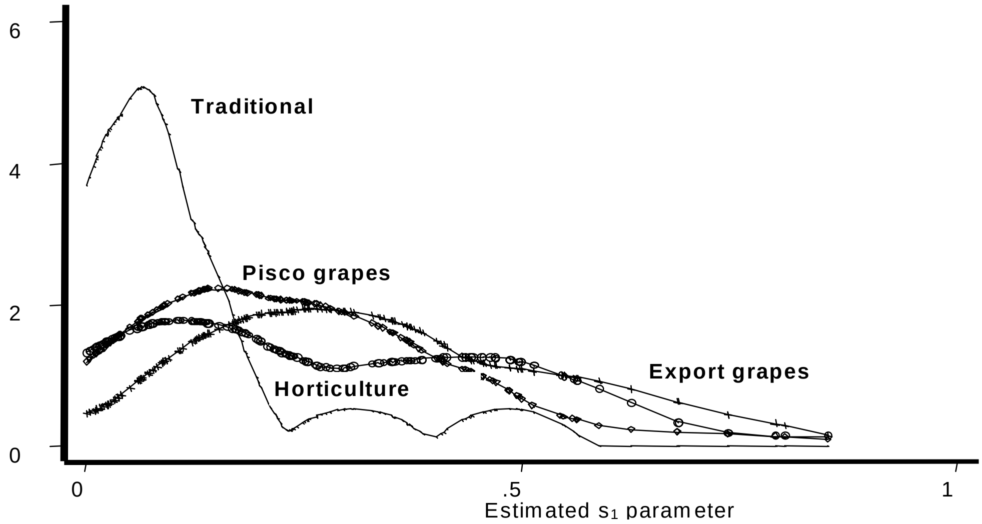
$$E(u_i \mid u_i + v_i) = -\frac{\sigma_u \sigma_v}{\sigma}\left[\frac{f(.)}{1-F(.)} - \frac{u_i + v_i}{\sigma}\sqrt{\frac{\lambda}{1-\lambda}}\right]$$

in which $\lambda=\sigma_u^2/\sigma^2$. Functions f(.) and F(.) are the values of the standard normal density function and standard normal distribution function respectively evaluated at the second (individual specific) value with negative sign in the brackets.

In Graph 6.1. I displayed kernel estimates of the estimated farmer-specific technical parameters applied to the four types of farmers.

As can be seen, the estimated "s_1" parameters are coincident with our previous categorization of farmers if the main interpretation of it is a embedded sunk cost measure. However, I stress the fact that the estimation may also contain differences in technical efficiency among farmers. Traditional producers appear as farmers with lower "s_1" in the sample, whereas export grape producers are the ones with larger average parameter with a distribution with thicker tail at the right side. Horticulture producers seem to be divided into two different groups, one with higher s_1 than the other. Pisco grape producers appear at an intermediate level, showing a more normal-like distribution.

Graph 6.1: Estimated "s_1" distributions by type



The estimation of individual-specific s_1 parameters is important for the operation of the water market. In Table 6.5. it is shown the differences in the mean of these parameters among participants-non participants in the water market.

Table 6.4: Estimated s_1 and water market participation

	Seller	Non-partic	Buyer	Total
Traditional		7%	19%	11%
Horticulture	17%	27%	33%	28%
Pisco grapes	17%	23%	29%	25%
Export grapes	24%	32%	40%	34%
Total	17%	24%	31%	26%

Fuente: Frontier Estimations

It should be noticed the relatively low estimated average of technical efficiency for the sample (23%), in contrast with other studies in which this estimation is around 70%. It is my impression that this difference comes from two factors: (i) I am using a sample with very high variability among farmers, who have different assets and crops; (ii) I am mixing technical efficiency and past investments in the frontier estimation. These factors increase the dispersion of the estimated parameter distribution, giving a lower average than in other studies in which farmers are croppers of the same crop and with low variability in assets.

Water buyers appear with a much more higher value of s_1 than non-participants and sellers. In general, my results suggest that the estimated parameter is indeed an important factor behind water transactions in the Limarí valley, allocating water from low value annual crops to high value permanent ones. I will use this parameters in the subsequent estimation of market participation decisions.

6.3. Estimating an ordered probit model of water market participation[15]

Now returning to variable $z_i(.|)$ in Section 6.1, I will assume that I cannot directly observe these but I know the regimen in which each farmer was in the sample: seller, buyer or non-participant. In this case the specification is in terms of a cumulative distribution function F(.) for the dependent categorical variable:

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[15] In Appendix 6.1 I present the main limitations of the ordered probit model for estimating all the relevant parameters of the theoretical model. The source of the limitation is the lack of information on transaction costs in the water market.

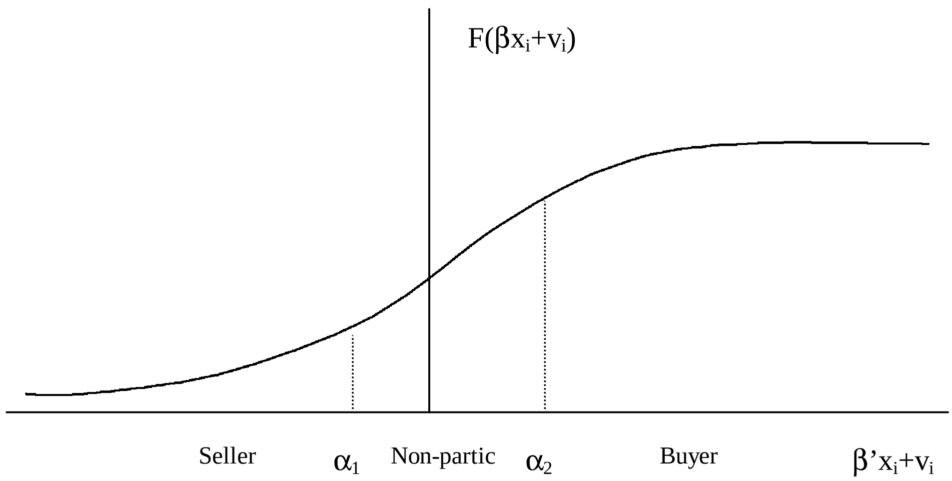
Prob(i=seller|x_i) = F(β'x_i + v_i > 0)

Prob(i=not participation|x_i) = F(β'x_i + v_i = 0)

Prob(i=buyer|x_i) = F(β'x_i + v_i < 0)

Now we know that F(.) being a cumulative distribution function is increasing in its argument. We can define two parameters α_1 and α_2 representing two critical threshold values with $\alpha_1 < \alpha_2$ at which the specific farmer will be at any of the three alternative regimes. Figure 6.1. displays the situation for one hypothetical farmer:

Figure 6.1.: Cumulative distribution for ordered-response model



Thus, the model can be re-parameterized in the following way:

$$\text{Prob}(i=\text{seller}|x_i) = F(\beta' x_i + v_i < \alpha_1)$$

$$\text{Prob}(i=\text{not participation}|x_i) = F(\alpha_1 <= \beta' x_i + v_i <= \alpha_2)$$

$$\text{Prob}(i=\text{buyer}|x_i) = F(\beta' x_i + v_i > \alpha_2)$$

Where v_i is redefined as a random variable with standard normal distribution $v_i \sim N(0,1)$, not correlated with x_i and independent across farmers.

The parameters of interest in this model are the two threshold values α_1 and α_2 and the β–parameters that allows to evaluate the individual specific critical-values $\beta^{est}x_i$ at which the three probabilities are estimated. The likelihood function for the model for m1 sellers, m2 non-participants and (n-m1-m2) buyers is:

$$\prod_{i=1}^{m1} \Phi(\beta' x_i - \alpha_1) + \prod_{m1}^{m2} [\Phi(\beta' x_i - \alpha_2) - \Phi(\beta' x_i - \alpha_1)] + \prod_{m2}^{n} (1 - \Phi(\beta' x_i - \alpha_2))$$

This function is used to estimate the parameters of interest using maximum-likelihood methods. For the specific estimation I used the variables for which summary statistics are presented in Table 6.5. for each of the three categories. Note that in this case I used up all the 195 observations. I assigned the mean sample value of the estimated "s_1" parameters to the no-production farmers in order to keep the important information for the supply function coming from these farmers in the ordered-response model estimation.

Table 6.5.: Summary Statistics for Regression Variables

	Sellers		Non-participants		Buyers	
	Mean	Stdv	Mean	Stdv	Mean	Stdv
Estimated s_1	0.192	0.125	0.245	0.170	0.303	0.204
Log(water price)	3.992	0.361	3.935	0.554	3.816	0.512
Log(land endowment)	2.909	1.578	1.538	2.020	2.445	2.078
Log(water endowment)	10.838	0.911	8.281	3.778	10.133	2.252
Log(livestock value)	9.031	6.663	4.428	6.362	4.722	6.699
Cogoti	0.111	0.323	0.097	0.297	0.302	0.463
Camarico	0.389	0.502	0.129	0.337	0.245	0.434
Limari River	0.056	0.236	0.169	0.377	0.094	0.295
Huatulame	0.000	0.000	0.234	0.425	0.057	0.233
Punitaqui	0.056	0.236	0.145	0.354	0.019	0.137
Observations	18		124		53	

The estimated coefficients for the model are presented in Table 6.6. The first specification (first three columns) does not consider endowments on the exogenous variables, whereas the other does consider these. However, these appear as not statistically significant at the 95% confidence level. In both cases the estimated "s_1" and water price appear as significant and with the expected signs. In increase in s_1 value raises the probability of being a buyer, whereas higher prices increase the probability of being a seller in the water market. Two organizations appear with higher probability of their farmers being buyers: Cogoti and

Huatulame, whereas Punitaqui appears as likelier to have more sellers. These conditions coincide with field observation regarding these organizations in the face of very high water prices in 1996/97.

Table 6.6.: Ordered Probit Water Market Estimation

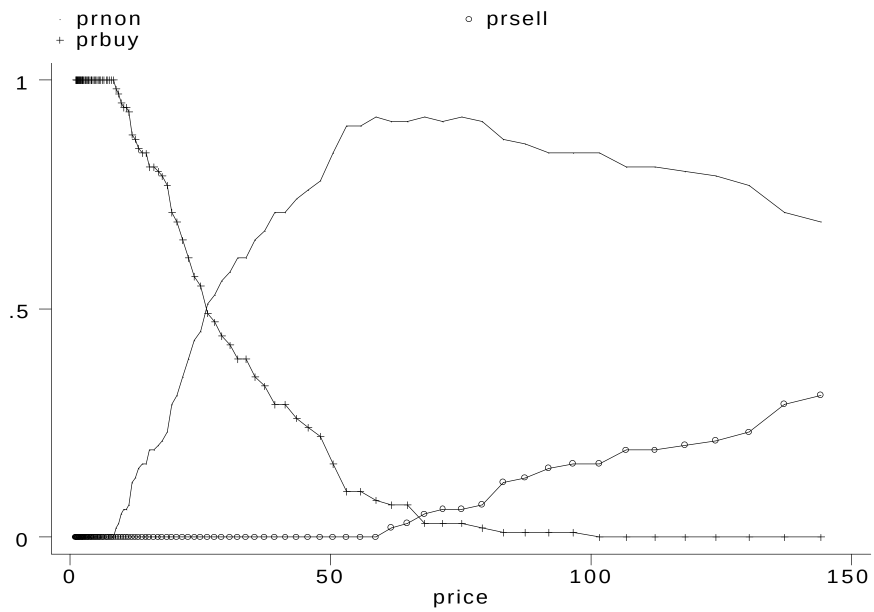
	Coef.(*)	Std. Err.	z	Coef.(*)	Std. Err.	z
Estimated "s_1"	**1.424**	0.505	2.821	**1.332**	0.511	2.607
Log(water price)	**-1.079**	0.344	-3.135	**-1.066**	0.347	-3.069
Log(land owned)	--	--	--	-0.027	0.060	-0.443
Log(water	--	--	--	0.012	0.036	0.342
Log(Livestock	--	--	--	-0.025	0.014	-1.809
Cogoti	**0.684**	0.282	2.427	**0.698**	0.283	2.463
Camarico	-0.070	0.263	-0.265	-0.078	0.267	-0.292
Limari River	-0.596	0.342	-1.743	-0.614	0.344	-1.784
Huatulame	**0.764**	0.399	1.914	0.580	0.418	1.386
Punitaqui	**-0.855**	0.394	-2.169	**-0.862**	0.403	-2.137
alpha1	**-5.253**	1.390		**-5.346**	1.471	
alpha2	**-3.148**	1.370		**-3.210**	1.450	
Number of obs	195			195		
LR chi2(7)	28.29			31.59		
Prob > chi2	0.0002			0.0004		
Log likelihood	-153.92			-152.17		

(*) Coefficients in bold are different from zero at 95% level

In Graph 6.2. I display the estimated probabilities of water market participation at individual real values for x and only depending on increasing water prices.

Graph 6.2: Estimated Probabilities

for increasing water prices



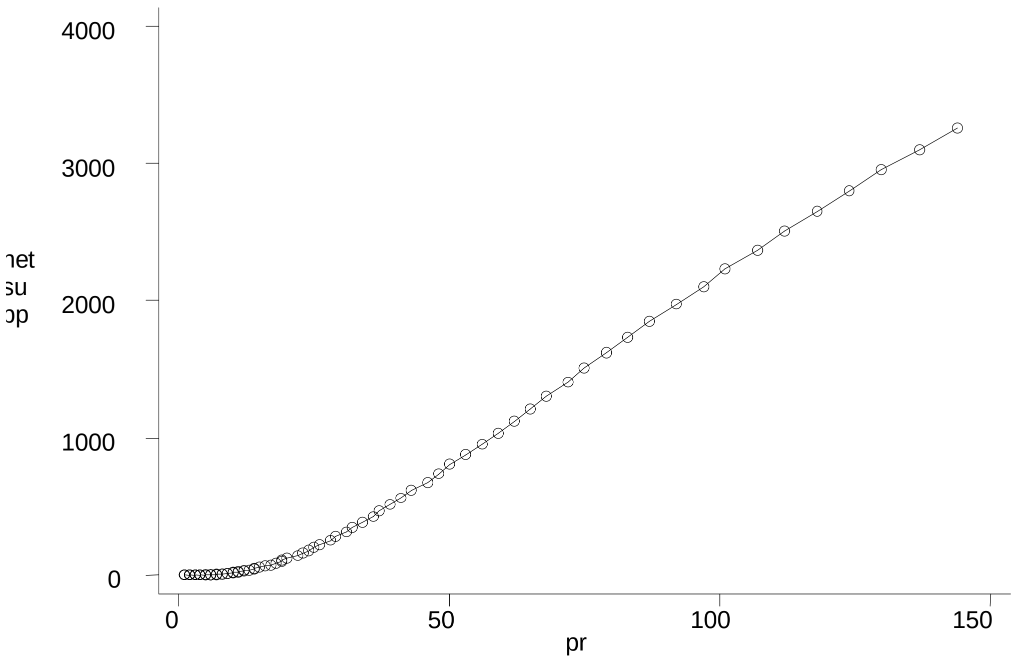
As can be seen, for prices below 60 Pesos the probability of being a seller is almost nil in the sample whereas the probability of non-participation reaches its maximum at 60-75 Pesos per m3. Indeed, the probability of not participating in the water market is higher than the probability of being a buyer above 30 Pesos per m3, and it keeps growing until water prices are as high as 70 Pesos per m3. This suggests a wide range of prices in which the net water supply function is flat as considered in the theoretic model developed in Chapter 5 when farmers are at their minimum water requirement constraint. Only with very high prices (above 70 Pesos) the net water supply function starts to have positive probabilities and so sellers are attracted to the market.

The estimated probabilities for market participation can be used to build a Expected "Potential Water Supply Function" which will be defined for farmer "i" as:

$s_i(.|p^w) = prob(i{=}seller|x_i)*W_i$

i.e. the probability of "i" to participate as seller in the water market multiplied by his/her water endowment. The summation of these individual-specific supply functions will conform to an aggregate water supply schedule as a function of market prices. This estimation for the sample of 195 farmers is shown in Graph 6.3.

Graph 6.3.: Aggregate Potential Water Supply Function



The supply is quite flat for prices below 30 Pesos and it starts to increase its slope after that price. It should be considered that for prices between 30 to 70 Pesos the probability of finding net sellers in the sample is very low, so the expected aggregate supply is quite low. The supply starts to have a more pronounced slope after 70 Pesos per m3.

6.4. Estimating water supply and demand using censored regression models[16]

The previous approximation to the water market decisions gives a good idea of the driving forces behind this market. As seen, production efficiency, prices and locations (related to different water endowments) seem to be the most important variables behind water market participation. The discrete form of the ordered probit model does not allow one to estimate more directly the demand and supply features, so in this section I use censored regression models for the demand and supply schedules.

In censored regression models (Maddala, 1997), the dependent (decision) variable for an economic agent has the following form:

$y_i = y_i^*$ if $y_i^* > c$

$y_i = c$ otherwhise

The resulting sample $y_1, y_2, \ldots, y_n$ is called a "censored sample", in which for variables $y_i = c$ we only know that $y_i^* \leq c$. Assuming a normal distribution for the dependent variable $y \sim N(\mu, \sigma^2)$ the likelihood function becomes:

$$L(\mu, \sigma^2 \mid y) = \prod_{y^*_i > c} \frac{1}{\sigma} \phi\left(\frac{y_i - \mu}{\sigma}\right) \prod_{y^*_i \geq c} \Phi\left(\frac{c - \mu}{\sigma}\right)$$

Where $\phi(.)$ and $\Phi(.)$ are respectively the density and distribution function of the standard normal distribution.

In the case at hand, I have $y^* = x'\beta$ as water bought in the market being a function of exogenous variables. The water sales variable is censored at $y^*=0$ for all farmers who either sold water or did not participate in the market at all. This particular case in known as the Tobit model in which c=0. The same model can be applied to the sold quantity, censoring the dependent variable at c=0 as well. The parameters of interest in this case are the βs which allow estimation of the demand schedule as a function of exogenous variables.

The maximum-likelihood estimation of these two tobit models for estimating water demand and supply (with the same variables as before) are shown in Table 6.7.

The water price appears as statistically significant at the 95% confidence level for both equations and with the expected signs. The estimated "s_1" only appears significantly different from zero for the demand equation. Using these parameters I could estimate both demand and supply schedule as a function of water prices. In Graph 6.4. these two schedules are depicted against the logarithm of water quantity.

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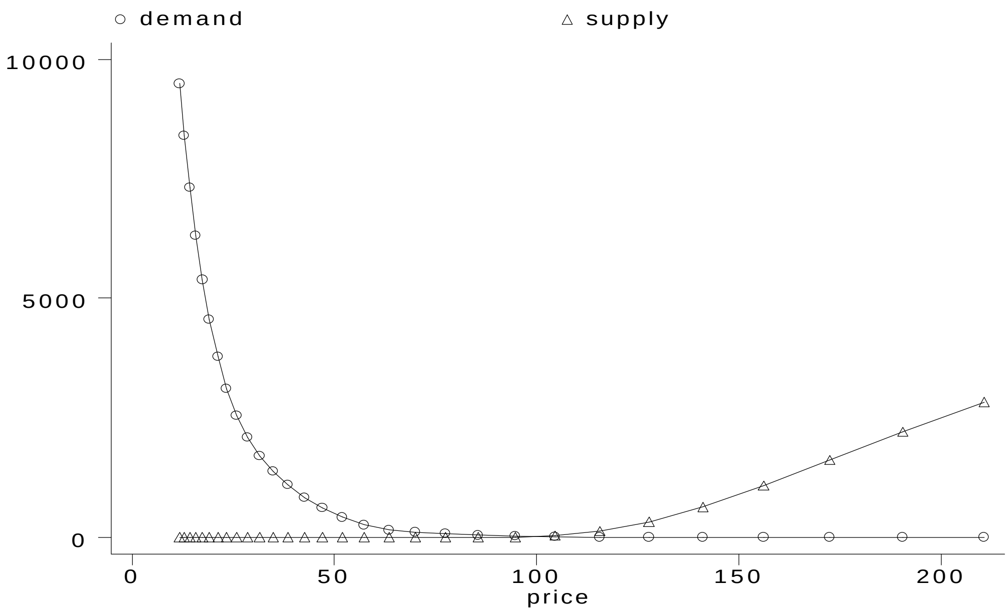
[16] Like for the ordered model, Appendix 6.1 presents the limitations of the Tobit model to estimate all the relevant parameters of the theoretical model.

Table 6.7.: Tobit estimates for water demand and supply

	Demand estimation			Supply estimation		
	Coef.(*)	Std. Err.	t	Coef.(*)	Std. Err.	t
Estimated "s_1"	**121.96**	41.94	2.91	-37.37	26.39	-1.42
Log(water price)	**-70.97**	25.26	-2.81	**33.87**	16.00	2.12
Cogoti	**78.38**	21.72	3.61	-6.98	11.63	-0.60
Camarico	4.97	22.01	0.23	3.61	9.88	0.37
Limari River	**-59.29**	29.31	-2.02	-0.64	16.64	-0.04
Huatulame	12.97	36.04	0.36	--	--	--
Punitaqui	**-114.0**	48.78	-2.34	-2.58	17.52	-0.15
Constant	184.78	99.35	1.86	**-156.53**	66.89	-2.34
sigma2	**77.82**	8.13		**28.60**	5.60	
Number ofobs	195			195		
LR chi2(7)	45.47			19.39		
Prob > chi2	0			0.0077		
Log likelihood =	-348.35			-115.38		

(*) Coefficients in bold are different from zero at 95% confidence level

Graph 6.4.: Water demand and supply schedules



The graph indicates that if a water market should work in the irrigated area only involving the sampled farmers, the equilibrium water price would be around 100 Pesos per m3. For the sample of farmers I got, the average observed water price was 55 per m3. This indicates that my supply schedule is somewhat downward biased as important sellers (non-producers) were not present in the specified sample scheme. In any case, these results indicate that the water supply in the irrigated area required at least 30 Pesos per m3 to activate, and that attracting more farmers to sell water required prices that reached even more than 100 Pesos per m3. This feature of the supply schedule is consistent with the idea developed in Chapters 4 and 5 of many farmers having (at the same time) valuable permanent crops with a flat net water supply functions for a wide range of prices.

Appendix 6.1.: Limitations of the Econometrics for estimating the full theoretical model

The main restriction I face for fully estimating the parameters of the theoretical model is that I do not observe all of the variables that create different market participation regimes in the context of transaction costs. For instance, remember in Chapter 5, Appendix 5.1, I defined the net water supply function:

$$\sigma^{i*}(p^w,T_1^i,A_1^i,s_1^i) = \begin{cases} A_1^i - q_2^*(.) > \theta^i; & p_2^w < p_2^w{}_{bind}^i; \text{ (unrestricted)} \\ A_1^i - \theta^i & p_2^w{}_{bind}^i \geq p_2^w \geq p_2^w{}_{exit}^i \text{ (restricted)} \\ A_1^i; & p_2^w > p_2^w{}_{exit}^i \text{ (exit)} \end{cases}$$

This is a "desired" net water supply function with only three possible regimes related to the shadow prices $p_2^w{}_{bind}^i$ and $p_2^w{}_{exit}$ that are not observable but that I know depend on some observable variable like s_1. The problem arises when I consider transaction costs, that cannot be ignored for such a market. With transaction costs, we observe transactions only outside some band of critical points that lets call α_1 and α_2 with ($\alpha_1 < \alpha_2$). Desired transactions that lie inside this band do not occur as costs surpass benefits from the transaction.

This means that I may have both restricted, unrestricted and even exiters inside the transaction cost band, and this makes identification of the critical prices $p_2^w{}_{bind}^i$ and $p_2^w{}_{exit}$ not viable with the information. Obviously, the only way to surpass this problem is with precise information on transaction costs in the water market, that I did not gather in the survey.

Even considering these limitations, I can estimate a mix of the critical parameters using Probit and Tobit models. Lets call $\sigma^i(.)$ the observed net water supply. In terms of the latent desired net water supply, this will be defined as:

$$\sigma^i(.) = \begin{cases} \sigma^{i*}(.) - \alpha_2 & \text{if } \sigma^{i*} > \alpha_2 \\ 0 & \text{if } \alpha_1 \leq \sigma^{i*}(.) \leq \alpha_2 \\ \sigma^{i*}(.) - \alpha_1 & \text{if } \sigma^{i*} < \alpha_1 \end{cases} \qquad (2)$$

Now the desired net water demand function will depend on some vector function $h(\beta, x_i)$ of variables x_i that might include crop structure (s_1^i), water price and location for the farmer and parameters β. For the sample, this relationship occur in a probabilistic environment defined as:

$$\sigma^{i*} = h(\beta, x_i) + v_i \quad , \quad \text{with } v_i \sim N(0, \sigma_v^2) \text{ and } Cov(v_i, x) = 0, \qquad (3)$$

and the desired demand is itself a random variable with conditional mean h(.) and conditional variance σ_v^2. In the case of x= water price, the form of the h(.) function is given by (1) and it has two price thresholds (p_{bind} and p_{exit}) at which it is not differentiable with respect to water price. Also, above p_{bind} he function has the partial derivative with respect to water price equal zero. Lets define the Tobit and Probit models.

Tobit model

A Tobit estimation of (2) is possible for each side of the net water supply function. For sellers, I have:

$$\sigma^{i}(.) = \begin{cases} \sigma^{i*}(.) - \alpha_2 = h(\beta, x_i) + v_i - \alpha_2 & \text{if } \sigma^{i*} > \alpha_2 \\ 0 & \text{otherwise.} \end{cases} \quad (4)$$

The main difficulty from this specification come from the form h(.) may take in view of (1). It is clear that in the case of water prices the marginal response of the net water supply function h'(.) is positive below p_{bind}^{w} and zero afterwards. A log specification for the price variable in the tobit estimation would approximate this model's feature although it cannot distinguish parameters from exit sellers from restricted sellers, and the same for buyers, as said before. The estimated price-response parameter would **contain a mix of unrestricted, restricted and exit sellers**, and **the same for buyers**.

Ordered probit

Now assume that we cannot observe desired net water supply $\sigma^{i*}(.)$ and also that we only know if farmers are sellers, buyers or non-participants in the water market. Also, redefine (3) such that the error terms is $u_i \sim N(0,1)$. In this case I have the following three probability functions:

$$\Pr(i=\text{seller}) = \text{Prob}[h(\beta,x_i) + u_i > \alpha_2] = 1 - F[\alpha_2 - h(\beta,x_i)]$$

$$\Pr(i=\text{non-part}) = \text{Prob}[\alpha_1 \leq h(\beta,x_i) + u_i \leq \alpha_2] = F[\alpha_2 - h(\beta,x_i)] - F[\alpha_1 - h(\beta,x_i)] \quad (5)$$

$$\Pr(i=\text{buyer}) = \text{Prob}[h(\beta,x_i) + u_i \leq \alpha_1] = F[\alpha_1 - h(\beta,x_i)]$$

In this case, assumptions about the form of h(.) are more problematic as the model requires the same function with the same parameters for the three market participation regimes. In this case the form of (1) also would suggest that the price variable be included in log form. The model cannot identify restricted from unrestricted or exit buyers, or restricted, from unrestricted or exit sellers. **The β parameters are a sort of average from the different types of market participants and in this case are forced to be the same for buyers, sellers and non-participants.**

Chapter 7: Discussing alternatives for improving the efficacy of the water market in the Limarí Valley

Introduction

In this chapter I discuss some alternatives for improving the efficacy of the water market in the regulated area of the Limarí valley. As I argued in Chapters 5 and 6, the water market in the Limarí valley, although an important and valuable allocation mechanism, started to face important limitations in the face of a severe drought. These limitations are associated to rigid net supply functions that in turn are associated to a certain production structure concentrated on permanent high-value crops.

In the context of the severe drought of 1996/97, the water market started to be less effective in allocating the resource, with a wide range of prices for which there was no apparent water supply to cope with high demand. This generated a extremely volatile water price distribution which may hinder incentives for further investment in permanent crops, one of main developing tools in the valley for the last decade.

As such, it is important to think in ways to improve the workings of the water market, especially when it becomes clear that negative water shocks (droughts) are a real possibility in the Limarí environment. In Section 7.1. I explore a technological alternative which might impact (and is impacting) on the functioning of the water market, such as drip irrigation. Section 7.2. analyses the introduction of an information system to reduce transaction costs associated with lack of information, which although were not explicitly measured in Chapter 6, were important in amplifying the limitations of the water market as field observation showed (see Chapter 4, Section 4.3). Finally, Section 7.3. explores a more ambitious set of potential policies oriented to introduce changes in the operation of the water storing system and a re-definition of water rights in the face of a changing environment. These changes are oriented to increase the responsiveness of the net water supply function to price incentives.

7.1. Technological innovations: drip irrigation

Technological innovations may have important impacts on how input markets work, as these reflect differences in production or post-production efficiency. In the case of irrigation, adoption of water-saving techniques such as drip irrigation might have significant effects on water market dynamics.

Returning to the theoretical model developed in Chapter 5, adoption of drip irrigation by farmers will tend to decrease their minimum water requirement parameter (θ) in the production function and this will have two effects on the net supply function: (i) move the minimum water price threshold $P(s_1)g'(\theta)$ to the right as $g'(.)$ is decreasing in its argument; and (ii) move the exit threshold $[P(s_1)g(\theta)+k]/\theta$ to the left[17]. These two movements will shrink the range of prices for which the net supply is flat and therefore making the water market to behave more smoothly.

The changes in minimum water parameter can be dramatic with drip irrigation adoption. In the farmers' sample drip irrigators consumed one third of the water (per hectare) than non-drip

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[17] The negative sign can be derived differentiating the exit threshold p_w^{exit} with respect to θ. This differentiation gives: $(1/\theta)*[P(s_1)g'(\theta) - p_w^{exit}]$ which is negative as the exit threshold is always larger than the minimum water threshold $P(s_1)g'(\theta)$.

irrigators and so this innovation might have quite important impacts on improving the operation of the water market, especially if adopted by permanent crop farmers as is currently the trend.

Notwithstanding this positive role, the adoption of drip irrigation imposes some challenges to the management of the irrigation system. The use of drip techniques for permanent crops requires a much more frequent delivery of water to farmers all year round. This changes the traditional way in which water is managed, where the distribution system have two or three months in which important cleaning and lining of canals is done. The increasing presence of drip irrigation obliges the management to have water flowing permanently through the canals, even when non-drip irrigators are not demanding much water. This sort of low compatibility between drip and non-drip irrigation inside the system may become an important source of conflict over water distribution in the near future.

7.2. Reducing transaction costs: introducing a water price information system

The presence of transaction costs were important in the water market operating in 1996/97 season as I argued in Chapter 4. Such an intensive operation of the spot water market with prices above 50 Pesos per cubic meter was a relatively new affair in the Limarí valley, where farmers were used to a more moderate water market with prices oscillating between 3 and 10 Pesos per cubic meter in the 1990s.

In the context of the severe drought of 1996/97, this context changed dramatically and farmers had to take decisions on water trades in a very uncertain scenario in which potential increases in water shortages were not totally known and with skyrocketing water prices in the spot market. A decision taken by one of the irrigation organizations (Limarí River) to prohibit water transfers to other organizations (arguing that transfers were having negative effects on third-party irrigators) increased the pressure over the market and the water price achieved a top of nearly 100 Pesos in October 1997, which was unreachable for most farmers. That decision was changed in November, and prices started to return to a 60-80 Pesos per cubic meter in November-December of that year.

It was clear in this context that there was a disorganized flow of information regarding how this market works and how the opportunities can be better used by a large group of farmers. In the case of Punitaqui, the poorest irrigation area, I heard many complains about the irrigation officers taking advantage of their information to sell water they bought cheaply to their associates to sell it more expensively to other water associations. Lack of information on current water prices by farmers was a common problem, especially with poor farmers.

Looking at the records of the organizations I found a number of persons who in 1996/97 season were doing as "middlemen" in water trades. They bough water from a farmer at one price and sold it out immediately to other farmers at higher price. Although these activities can be welfare improving, in some cases there was abuse with poorer and less educated farmers who had little information on current water prices in a little known water market.

Other situation encountered in some of the organizations was that there was some minimum amount of water required for a large transaction with an attractive price. This amount could have been supplied by a group of small farmers who were not able to organize despite the efforts by the administrator of the organization. Disputes about the best way to do the trade discouraged the buyer who preferred to deal with one big seller instead of many small ones.

In general, when I was doing my field work I heard a lot about the lack of transparency in the water market. For many farmers (especially small, but also some large farmers), this market only worked for some privileged farmers, who had much more power in the irrigation organizations (as mentioned before, representation is based on number of shares).

Some of these complains are justified but others are not. There was an important number of small farmers who were able either to sell or buy water at favorable prices in the 1996/97 season as the records kept by the organizations indicated.

As seen in 1996/97, the water market of the Limarí valley increasingly requires some sort of centralized body that can make water trade more transparent and can generate useful and opportune market information for potential participants. This idea is not expensive as all water trades are currently registered by organizations, although price recording is not obligatory. The organizations can make price registering obligatory and have a unified information system of water trades which must be accessible for all farmers along the irrigated area. This will increase the transparency of the market and expand the opportunities of the market for many currently excluded groups.

7.3. Institutional innovations: re-defining rules for reservoir management and water rights

At the background of water market failures I investigated in previous chapters there are some assumptions regarding total water supply and on how water rights are defined. In this section I explore some alternatives re-definitions of water rights and water management that can make the net water supply more responsive to water prices, i.e. more efficient.

Location-specific water losses

One important feature of water management in the regulated area is that average seepage losses are assumed collectively by the users of each canal. For example, the Camarico Canal has an estimated 35% of seepage losses. This average is equally distributed among all user even when water losses are location-specific. There are areas with higher water losses due to the bad maintenance of the canal, or there are other physical conditions that increase water losses along the canal.

This practice has efficiency implications for the water market. If water losses were associated to the location of farmers, the water market could play a role in reallocating water from farmers with higher water losses to farmer with lower water losses. For some range of prices, these type of exchanges can increase total output and social benefits in the irrigated area.

Like in the previous case, this reform may have important transaction costs as there is the need to have accurate measurement of water losses. Also, the whole process of water management becomes more complicated as water rights become location-specific. It should be mentioned that water losses are highly sensitive to investments in maintenance and improvement of canal infrastructure. As such, water rights may be changing too often and the costs of each redefinition may be higher than the benefits.

In any case, it is clear that the water market will work better if water rights become location-specific.

Mobility of water endowments

One of the most controversial issues in the Limarí valley is the strong opposition of farmers to re-allocation of water rights among irrigation organizations. The Chilean water code allows these reallocations, but the problems and conflicts that arise have limited this practice.

In case that water rights could be reallocated among irrigation organizations, the water market can also improve its efficiency, especially in the long run. Irrigated areas with lower seepage losses or/and higher crop value will benefit with more water rights. In this reallocation, the probability distribution of the total water supply should play a role, and zones more economically affected by droughts will be allocated more water (through the market). With a more efficient water rights basis, the spot water market would be less apron to extreme price volatility.

However, breaking the opposition to water rights transfer is not an easy task. These reallocations may benefit directly to the owners of the rights but may negatively affect the rest of farmers both in the receiving and giving area, depending on the conditions in which the whole system works. For instance, if water losses are still collectively allocated, it is very difficult to reallocate the implicit water losses among irrigation organizations with different water losses. This complication is more serious when the storing devices are different among the exchanging organizations.

This exchanges are often opposed by the giving area as the non-participant farmers there will see the total water distributed to their area reduced, whereas the cost of administration of their canals remains fixed. This is a common source of opposition to water transfers in many contexts.

Water saving

Although farmers in the regulated area could save water for the next season, this practice is heavily penalized (20% of penalty) under the argument that evaporation losses are of that amount. So in 1996/97 I did not observe any water savings by individual farmers, less in a very dry year.

However, the practice of saving water by individual or grouped farmers may improve the workings of the water market in the Limarí valley. Because farmers with permanent crops have different exposure to risk than farmers with annual crops, it is conceivable to imagine that they will have different incentives for saving water at each season. Currently the decision is centralized and is based in a rigid operational rule which was set up many years ago when permanent crops were not important in the valley. The last update of the parameters for the operational agreement was made in 1970s, and it did not consider the crop structure of the valley but only how to improve the delivery of a minimum amount of water each year.

If saving water starts to be a real option for farmers in the Limarí valley, this may change the way in which the water market works, reducing the flatness of net supply functions. With permanent crop farmers saving more water than non-permanent crop farmers, we will have a reduced probability of seeing permanent crop farmers at the minimum water requirement parameter for each season. This will reduce the range of non-response prices in the net supply function, improving the functioning of the market.

The implementation of the water saving idea can be cumbersome depending on the degree of reform that one wants to introduce. The most radical alternative would be an overall re-definition of individual water rights in which each individual has a proportional share of the total capacity in the system (1,000 million m3). If we are talking of 33,000 shares, each share would have 30,000 m3 of capacity assigned. An example of how this may work follows.

Imagine a farmer with one share in a first season in which this re-definition takes place and when stored water (after evaporation losses from previous season) is 500 mill m3. He would have 15,000 m3 of stored water assigned and 15,000 m3 of his capacity not used. Discounting 20% from seepage losses, he will have 12,000 m3 to consume for that season. Imagine he only wants to consume 8,000 m3 for that season and wants to save 4,000 m3 for next one. The next season total stored water (after evaporation losses) turns out to be 300 mill m3, and he then has 10,000 m3 stored plus the 4,000 m3 saved, so his total is 14,000 m3 from which he can receive 11,200 m3 after seepage losses. The farmers is able to "smooth" water consumption using water savings.

Important implementation problems may arise from this type of reform. Some upper limit must be imposed on individual savings as there is a risk of having the reservoirs totally full with potential flooding problems and extreme water waste. If many farmers are saving at the same time in abundant years, the risk of flooding increases and this may turn out to be a severe managerial problem. Using long water supply series and established parameters it can be determined an upper limit for individual savings which can be individual specific or group specific.

The second important problem is related to evaporation losses. In the example above there was no penalty to savings from evaporation losses. The truth is that part of the saved water will be lost to evaporation but how much is that is an open question. For instance, in the Paloma reservoir, annual evaporation losses are estimated to be between 15 to 20% as it is a very extensive reservoir (it has 3,000 Has and about 25 meters of depth). Should this rate be applied to the savers?. Probably the correct answer to this question should be based on the following calculation: after all savings are known from previous season, estimate evaporation losses "with savings" and "with no savings" for the coming season, and divide up the difference between these two figures proportionally among the savers. In this case only the real impact of savings on evaporation losses are considered and this may be much lower than the overall rate for the total water stock.

A third potential problem is related directly to the redefinition of water rights itself. As in any institutional change, there are important transaction costs involved. The possibility of water savings will indeed increase the need of more precise measurement of water flows at the individual level and also to strengthen the enforcement capacity of water distributors. Precise records of water savings must be kept and carried out for each season, and neighboring farmers must respect water saving decisions. One related problem here is that when a farmer decides to save water, he is reducing the average flow in the canal. Because water losses are fixed and not proportional to water flow, the reduction in flow may leave less water than expected to other canal users. All of these are measurement problems which can be addressed with more precise measurement mechanisms. However, it is not only a technological issue, if farmers do not feel or understand that this redefinition of water rights is fair and efficiency-enhancing, the reform would certainly not work.

Thus, although the problems are several (and perhaps many other problems cannot be predicted right now) these are not difficult to solve if there is enough will and farmers sense that this reform is to benefit them. This institutional innovation will require special expertise in water management at the general (reservoir) and at the farmer levels. It requires lot of consensus among farmers about the rules.

A potential way to start this reform is re-defining water rights first only at the irrigation organizations level. Each organization can decide at the beginning of the season (with some adjustments permitted during the season) how much water do their associates want to save for next season (respecting upper limits). This will introduce the reform in a more manageable way and people can learn how to work the important problems that can arise in a more appropriate environment.

7.4. Concluding remarks

In this research I have discovered a real water market working in agriculture. This is not an usual event for economists, who tend to assume that markets are the rule rather than the exception even for natural resources. In the case of water for irrigation, using a market is still an exception, but it is clear than it will become a more and more important institution as water scarcity increases.

What I have been uncovering in the chapters is that this particular market is very sensitive to some specific factors: (i) geographical location; (ii) irrigation technology; (iii) water rights; (iv) system management; (v) cropping system; (vi) information; among others. It was clear form me that I needed a theoretical paradigm that considers market imperfections, and I focused on one of the potential failures: lack of investment coordination. In the case of the Limarí valley I found that “excessive” investments on permanent crops may have reduced the efficacy of the water market for allocating the resource.

Obviously, more investment in permanent crops is needed, as it increases economic development and income stability. Thus, what we need is not to reduce investment in permanent crops, but to make the water market more efficient in the face of this trend. For these I have explored three areas of action: drip irrigation, an information system and re-definition of water rights. These three policy areas are important and may have a better impact if taken together. The main goal is to reduce the rigidity of the water demand schedule, which means making farmers less exposed to downward risk in the face of a water supply distribution in which potential droughts may have devastating effects.

The general feeling I have is that the water market was much better than other non-market mechanisms in coping with the 1995-97 drought, at least in efficiency terms (I did not explore the equity implications in this research). This does not mean that we cannot improve the utility and efficiency of the water market for farmers. This last chapter and the whole thesis was devoted to make some recommendations in this direction.

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