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Getting the Farmers' Feet Wet (Dry?) in the Water Market: Why isn't the Invisible Hand Working?

By

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Getting the Farmers' Feet Wet (Dry?) in the Water Market: Why isn't the Invisible Hand Working?[1]

A Survey

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Introduction

Water reallocation through markets has been proposed as an efficient way of handling the increasing water scarcity facing urban and environmental uses in the United States. The case for water market development has been based on the fact that the value of water in agriculture, which accounts for most freshwater consumption nationally, is significantly lower than the value of water for urban uses, hydroelectricity generation and other non-consumptive uses that benefit the environment. Limited markets have evolved in areas of the U.S. to facilitate the transfer of water from agriculture to higher value needs. However, the success of such efforts has been low both in terms of number of participants and the volume of total transfers.

A number of reasons have been cited for the low inclination of agricultural water-rights holders to water trading. Economists have analyzed the institutional setting and the political economics underlying water market development. An important factor involves the risk perception of farmers and their wariness of water trading due to potential droughts. Water trade may have adverse impacts on water sellers. The farmer has been thoroughly scrutinized, from his wallet to his head. Yet, significant additional research will be required in order to fully understand all the nuances involved in development of operational water markets.

The traditional theory on market evolution projects a stylized evolutionary process involving various stages of market development from a nascent state to a well functioning market. However, such a characterization ignores critical feedback feedbacks between the market and infrastructural and institutional conditions accompanying it. A brief review of water market development patterns in the US highlights this frictional pattern of co-evolution. Whereas some States have advanced into well developed water markets characterized by formal spot and options markets with supporting institutional structures, other States lag far behind. There is a need to investigate the underlying interactions between the institutions and the markets that influence the extent of water market development.

While the literature on water markets has addressed various aspects of this problem-borrowing from a vast array of concepts in economics, psychology, finance and political economy- there exists a need to glean from the current and past work in the theory of water market co-evolution in order to develop a comprehensive analysis of the process.

In this paper we seek to explore the market development process through a brief survey of the existing literature, highlighting selected studies that examine key elements of the evolutionary nature of water markets. We begin by examining the evolutionary stages of water markets with feedback linkages on various institutional settings. In doing so, we focus on factors such as transaction costs, transactions risks, role of property rights, third party impacts, behavioral responses, and the political economy and their ability to shape the water market development. Special attention is devoted to the role of selected market instruments such as permanent rights transfer, spot markets, and particularly contingent markets. The approach in much of the existing literature has been to borrow from finance theory on options to evaluate the feasibility and impacts of contingent water markets. However, contingent water markets differ from general options markets in a number of ways due to the unique characteristics of water. We borrow from the literature from the behavioral economics to delve in the behavioral aspects of farmers in explaining their risk averse nature. This may help explain the success of advance markets such as spot and options markets. Finally, using a simple model, we suggest that ignoring such considerations, when calculating option value for leased water may give misleading results.

Feedback Co-evolution and Stages of Water Market Development

There exists a pattern in the evolution of new markets. This evolution has been observed, most notably, in the case of certain agricultural commodities and markets for pollution permits. Specifically, seven stages have been identified in the evolution of new markets that span creation of demand for capital, uniform standards, development of legal infrastructure, informal spot and forward markets, development of securities and commodities exchange, organized future and options market and deconstruction (Sandor et al. 2000). The seven stages approach, while a useful construct, gives the impression that there exists a somewhat linear tendency of market evolution from its nascent stages to the final stages towards maturity. However, the actual evolutionary process may involve a complex system of feedbacks involving the various stages and the existing political, physical, legal and institutional infrastructure that drive changes in both market structure and supporting infrastructure. In cases where serious bottlenecks exist in market infrastructure, and normal feedback effects fail to overcome them, the evolution of the market may be stymied. This failure may be reflected in terms of rising gaps between potential and actual consumer surplus attained through market transactions, wasteful uses of scarce resources in some sectors despite high opportunity costs in others, growing discontentment with the existing structure of property rights and increasing number of related lawsuits, prevalence of political economy over economic-efficiency based motives in federal rules and regulations, high transaction costs associated with commodity exchanges, etc. When such conditions exist and are hard to overcome, the evolution of markets may either be significantly restricted. The degree of market restrictions may vary from region to region based upon the mix of structural bottlenecks.

Water markets in the US have failed to evolve into advanced stages of market development despite the rising urban and other non-agricultural high values needs. The need to transfer water at least cost, while recognizing property right claims is a major challenge to water managers and policy analysts. In the following sections we propose a construct for the various stages of the market development as applied to water, and the infrastructural and exogenous forces that interact with market development and in turn are modified through the process. This mutual interaction forces the evolution of both markets and supporting infrastructure through the various stages of development. For purposes of discussion, we classify the infrastructural network into three distinct categories: physical, legal and financial, each depicting an evolution from nascent (or informal) stages into highly developed stages. Evolution of the physical infrastructure involves a shift from the traditional methods of storing water to the ability to access water from far off regions through canals and finally to be able to allocate current storages and transfers based upon future availability. Legal infrastructure in its primitive stages may offer ill-defined property rights that evolve through government enforcement to incorporating third party impacts and finally to private enforcement. Financial infrastructure evolves from primitive forms of water market transfer contracts and no or little scope for hedging of risks through financial instruments to advanced stages in which a host of financing agencies such as banks and markets such as spot and options market co-exist. The stages of water markets have been classified accordingly. These involve informal between –agriculture exchanges to out of agriculture exchanges which are facilitated by water banks and spots and options markets. These are represented in figure 1 below.

INSERT FIGURE 1 HERE

In addition, there are several external forces that influence both market and infrastructure development. These include changes in water and agricultural demand, changes in public preferences towards the environment, changes in the political economy, external financial innovation, changes in the technology, etc.

It is clear that advanced stages of development in a water market would require similar advancements in the accompanying infrastructure. Yet, the forces at play between these are subtle and need to be clearly identified. Besides the exogenous forces, we have identified a number of key endogenous forces that act upon the system including, transaction costs, third-party impact relating to litigation costs, federal regulations redefining property rights and monitoring and enforcement of infrastructure to note a few. This feedback related evolution is depicted in figure 2 below. The flow of feedback is depicted through arrows that go in either directions, connecting institutions and market. Well defined property rights lead to evolution of the market and an evolving market throws new challenges to the legal infrastructure in the form of legal nuances that need to be taken care of to reduce market friction. This causes further refinement of the property rights. For instance, redefinition of property rights to allow small scale transactions may facilitate marginal purchases of water thus allowing buyers to wait until their needs become known instead thus avoiding costly and irreversible over-investment in water rights (Howe and Goemans 2003). Property rights may also be affected by exogenous forces such as the political economy. Well defined property rights may further facilitate the evolution of physical infrastructure as investment in infrastructure such as canals (which yields low returns and thus needs a longer break-even time) would get a boost from assured water transactions in future. Physical infrastructure in turn makes possible and insures water transfer from far-off areas thus extending the market. Similar co-evolution can be observed in the case of financial infrastructure and the markets with better modes of finances and insuring coming up in the more developed stages of the market.

In order to get a better insight over this co-evolutionary process with respect to the water markets we look at the forces that facilitate these linkages namely the property rights, transaction costs and risks, third party impacts, etc. Markets are characterized by participants and institutions. At the center of this evolutionary process are the market participants, the buyers and the sellers of water. Whereas, the feedback linkages are a major determinant to market evolution, we also need to explore the forces that facilitate market participation. Due to special characteristics of the market such as seasonal supply, limited transferability and storability, risk plays a prominent role in facilitating market participation. When the market is in primitive stages and the transactions are low, an informal mode of exchange prevails. However, with the sophistication of the market there is a manifold increase in transactions accompanied by an increased level of risk. As the market evolves, the nature of participants itself may change from individual farmers to large organizations representing the interests of several farmers. However, the nature of evolving participants is subject to the co-evolution of institutional and exogenous factors also. For instance, adequately developed physical and informational infrastructure may facilitate a development of a competitive market, thus making possible the participation of large number of uniformly sized water rights holders. Whereas, high transaction costs, risk aversion, property rights uncertainty may limit market participation to a few. Evolving participants would vary in their response to risks. For instance large participants are more likely to be risk taking as compared to smaller ones. Organizations would vary in their risk aversion depending upon the objectives of the mangers which in turn would be guided by the voting rights of the members. Further, repeated transactions may affect risk aversion, a topic which is getting a lot of scrutiny in behavioral economics.

Therefore, the co-evolution of markets and institutions becomes highly dependent upon forces impacting linkages and participation. This issue needs special attention due to the current emphasis on promoting the advanced stages of markets such as the options and the spot markets. We explore the influence of such forces on the success of these advanced stages in the final section.

Ideal Conditions for Water Markets

One fundamental prerequisite for functional markets is the presence of a sound institutional setting. Optimal institutional arrangements have, so far, evaded most of the States in which water trade has occurred. Young (1986) describes four basic ingredients of an institution that would make water markets viable- security, flexibility, certainty, and consideration of third party impacts. Until now, the water markets served by the Colorado-Big Thomson (C-BT) project have been the most successful in terms of facilitating transfers between buyers and sellers of water. Some 2,698 water-use rights exchanged hands in the period between 1970 and 1993. Michelsen (2000) has identified a number of ideal conditions that exist to facilitate transfers. First, is the availability of well-defined and clearly understood property rights. Second, supply uncertainty in the dry years has been a minimum, allowing for improved decision making. Annual delivery for the period of 1957 to 1993 averaged 65 percent of the maximum acre-feet available to the right owners. Certainty of high supply is extremely essential for trade, as it is the 'wet' water that would be used and not the 'paper' water. Third, water rights are easily transferable from one party to another. Since C-BT water is imported from outside the watershed regions, the issue of ensuring return-flow of water does not exist and transfers between two parties does not infringe upon the rights of a third party. Fourth, transaction losses are minimized through an efficient network of reservoirs and ditches. Fifth, administrative procedures associated with water transfer are fast and clear-cut. A water rights transfer application requires a flat $75 fee irrespective of the number of units transferred. Maximum time required to process a C-BT transfer is four to six weeks, in contrast to an average 20 months for other water rights transfers in Colorado. Sixth, any water that has been unutilized through conservation activities can be transferred to another use by the farmer.

Feedback Linkages

Property Rights and Water Markets

A number of theories exist in the property rights literature that identify its evolution either as an endogenous or an exogenous process. Brooks et al. (2003) have provided a brief review of the existing points of views driving property rights evolution. Demsetz (1967) argues that property rights evolve endogenously to internalize the gains from technological change or prices. Eggertsson (1990) adds on the role of political and social environment inn shaping the evolution of property rights. Posner (1998), in his common law efficiency argument, argues against the ability of the legal system in bringing redistributional changes in the society which forces them to redefine property rights in a way so as to maximize social wealth. Brazel (1999) argues that the property rights evolve in order to legalize the contracts desirable to both the parties. Whereas Sened (1997) ascribes to the influential political entrepreneurs the role of bringing about changes in property rights to suit their own needs.

According to many observers, the most significant institutional element required for facilitating water transfer is the presence of well-defined property rights. While some (citing the Coase theorem) have downplayed the role property rights could play in determining an efficient allocation of water amongst users, Richards and Singh (2001) contend that the issue of property rights cannot be ignored. Some of the basic conditions that need to hold in order for the Coase theorem to be satisfied do not hold in the case of water. These include wealth effects and transaction costs. The wealth effect requires that the amount of compensation required by an individual in order to switch from one commodity to another should not vary with level of income. Richards and Singh argue that some of the non-economic factors that determine the sale of water may be counted as wealth effects. Non-economic factors that may raise the seller's reservation price include 'access value', 'regional economics impacts', and 'community cohesion' (Young 1986). Further, the fact that water is perceived as an asset may cause a significant diversion between willingness to pay and willingness to accept compensation for water. When agents are risk averse, disutility from loss may be much higher than gain in utility from an equivalent gain. There are also significant transaction costs involved with water transfer. Richards and Singh cite uncertainty over enforcement of contracts and lack of credible commitments as two major transactions costs involved in exchange of water.

There is some literature on the evolution of property rights in water markets over time. Howitt (1995) looks at the evolution of property rights as an endogenous process determined by the evolution of water demand, uncertainty of future water supply and the institutional costs of redefining water rights. The water rights, according to Howitt (1995) are malleable, with economic pressure being the primary force acting on established rights. Thus, riparian rights gave way to the appropriative rights as use of water for exploitation of exhaustible resources required different sets of conditions than riparian rights which basically allocated water rights based upon land adjoining the river course. Later, the water rights were further modified to incorporate the 'beneficial use' of water as urban water demand rose. Therefore, it is apparent that while well defined water rights are crucial to the development of water markets, water rights themselves are shaped in part by the economic pressures and the existing market structure of the times. Water rights are also subject to third-party impacts and environmental uses, reasserting the public good aspect of water. For instance, even well-defined water rights could be challenged if water is needed for preservation of endangered species which may be given a higher priority in the 'public trust'. The definition of public trust/use itself is subject to change with the societal evolution. In the 19th century water diverted from main streams fro agricultural purposes was considered as 'public use' as there were no other beneficial uses of water. Now, it is the environment which is considered to have a higher beneficial sue for water.

While the need for establishing clear-cut water rights has been widely acknowledged in the literature, one study (Gaffney 1997) takes a critical view of the property rights argument to water marketing. Gaffney challenges the notion of providing firm water rights to current users of water. He argues that one reason why sellers are "de-motivated" from selling their water is that the benefits from speculative use during dry years are often high compared to a one-time sale of such rights. This disincentive is further strengthened by rising land values and the fact that water permits are costless and 'free of property taxes'. He proposes water taxation, either via a property taxation or severance taxation and water royalties, as a means of overcoming the 'de-motivation' obstacles. Such taxation could be either property taxation or severance taxation or water royalties.

The establishment of clear-cut property rights to water users has not been easy to implement. A key institutional bottleneck involves the non-separability of water rights from land. Crouter (1987) applies the theory of hedonic prices to determine whether water prices are separable from land prices. Crouter identifies several reasons why water and land attributes could be intertwined. First, legal and institutional restrictions on water rights transfer might prevent it from being sold separately from land. Such appurtenancy restrictions are imposed in order to protect the water rights of downstream users of water who depend upon the return flows. Transaction costs related to overcoming legalities and subsequent negotiations may represent a further hindrance to separate water markets. Further, legal restrictions that prevent arbitrage possibilities may hinder the development of a competitive water market. Due to such inseparabilities, land and water qualify as *Rosen commodities* whose attributes cannot be sold separately.

Crouter demonstrates that in a market where competitive bidding is allowed, the hedonic price of attributes is equal to that which the buyers are willing. Therefore, in equilibrium, the joint price of land and water would be endogenously determined by the bids of the buyers. Now, if there exists a separate market for water, the hedonic price function would be separable in land and water. In order to test this hypothesis of separability the model is applied to Weld County of Colorado for land parcel transfers for the first six months of 1970. Results indicate non-separability of land and water attributes.

Transaction Costs/Risks, Third Party Impacts and Water Markets

For exchange of goods between two parties to be Pareto optimum, the transaction costs must be zero as specified by the Coase theorem. In real life transactions costs are never zero thus making the initial endowment of property rights a significant determinant to the efficiency of trade outcome. Lund (1993) distinguishes between transaction costs and transaction risks. He shows that the risk associated with the actual delivery of water matters, and can be a significant factor in determining the success of water markets. Such risks of failure generally arise from court challenges posed by third parties who might be affected by such transfers. In such settings, transaction costs can be divided into pre-contract and post-contract costs. Since there is a significant time lag between the contractual agreement for transfer of water rights and the actual delivery of water, such risks may force the buyers to consider alternative water supply. Using a numerical example, Lund demonstrates that when the risk of a successful transfer is 50% and the post-contract transfer costs are 10% of the difference between the transfer volume and an alternative supply, the buyer would be willing to pay only 55% of the pre-contract costs under the case with certainty. The willingness to pay for water transfers may fall further if the buyer is risk averse. The above analysis may have significant implications for the study of options market, as so far such transaction costs and risks have not received any additional consideration in the few studies that exist in this area.

Transactions costs, on the positive side, play a key role in the evolution of institutions as is widely supported by the theory of institutional economics (Williamson 1985). High costs of searching for water rights holders may lead to the formations of large organizations such as the California's IID and WDM. Similarly high risks of failure to ensure future water delivery may bring in changes in the property rights through continual litigations. Arguably high transaction costs in the water market have hindered market participation, but they have also worked in their own way to prune the system and aid in market evolution. Colby (1990) justifies the presence of transactions costs in water transfers as policy induced transfer costs (PITC) that help bridge the gap between private and social costs of water for the non-agricultural users[2]. This is so, because, water right holders often do not adequately reflect the indirect impacts imposed on third parties and environmental interests. She argues that the stronger the third-party and environmental interests associated with water transfers, the greater the number of protests filed with such transfers, thus reducing or otherwise delaying the chances of a successful transaction. Litigations and delays may reduce both the benefits and the number of transactions to a level where private costs approximately equal the social costs. This works much like a Pigouvian tax, except that costs of legal guidance and delays might be thought of as dead weight losses to society. However, Colby argues that such costs help enforce the property rights of third parties and that transaction costs that arise from government regulations are therefore justified. She notes that over the period of 1975-

1984, such transaction costs were about 6% of the water rights prices in Colorado, Utah and Mexico, and it is possible that in the presence of significant third-party effects the water markets have been *under*-regulated. Howe, Boggs and Butler (1990) examine the importance of third-party opposition to transaction costs for water transfers. In a model of water transfers in Colorado, they regress per acre-foot transaction costs (ATC) on size of transfers (AF) and whether or not the transaction faced any opposition (OPP):

$$ATC=799-148\ln AF + 660\ OPP,\ R^2=.61$$

They find that while size of transfers leads to economies of scale, third-party claims often significantly influence the transaction costs. Howitt (1994), in a study of the effectiveness of the 1991 California Drought Water Bank evaluates both direct and third party impacts. He finds that while the exporting regions suffered net economic losses, the importing regions derived net benefits, thus leading to positive net benefits to the society from establishment of such a bank. However, the study also brings out an important problem associated with water market creation; the third party impacts. Trade in water assumes that the fundamental property right of water belongs to the farmer. However, the interests of third parties that derive significant pecuniary and technological benefits from agriculture must also be taken into account as most of the facilities such as canals that facilitate irrigation were financed through public expenditure. These third-party impacts are mostly non-point in nature. The study finds that the third party impacts could be reduced by lowering the intensity of water sales in a given region and spreading them as widely as possible.

Behavioral Factors affecting Market Participation

[2] See Sandra and Renwick (1998) for more on PITCs.

The fear of adverse consequences from trade may form the most significant hindrance to market participation. Adverse impacts on the farmers from federally induced markets may have political fallouts. In absence of conclusive evidence over such impacts, a cautious federal policy may slow down the evolution of new markets. Risk aversion of participants itself is another significant factor. Participants may be more wary of small losses than the prospect of small gains from market participation. The traditional theory of risk aversion through expected utility maximization has been found to be lacking in explaining such behavioral anomalies. We borrow from the insights offered by behavioral economics to capture a more realistic risk aversion behavior. This theory is then applied to explore the success of the advanced markets such as the spot and options markets. Finally, the nature of participants also may play a significant role in determining the success and outcomes of markets. This aspect is briefly dwelt upon.

Adverse Impacts of Water Markets and the Political Economy

Perhaps the most significant bottleneck involves the political nature of water rights which are mostly owned by agricultural farmers who have significant clout over the water transfer decision processes. Gaffney (1997) emphasizes the political economy aspect of water rights as the main obstacle to the proper functioning of the water market. Water used in agriculture is heavily subsidized by the federal government. For example, the water drawn from Santa Ana River in Southern California is available to the farmers for $30 per acre-foot, whereas the social cost of the same water has been estimated at about $3000 per acre-foot. Gaffney (1997) argues that giving permanent property rights to the farmers transfers the value of this subsidy to the farmers. Gaffney proposes allowing water transfers, but requiring the gainers from such transfer to pay for the subsidies inherent in such rights. Further, the social cost of water must not be measured as the cost of acquiring the water, but the cost of providing a substitute for that water.

An additional challenge to implementing water markets is the fear that agriculture would be severely impacted in the wake of continued droughts. However, most studies have found little impact on the agricultural sector from water transfers. Howe et al. (1990) examine the impact from water transfers on the area of origin for a seven-county reach of the Arkansas River in southeastern Colorado. Their analysis involves an input-output based approach that incorporates both backward and forward linkages of the agriculture sector. They find that total losses to the agriculture sector from irrigation reductions are insignificant and easily accounted for by the gains to urban areas from increased water transfers. They argue that such losses could be further reduced where revenues generated from water transfers are properly internalized within the agriculture sector.

On the other hand, Moore and Dinar (1995) come up with opposite conclusions. They design various models of input use involving two inputs- surface water and land- to test whether such factors might be treated as fixed by the farmers. Empirical models are estimated using data from western San Joaquin Valley of California. The model results indicate that farmers treat surface water as fixed input rather than a variable one, with significant implications for federal water policy, the Central Valley Project Improvement (CVP) Act. The CVP act was proposed to charge water price to agricultural water users in a three tiered approach, with rising prices for the last 20% of allotted water use. The purpose of this act was to facilitate transfer of water to urban users and induce farmers to conserve water. Moore and Dinar, however, claim that treatment of water as a fixed input by the farmers would make such conservation goals ineffective as the price of water does not figure in their decision of how much water to use. Further, the Reclamation price charged by the government may not adequately reflect the actual shadow price of water to farmers and therefore the difference between the Reclamation price and the urban willingness to pay should not be interpreted as the benefit from water transfer. The benefits would be much lower if shadow prices are taken into account. The authors suggest that such a policy would also create significant costs to government if compensation were provided to the farmers for lost output. Their results indicate that a 12 percent reduction in water supply would lead to a reduction of regional cotton acreage (which is mainly exported) by 0.8 percent of total cotton acreage nationally.

Market-based approaches often fail to provide for public goods and water markets are not an exception. An important issue with water rights is how non-consumptive benefits should be accounted for in water transactions. Booker and Young (1994), in a significant departure from traditional approaches that focus at efficiency gains from market transfers resulting to consumptive users only, include non-consumptive uses of water such as salinity reduction and hydropower generation from instream water flows. Their study focuses on the Colorado River basin that supplies water to the agricultural users within Colorado, urban users in Southern California and international treaty obligations. They conclude that while market transfers might minimize costs to the consumptive users, they fail to account for non-consumptive benefits and may prove to be inefficient in the presence of substantial non-consumptive benefits and absent institutions through which interests of non-consumptive benefits could be reflected.

Their estimates suggest that markets could only achieve as much as 50% percent of efficiency gains that are theoretically possible through water transfers.

Risk Aversion, Speculation and Water Markets

While institutional bottlenecks can be serious impediments to creation of water markets, institutional reforms do not necessarily guarantee that water markets would function correctly. Further challenges lie in ensuring a competitive environment that minimizes strategic behavior on part of the participants. Young (1986) hypothesizes that one reason water markets are not being successful is that the seller's willingness to pay may not be considerably large relative to the buyer's reservation price in order for water exchanges to take place. Mitchelson et al. (2000) explore the role of expectations of future water-right prices in determining current prices. They observe that in the case of Colorado-Big Thomson Project the water right prices were well above returns in irrigation for the period 1986-1993. The authors suggest that owners of water-rights may treat water as a speculative asset. They find that water-rights prices were correlated with the prices of speculative natural resources such as farmland, crude oil and silver. Some of the key variables affecting expectations of future water-rights prices in their study are historical water prices and level of regional economic activity. Goodman and Howe (1997) conduct an econometric analysis to determine the fluctuations in the share prices of ditch companies in Colorado that are owned by the water-rights owners. The price of the shares (for 1983-1990) were positively correlated with seniority of water rights and average diversions of water per unit of share by the farmer, and negatively correlated with transportation losses. Importantly, price of crops was not significant in determining the price fluctuations. Further, prices paid for shares varied widely by cities acquiring water. Goodman and Howe (1997) attribute such differences to varying degrees of risk aversion, expectations of future growth and urban expansion around the agricultural lands.

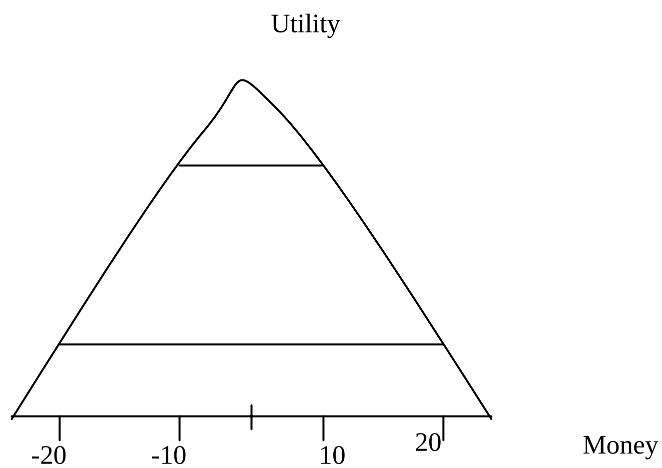
Behavioral Economics too may have some insights to offer regarding the reluctance of sellers to part with water rights. In one study, List (2003) conducts experiments involving 500 participants in a market to study the willingness of participants to sell their entitlements based upon their record of past transactions. He concludes that the willingness to sell increases with the level of experience with past transactions.

Accurately assessing the demand side too is not free of problems, contributing to restrictions in water transfers in some cases. Hersh and Wernstedt (2001) look at the difficulties faced by water utilities in Portland in utilizing their water rights. Despite the fact that one of these utilities possessed three times as many senior water rights than their current use, it was unsure of its ability to utilize all of that water in dry seasons due to infrastructural bottlenecks, such as need for large intake structures and pipelines, which would require extensive negotiations with the federal and state governments to construct. The feared reaction from environmental groups posed an additional element of uncertainty.

Role of Risks: A Fresh Look from Behavioral Economics

Risk averse farmers would hold back water from the water market if the sale of water poses future threats to property rights. Risk could also be associated with the price of agricultural commodities, and depending upon the relative revenues earned by water in agricultural production or the water market, the allocation of water would be decided.

Figure A



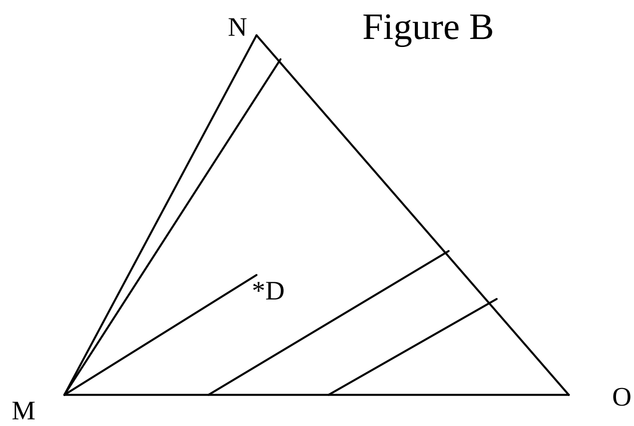
The conventional approach, so far, has been to model risk aversion with a concave utility function. However, a growing body of literature has pointed to some of the weaknesses of this kind of approach. Consider figure A. If the farmer is unwilling to accept a gamble that would give him 10 and -10 with equal probability, then there is no way one could make him accept a gamble that gives him -20 with probability half and an infinite amount of money with probability half. Similarly, people have been found to act in ways that violate the expected utility hypothesis. For instance, individual generally place more weight on payoffs that are certain as compared to uncertain payoffs (depicting risk aversion). However, when two uncertain payoffs, both with low probabilities, are available, a risk-taking behavior has been observed. This phenomenon was first documented by Maurice Allais and is popularly referred to as the Allais paradox (Starmer 2000). One of the most popular alternatives to the conventional risk aversion theory, termed the 'prospect theory', has been presented by Kahneman and Tverskey (1979) in introducing the concept of 'reference dependence'. Individuals do not consider their final utility while making a gamble, but consider the losses and gains from some reference point (such as their current wealth). This choice is characterized by 'diminishing sensitivity' and 'loss aversion'. Diminishing sensitivity implies that the losses that are far away from the reference point would have lower psychological impact relative to losses closer to the reference point (Starmer, 2000). Loss aversion implies that losses are given higher weightage than gains, i.e., $u'(x) < u'(-x)$ (Starmer, 2000). The effect of both diminishing sensitivity and loss aversion may lead to an S-shaped value function. The Rank Dependent Expected Utility theory, proposed by Quiggin (1982), claims that agents tend to put higher subjective weightage on events that lead to lower values (pessimism) and lower weights to events that lead to higher outcomes. Such kind of weighting of the probability distribution may lead to non-linear probabilities and may consequently alter the risk aversion of the agents. For instance, people with high risk aversion and pessimistic attitude would be 'universally risk averse' (Starmer 2000). On the other hand, people with high risk aversion but who tend to put high weights on higher valued outcomes and low weights on low-valued outcomes may still turn out to be risk takers[3].

[3] While the reference dependent preferences theory has merit and is rightly being applied to explain economic behavior, one could easily get swept away by the deluge of theories in psychology to explain risk aversion. Recent advances in psychology have tried to explain risk taking behavior through mood swings which could be brought in by factors such as weather conditions (Kliger and Levy, 2003). Apply this to water markets and you get risk taking behavior under sunshine (read droughts)!

So what implications can be drawn for water markets from this new emerging theory of risk aversion that accommodates psychological and behavioral aspects? First, the prospect theory suggests that if farmers consider the potential loss of water rights to be real, then risk of water rights loss represents a further disincentive for them to enter the water market. Similarly, the rank theory would imply that farmers with high subjective probabilities regarding the loss of water rights would shy away from water market participation even if they are not risk averse by nature.

The literature on behavioral economics has largely relied upon the use of 'Machina' triangles (Machina 1982) to depict the indifference curves between various prospects given their probabilities. The figure below gives an example.

Figure B



In the above triangle, M, N, and O represent three prospects. The probabilities of their occurrence are depicted on the sides of the triangle. For instance, event M occurs with certainty at point M with falling probability as one moves along the side towards O. Similarly, the probability of M falls along the side towards N. Point D puts positive probabilities on the occurrence of all the three events. The straight lines connecting the sides represent the indifference curves between the three prospects. These indifference curves increase from south to north and east to west. Risk averse behavior would imply that prospects M (at the origin M) and D both of which yield the same value do not lie on the same indifference curve. Prospect M (at the origin M) lies on a higher indifference curve than D. This is because M is received with certainty whereas D is in probabilistic terms. This risk aversion has been captured by the 'fanning out' of the indifference curves as they move from east to west and south to north, thus implying that a certain prospect could be forgone for an uncertain one only if the probability of the uncertain event rises by more than what is required to give the same expected value as the certain prospect. Let's consider the application of the above approach to the case of water markets. A major decision for the farmer's involves participating in spot and options market into order to hedge against the risks or simply to make speculative profits. We use the Machina triangle analysis to depict the preferences over the two markets. Figure C below depicts the case when spot markets yield the highest profits followed by options markets and finally the agricultural markets yielding the least profits. ON and OM represents the indifference curve between option, spot market and agricultural profits. Risk aversion implies that a prospect R which yields the same expected profits as a sure return in the option market denoted by the origin O lies below the indifference curve that ranks a sure profit from the option market with probabilistic outcomes in all the three markets. Therefore, when profits in the option market are sure and higher than the agricultural markets, spot market participation would be deterred. This may not be the case when uncertainties in the option market increase as shown by point S, which lies below the indifference curve OM. In such a case the farmer is willing to take more risks as is evident from the figure, with point S lying above the indifference curve OM. The tradeoffs between the spot and options market are not that straightforward in real life. Options markets are more prone to transaction costs imposed by litigation which may not be found in the spot markets due to the short nature of their transactions. This case is shown in figure D. Note that the east axis of the triangle holds the options market profits implying that the profits from agricultural markets are now higher than the spot market profits. Note that in this case point S’ that yields lower probabilities of agricultural returns and higher probabilities of a lower option market return make the farmer a risk taker inducing option and spot market participation.

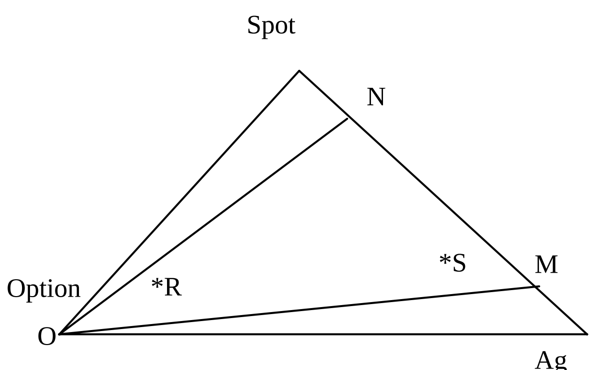


Figure C

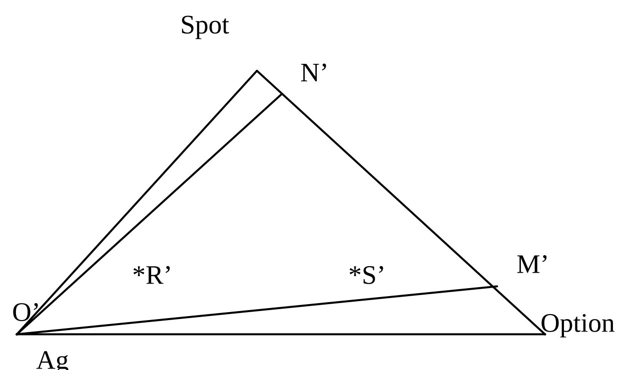


Figure D

On the other hand when the chances of agricultural profits are high, both spot and option market participation is discouraged as show by point R’ which lies below the curve that would make the farmer indifferent between a sure return in the agricultural market and an uncertain return from all the markets.

Organization and Water Market Failure

The nature of market participants is another factor affecting water development potential. Rosen and Sexton (1993) provide an interesting explanation for the infrequent trade in water between the rural and urban areas. They argue that most of the water rights are owned by large organizations in the West which suggests an element of co-operative decision making between water sellers and buyers. For example, in southern California, the Imperial Irrigation District (IID) provided about 2.6 million acre-foot of irrigation water to about 6,900 farm accounts annually in the 1980s. On the other hand, the predominant buyer of water from IID was the Metropolitan Water District (MWD), a water wholesaler to about 27 municipal and county water districts. Vaux and Howitt (1984) claimed that water trade between IID and urban users could reach up to 1,090,000 acre-foot. resulting in a gain in capitalized value of $3 billion. However, the actual trading between IID and WMD reached only to a level of 10, 0000 acre-foot. in 1989 after a protracted period of negotiation spanning almost a decade. In their study, Rosen and Sexton attribute this low level of transactions in the face of potentially large gains, to inefficiencies brought on by the intra-organizational conflict within the IID. They argue that in such a cooperative entity, majority voting may not lead to an optimal equilibrium due to the *cycling effect*. Cycling is caused when it is impossible to arrive at an organizational preference that is transitive in nature, i.e., even though individual preferences may be transitive, group preferences may not. Further, even if no cycling is observed, the group choice may not maximize group welfare if voting rights are not properly defined. In the case of IID, voting rights were defined on per-person per-vote basis. Four types of policies were available to the group. The first, *limited entry,* was to not participate altogether. The second, *expanding the resource,* would lead to utilization of trading revenues for conservation and expansion of water supply. The third, *negotiating certificates,* would allow distribution of revenues based upon the level of individuals' water rights. Finally, the fourth, *maintaining the resources,* focused upon maintaining water deliveries at their pre-trade levels. The actual transaction between IID and WMD required that a substantial portion of the revenues from trade be devoted to irrigation system improvements which were ineffective. The parties within the IID that would have benefited most from this trade were the absentee landlords owning large tracts of land. Whereas, the parties that would have lost most were the high-value crop growers that mostly rented their land and large land owners with crops that yielded low values. The main point of this paper is that due to the one-person, one-vote nature of restriction in the cooperative, maximum benefits could not be realized. Further, a clash of interests among the water right owners within the cooperative resulted in inordinate delays in operationalizing the water market.

Spot and Options Markets: The Advanced Stages of Water Markets

While trade in agricultural water proved so complex, ironically, some agricultural commodities have been successfully traded in the options market since the 19th century. After a governmental ban on agricultural commodity options in 1936, trading in agricultural commodities options was reintroduced in 1984 by the Commodity Futures Trading Commissions (CFTC). The Chicago Board of Trade (CBT) today trades commodities options such as corn, soybean products, wheat, rice, etc. Future markets also exist at New York's Cotton Exchange and Chicago Mercantile Exchange. The main purpose of future options has been to allow the farmer to hedge against the risk of volatile future prices. Similarly, options markets exist in the natural resources arena. Brennan and Schwartz (1985) apply the option pricing theory to study investment in copper mines. The option to invest is related to the value of mines, which is related to the price of copper in spot markets. Paddock, Siegel and Smith (1988) have looked at the oil sector to study the option value of oil exploration and extraction, related to the future prices of oil. Watters (1995) points out the supply-side similarities between oil and water markets; while oil supply is a function of geological uncertainties, water supply risks are hydrological.

Psychological factors may play an important role in determining the amount of options traded the water markets. For example, when prices are rising, sellers may have expectations of still higher prices and may hold back sale of their water. Lutgen (1999) demonstrates that when other financial instruments such as insurance and bonds are available, the farmer may buy insurance to guard against falling prices while wait until the premiums on the put options start to fall, before selling.

Limitations of water market development may vary with the type of market transaction. There are three basic types of water market: the permanent water rights transfer, spot water market, and the contingent (or options) water market. Temporary transfers have been advocated due to reduced impacts on both the farmers and the environment. Some impacts of long term water transfers include loss of soil fertility due to prolonged periods of no-cultivation, invasion of fallow lands by alien species that might be costly to eradicate, increased waste water treatment costs, and reduced agricultural productive capacity (Howe 1997).

Most studies have treated water rights as assets that are traded through long-term contracts. However, some studies have emphasized the role of spot markets in facilitating water transactions as they allow more flexibility and generally do not cause severe third-party impacts. Saleth et al. (1991) assess how spot markets would be restricted to few participants in presence of third party impacts caused by the flow pattern of water. For example, if a water transaction between two parties infringes upon the original water rights of downstream users, the scope of water transactions may be limited. In presence of such thin spot markets**,** transactions may be characterized by bargaining, the outcome of which would be affected by such factors as the size of the bargaining units, the nature of water rights (equal sharing versus priority sharing), the nature of the bargaining mechanism, and the availability of information on the participants payoffs.

One common form of bargaining involves a process in which the product of the payoffs of the bargaining parties is maximized. Formally stated, if π_i is the payoff of agent *i* from a successful bargain and c_i is his payoff in presence of a failed bargain, then a bilateral bargaining equilibrium (*bbe*) would be to maximize the Nash product $(\pi_i - c_i)(\pi_j - c_j)$ between two participants i and j. In case of multiple agents, a multiple bargaining equilibrium (*mbe*) would be an outcome of simultaneous $\frac{n(n-1)}{2}$ *bbe*s between all the *n* parties participating in the bargaining game. Saleth et al. use a modified version of the above bargaining rule designed by Zeuthen (1930) and Harsanyi (1967-68) that incorporates the possibility that a bilateral deal struck between two players may foreclose the possibility of trade for other participants, a defining characteristic of the water market. In the modified approach ‘risk limit’ of players is used to resolve this issue. Risk limit, or the level of a player’s vulnerability to a successful bargain is defined as:

(1) $$r_i = \frac{\pi_i^i - \pi_i^j}{\pi_i^i}$$

That is, player *i*'s risk limit is a function of the difference in *i*'s payoff and the amount offered by bargainer *j*. The higher this number, the higher the risk limits of player *i.* Saleth et al. (1991) apply this approach to a case of Crane Creek watershed in the Kankee County of Illinois. Their results indicate that the vulnerability of a market to bargaining-related distortions is inversely proportional its size. Distortions are measured in terms of payoffs relative to a competitive case outcome. Distortions are also found to be greater under an Equal sharing scheme as allocation of an equal amount of water results in more bargaining power for all agents. Similarly, the case of perfect information about each others' payoffs is less efficient as compared to imperfect information. In the case when information over other party's payoffs is not available, concavity of yield function results in lower expected payoffs thus restricting the bargaining strength of parties. Recently Murphy et al. (2000) have looked at the performance of spot markets through Experimental Economics**.** In such experiments computers are used to jointly maximize the total surplus of buyers and sellers, wherein bids are submitted by buyers and sellers in the spirit of auctions. The authors argue that such experiments help better understand the real world problems and allow us to prepare in advance for them. The experiments face similar problems faced in a real spot market, namely low efficiency in case of thin markets and high volatility caused by participants' reluctance to wait until the last moments of the game before releasing information regarding their valuation for water.

Of the three main types of water markets, the permanent, the spot market and the contingent market, the last one has been advocated to be of particular interest in various regards. Howitt (1998) makes the case for options markets by arguing that spot markets and the permanent-rights markets constitute two polar cases wherein risk is shifted from one party to the other. In case of spot markets, most of the risk is borne by the buyer due to the thin market characteristics of such transactions. In the case of permanent rights market, the seller of the rights needs to evaluate the value of his rights given current and expected future demands. The risk of selling the rights at a lower price than what may occur at sometime in the future is always there, especially if the seller is risk averse. These risks and uncertainties introduce significant transaction costs. He argues that options markets can help lower the risks arising from both supply and price uncertainties to both parties. The analysis of options has been largely restricted to the finance, literature and relatively little is available in terms of derivation of option value of water.

Michelson and Young (1993) examine the role of water-supply options contracts in facilitating water markets. Under this kind of contract, owners of the water (farmers) do not give up rights to water and typically lose access to water only in the dry periods. A number of conditions must be satisfied in order for the option markets to work. Chief amongst them are reliability of water supplies (to ensure sufficient water during dry years and plenty during normal years), well defined property rights, ability of the seller of the water rights to temporarily suspend his operations, availability and knowledge of risks of drought, and attractiveness of option contract costs as compared to alternative costs of attaining water in dry years. The authors further cite features of the water market that distinguish it from other kind of options contracts. These include the temporary nature of the contract (transferring use Vs ownership rights), potential exercise of the option multiple times over the contract period, and exercise of option being supply- dependent rather than price dependent. They define the option value of water as the difference in the cost of the options contract and the next best alternative source of water. Applying their model to water supplies for Fort Collins, Colorado, obtained from the irrigated farmland in Cache la Poudre River Basin, they derive the maximum option value of water to be about $295 per acre-foot, which is well above the range of farmers' forgone benefits in 'dry' periods that fall in the range of $39-$135 per acre-foot. In their results, farm offer price- defined as the cost of exercising the option- has a negative impact on the value of options; on the other hand, the option value rises with both water-right prices and the discount rate. It may be possible that farmers incorporate both the price of water rights and benefits from future contracts in deciding the amount and price of future contracts. For example, if the expected benefits from future contracts fall below the water right prices, they would be more inclined to sell their rights rather enter into an option contract. This kind of analysis would involve a simultaneous solution of demand and supply curves for buyers and the sellers and could be examined in a possible extension to the above work.

Using a continuous-time stochastic dynamic approach, Howitt illustrates some of the features of the option value of water. Assuming that the value of water rises over time, its growth rate could be defined as:

(2) $$\frac{ds}{s} = \mu dt + \sigma dz$$

where, μ is the deterministic drift parameter and σ is the standard deviation. dz is a Weiner process that is equivalent to a continuous time random walk. Now, the value of water at time T is what the buyer would be willing to accept or the seller willing to pay at that time. Therefore, if the price for use of water at time T is E, then the option would be of value S(T)-E, if S(T) is higher than E; on the other hand, it would be valueless if the above difference is negative. Howitt then defines the worth of an option at any time t before its maturation period as:

(3) $$p(t) = f(S, E, T, t)$$

Using Ito's Lemma, the rate of change of this price of option is then derived as:

(4) $$\frac{dp}{dt} = rp - rS\frac{df}{dS} - .5\sigma^2 S^2 \frac{d^2 f}{dS^2}$$

In the above equation, *r* is market rate of interest. Thus, the change in the value of an option over time is a function of the ongoing market rate of return, the value of water at that time and its variance. From the above equation one could infer that the rate of change in the option price for water would be lower at a higher value of water assuming concavity in the option price and value of water relationship. Also, a higher variance in the value of water would raise the rate of change in the price of options. Howitt also provides the solution to the option price from the past literature (which is too cumbersome to put here, see equation 6, pg. 129). However, from that equation it can be inferred that the option price of water varies positively with the time of maturity of water and the market rate of return. A higher time of maturity raises the price of the option because it helps spread the risk over a longer time horizon. Howitt sees this as a particularly significant contribution relative to spot markets and permanent water rights, as it allows spreading of such risks without requiring permanent transfer of water rights.

Houffaker et al. (1993) study the potential use of contingent water markets to augment stream flows in the Snake River that would help the downstream migration of salmon stocks listed as 'endangered' under the ESA. The authors note that most of the cost of buying water through contingent markets could be borne by electric powerplants that use inriver flows for generating electricity. They point out that given the beneficial impacts and the federal priority for protection of endangered species, legal obstacles that have hindered contingent markets from developing could be readily overcome.

While Howitt (1998) assumes that the value of water rights are influenced by stochastic supply and demand conditions, numerous factors determine the supply and price of options. The seller's perception of the risk from loss of water in a dry year is regarded as a major determinant of the supply response for water rights. As one study (Moore and Dinar, 1995) points out, water might be regarded as a fixed input rather than a variable input, thus substantially increasing the opportunity costs of water to the farmer. The drift term μ and the variance term σ may only capture the change in value of water brought by rising urban demand and land values. However, these reflect the demand side impact. The supply-side impacts can only be determined by incorporating the farmer's optimization function given his perception of future risks from supply shocks. Further, some (Gaffney 1997) have even argued that water is over applied in agriculture and thus any future reduction in supply could easily be absorbed at no loss of profits or substituted through groundwater extraction. If such is the case, some farmers might be inclined to use water for speculative gains in the spot markets instead of hedging in contingent markets. Similarly, size of the water market would have implications for the profits farmers could earn from selling contingent claims. Currently, not much work has been done to model such supply side issues related to water rights in order to fully integrate it into a contingent market framework.

A related study that looks at contingent water markets is by Villinski (1999). Villinski notes some of the drawbacks of the current contingent water market approach.

One major drawback of adopting the contingent market approach from finance involves the manner in which evolution of uncertain prices has been handled. The assumption of a Brownian motion implies that prices follow a continuous-time, random walk with mean zero and variance of one that is rising linearly over time. Villinski points out that water prices might show seasonality, and perhaps a mean-reverting approach would be more fitting. While she follows a similar framework as Howitt, the methodology used is quite different. Drawing on data from Watters (1999) and applying it to the case of California, she solves for the European call option value of water, which could be exercised two times in a three year period. While the calculated option value is quite low ($1.45), it approximates the real option value that the buyers of water in California were willing to pay in case of an options market in 1994-95. The California department of water resources, in an attempt to reduce the scarcity of water to the urban areas, invited bids from both buyers and sellers for sale of options for water for 1995 (Jercich 1997). Some 310, 000 acre-foot of water were demanded by the buyers in response. However, only 230, 000 acre-foot of option water supplies was offered by the sellers. The negotiated option value of water turned out to be $3.50 per acre-foot with an exercise price of $36.50 per acre-foot. However, due to high precipitation in 1995, these options were never exercised.

Another example of contingent water trade (Howitt 1998) involves the Palo Verde irrigation District (PVID) and the MWD of California. In this program irrigators were promised $620 per acre that was fallowed. This led to a total conservation of 114 million m^3 of water, which could be called by the MWD at any time up through year 2000.

Options market may also have unintended effects of mitigating third party effects. Because of the time lag between the sale of an option and the exercise of the option, the seller has sufficient time to inform the third parties of potential impact. Similarly, the indirect impacts of forgone agricultural output can be mitigated substantially through advanced planning and supplementary income generated through options sale.

A Simple Model

In most modeling applications to water markets, the exercise price of water-or the price paid for use of water in the future- is treated as a constant when assessing the option value of water. In reality however, the exercise price and the option value are likely to be both endogenous and related. As a consequence, the option value cannot be accurately solved for when ignoring such supply-side factors as farmers' level of risk perception and size of market. Consideration of these factors is explained below with the help of a simplified model.

Let w_{tot} be the water available to the farmer in a wet year when full water entitlement is used, and w_{tot-s} be the water available to him in a dry year when he sells *s* units of water through the options market. It is assumed here that the farmer is able to substitute groundwater for reduced surface supplies, in a dry year, so that he has *tot* units of water whether or not drought occurs. Only reduction in supply he faces is through his water sales; water transfers cannot be made up by increased groundwater use. Let $\pi(w_{tot})$ be the profits from water use in the wet year and $\pi(w_{tot-s})$ the profits in a dry year. Also let h be the option price for water this year and k the exercise price of water next year. Now, if he decides to enter the market his profits are computed as[4]:

[4] This is a one-year option with one-time option value.

(5) $$hs + \frac{(1-q)\pi(w_{tot}) + (q)(\pi(w_{tot-s}) + ks)}{1+r}$$

where, q is the probability of a dry year next year, and r is the market rate of interest. The optimal amount of water he sells would be determined by the maximization of the above objective function with respect to water sales. If he stays out of the market, his net present value of profits next year is[5]:

(6) $$\frac{\pi(w_{tot})}{1+r}$$

Assuming transactions costs and risks are zero, the farmer would enter the market if:

(7) $$hs^* + \frac{(1-q)\pi(w_{tot}) + q(\pi(w_{tot-s}) + ks^*)}{1+r} > \frac{\pi(w_{tot})}{1+r}$$

where s^* is the optimal amount of water sold. Rewritten, this can be expressed as:

(8) $$h > \frac{(q)}{1+r}\frac{(\pi(w_{tot}) - \pi(w_{tot-s}))}{s^*} - \frac{qk}{1+r}$$

The option value has to be larger than the expected value of the difference between 1) the per unit opportunity cost of sold-water to the farmer and 2) the exercise price of water. The above equation defines a relation between the option value and exercise price (exogenously specified, thus far) and farm level parameters such as productivity, market discount rate and risk perception. Note that if the opportunity costs of forgone water are higher than its exercise price, the total option value required to induce the farmer to participate (on the left hand side in equation (8)) becomes larger, the larger is the probability of a dry year. On the other hand if the exercise price is well above the opportunity cost of water, the inducement threshold would fall as the probability of a dry

[5] This is the simplest case. If the seller does not enter the market, he might still have the option to indulge in spot market sales with the possibility of higher gains.

year rises. Risk perception of the farmer, therefore, turns out to be an important parameter in the above case. Also, note that if the profits from water usage are concave and the farmer is fully using his water entitlement, the opportunity cost of water sold at the margin may be lower, thus lowering the threshold for market participation. Finally, if the farmer is risk averse, his expected utility (the right hand side) would be much lower than if he received the same income with certainty. In that case, for a given option value, the exercise price would have to rise to induce him to participate.

The above equation also yields a negative relationship between option value and exercise price, keeping everything else constant. In reality, the farmer may be able to fix both while negotiating with the buyers. Therefore, significant opportunities exist for the farmer to incorporate both the option value and exercise prices as endogenous parameters into the sellers profit maximization function in order to maximize his own gains. However, in cases where the market size is large, such opportunities may be limited. Consider a simultaneous settlement of exercise price and option value by both buyers and sellers.

From the above, the relationship between option value and exercise price for the seller can be characterized as:

(9) $h = h(q, r, \pi, k)$

The buyer of water has a similar negative relationship between option value and exercise price (see Howitt 1998):

(10) $h = h(v, r, k)$ where v is the value of water to the buyer[6].

[6] Buyer's option value, among other things is affected by the next best alternative source of water to him.

Howitt derives the option value of water under the assumption that water price evolves stochastically over time in a geometric Brownian motion fashion, and therefore is not directly applicable to our model. We instead, borrow an exposition of option value from Cox et al and apply it to the case of water. Following Cox et al., we can write the option value of water as:

(11) $$h = \frac{1}{r}\left\{ (\frac{r-d}{u-d})h_u + (\frac{u-r}{u-d})h_d \right\}$$

where, r-1 is the risk-free rate of return, u-1 is the value of water in a dry year, and d-1 is the value of water in a wet year. Further,

(12) $$h_u = uP - k \; \& \; h_d = dP - k$$

where P is the current price of water. This formula however reflects the no-arbitrage condition which requires that the option value of water could be replicated by a portfolio consisting of water stocks and a risk-less bond. In reality however water is not traded in the stock market. Therefore, we simplify the above formula by assuming that the option value of water is simply its expected return in the future given by:

(13) $$h = \frac{q(uP-k) + (1-q)(dP-k)}{1+r}$$

or,

(14) $$h = h(q, P, k, r, u, d)$$

Notice that the option value falls with exercise price as suggested in the literature. Plugging the value of *h* into the farmer's participation constraint given by equation (8), we derive the threshold level of current price of water beyond which the farmer would find it attractive to enter the market as:

(15) $$P > \frac{\pi(w_{tot}) - \pi(w_{tot-s})}{s\{q(u-d) + d - k(1-q)\}}$$

Figure 1 represents the relationship between option and exercise price of water, and possible cases that would lead to an exchange and those that won't.

[NSERT FIGURE 1 HERE]

The solid line is the (*h*, *k*) relationship for the buyer, the dashed lines are for the seller[7]. In case A, the seller values the option price highly relative to exercise price, whereas in case B the exercise price is more valuable. The relative importance of the two would be determined by the farmers own discount rate, which is a function of the market rate and individual risk perception. Both these cases would potentially lead to a successful transaction. On the other hand, case C represents a market failure as the buyer's willingness to pay is below what the sellers are willing to accept, not uncharacteristic of conditions in current day water markets. This may also occur when the farmer compares the benefits from participating in the spot markets and the options market as well. Formally, if uP is the price in the spot market for a unit of water, his participation constraint would be given by[8]:

(16) $$q\pi(w_{tot-z}) + \frac{zuPq}{1+r} + \frac{(1-q)\pi(w_{tot})}{1+r} > \frac{q(\pi(w_{tot-s} + ks) + (1-q)\pi(w_{tot})}{1+r} + hs$$

In the above equation, z is the amount of water sold in the spot market. The optimal amount of z would be determined by the optimization of use of water in agriculture and expected profits from the spot-market sales. Similarly, the amount of water sold in options market would be determined by the maximization of the right hand side term in

[7] Note that the buyer's (*h*, *k*) relationship could be non-linear, but is assumed linear here for simplicity.
[8] We make a simplifying assumption here. There is no spot market in a wet year as the buyers can access alternative sources of water much cheaper than those from agriculture.

equation (16). If equation (16) holds, then the farmer would rather sell his water in the spot market instead of the options market. The profit curves from the two cases are depicted in figure below.

[INSERT FIGURE II HERE]

AB represents the falling marginal productivity of water in agriculture. L'L is the option value of water and N'N is the spot price of water. AL is the use of water in agriculture in the case of option sales. In the case when the farmer intends to sell water in the spot market, AM is the use of water in agriculture when spot market happens and AMB is the use in a wet year. The profits in case of option market participation are ANZ and in the case of spot market activity are AUW with probability *q* and AMB with probability (1-*q*). The condition that would determine whether spot market participation is more beneficial would be given by:

$$(17) \qquad q\pi(w_{tot-z}) + \frac{zuPq}{1+r} + > \frac{q(\pi(w_{tot-s} + ks)}{1+r} + hs$$

Not that the first term on the left hand side is the expected profits in agriculture from spot market participation, whereas the first term on the right hand side is the expected profits in agriculture from sale of water in the options market. Since water drawn from out of agriculture would have the same impact on loss of productivity whether in a spot market or the options market, we could discard the two terms to get:

$$(18) \qquad \frac{zuPq}{1+r} + > \frac{qks}{1+r} + hs$$

The above condition requires that expected profits from spot market sales must be larger than the sum of the option value and the expected exercise price. In the above equations we have assumed that the farmer chooses between spot and options markets on an 'either/

or' basis. However, if the above condition holds, that choice would still be optimal even in a case where profits are maximized by allocating some water to the options market and some to the spot market. This is so because we have assumed that there is no demand-side constraint and that the farmer is able to supply as much as he chooses. Given that, if it is optimal for him to sell one unit of water in the spot market, it will be optimal for him to sell the next unit as well since his marginal revenues do not fall. Note that while the gains from both the spot market and the exercise price in an option value market are assessed in terms of expectations, the option value is certain. Therefore, a higher option value-despite high expectations of profits in a spot market- may deter the farmer from participating in the spot market. However, from above we know that the options value is given by:

$$(19) \qquad h = \frac{q(uP-k)+(1-q)(dP-k)}{1+r}$$

Plugging the above back into (18), we can solve for the critical threshold for current price of water beyond which the spot market becomes an attractive option over the option market. This is given by:

$$(20) \qquad P > \frac{sdP-(1-q)ks}{q(zu-s(u-d)}$$

The above is a simplified model. Decision rules would be far more complicated within a multi-period setting with multiple exercise options or when more realistic scenarios such as transaction costs and risks are incorporated. First consider the impact of significant transactions costs on the above results. Transaction costs would lower the effective price received by the farmer from his sale of water options. This would, therefore, require a higher threshold level of current price of water (given by equation

(15)) in order for him to participate. Similarly, the threshold level of price derived in the case where he has a choice between participating in spot market or water options market would be affected by the relative transactions costs of the two markets. Typically, the transaction costs of water are much higher in an options market as it may involve an actual transfer of water rights (over the specified period). In such a case, the spot markets would become more attractive and the threshold level of current water price (given by (20) above) would fall.

There are a number of other significant characteristics of water markets that have not been addressed by this simple model. First of all, the model assumes the existence of a competitive market. However, in reality, the size of the market would vary across location based on level of urban needs; presence of alternative supplies of water; existence of regulatory, legal and financial infrastructure necessary for successful water markets; and other factors. A small market would have a higher element of strategic behavior as compared to a market with a large number of participants. Strategic behavior would make the option value endogenous as sellers could affect it by holding back water.

Second, decision rules would be much more complicated in a multi-period setting with multiple exercise options. While, the one period model considered only the risk of water shortage from drought, there are other types of risks too may become more significant in a multi-period setting. Transaction risk from third-party claimants to water may increase with contractual arrangement tied to future water supply contingencies, and uncertainty regarding future water supply demand conditions. Another source of risk involves the fear of loss of water rights for farmers who trade their water in the markets. This reflects a concern that future adjudications of water rights might consider previous use pattern of water (agricultural consumption versus market sale) by farmers and that market sale may not be regarded as a beneficial use. Finally, there are various demand-side risks. Prices of commodities might fluctuate with weather and global supply conditions. Such risks would affect the way the farmer views his profit potential from agricultural output in a water-constrained year. Some input supply and output processing industries that depend upon a reliable production of agricultural commodities, might shift to water-surplus regions if water markets affect agricultural productivity, with implications for agricultural sector returns. There is also a risk of irreversible changes to the productivity of farmland from sale of multiple year options. In case of a severe sustained period of drought, farmers' land could get invaded by invasive weed species which might be difficult to eradicate. Other effects of multi-year fallowing may include loss of employment; farming skills; equipment depreciation; loss of tax base, etc. resulting in reduced support for water transfers.

The modeling of long term risks of droughts may require a different approach. While year to year water supply is forecast based on the current status of hydrological conditions, long-term forecasts require a historical assessment of such events. In the finance literature, the value of an option is composed of two parts; time vale and intrinsic value. Time value is determined by the time left to expiration of the contract. The farther is the time to expiration, the higher the time value, as uncertainty is higher. In the case of a multi-period water option, time value would need to be determined by the historic probabilities.

Conclusion

Water constitutes one of the most fundamental needs for the humans, animals and the environment. However, there is not enough water to meet the needs of all. To compound the problem, current allocation of water does not meet the efficiency criterion of water going to the neediest. It is with this need that efforts are being undertaken to implement water markets in USA and rest of the world. Yet there are significant challenges to implementing water markets. Surface water has certain unique feature that separates it from other commodities. The supply of surface water is seasonal and uncertain, largely dependant upon the hydrological conditions. Further, there are significant limitations to the extent it could be transferred and stored. Other challenges include uncertainty of water supply, institutional bottlenecks, behavioral responses, etc. Such challenges manifest themselves at various levels of water market development. Whenever the institutional infrastructure fails to co-evolve with the water markets or is completely lacking, the development of water markets is stagnated. Evolution of markets also leads to the evolution of market participants which in turn requires further evolution of institutions to match with their specific needs. The survey of the literature suggests that while transactions costs, ill defined property rights and third party impacts constitute significant institutional deterrents to market development, response to risks and future expectations of government policies make for major participatory risks to its development. The advanced stages of water market, namely spot and the options market need the backing of very sound institutional settings to function effectively. Further, the choice between the two itself is dependent upon several factors which affect the impact of water trade upon the buyers and the sellers. Even when the institutional development is sound and forthcoming, inexperience of water right holders in market transactions coupled with suspicion over market induced federal policies that may take away their water rights could be a significant inhibiting factor for water trade. Further research will need to focus upon these behavioral responses in order to come up with meaningful policy implications for water market management.

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Figure 1: Market and Institutional Evolution

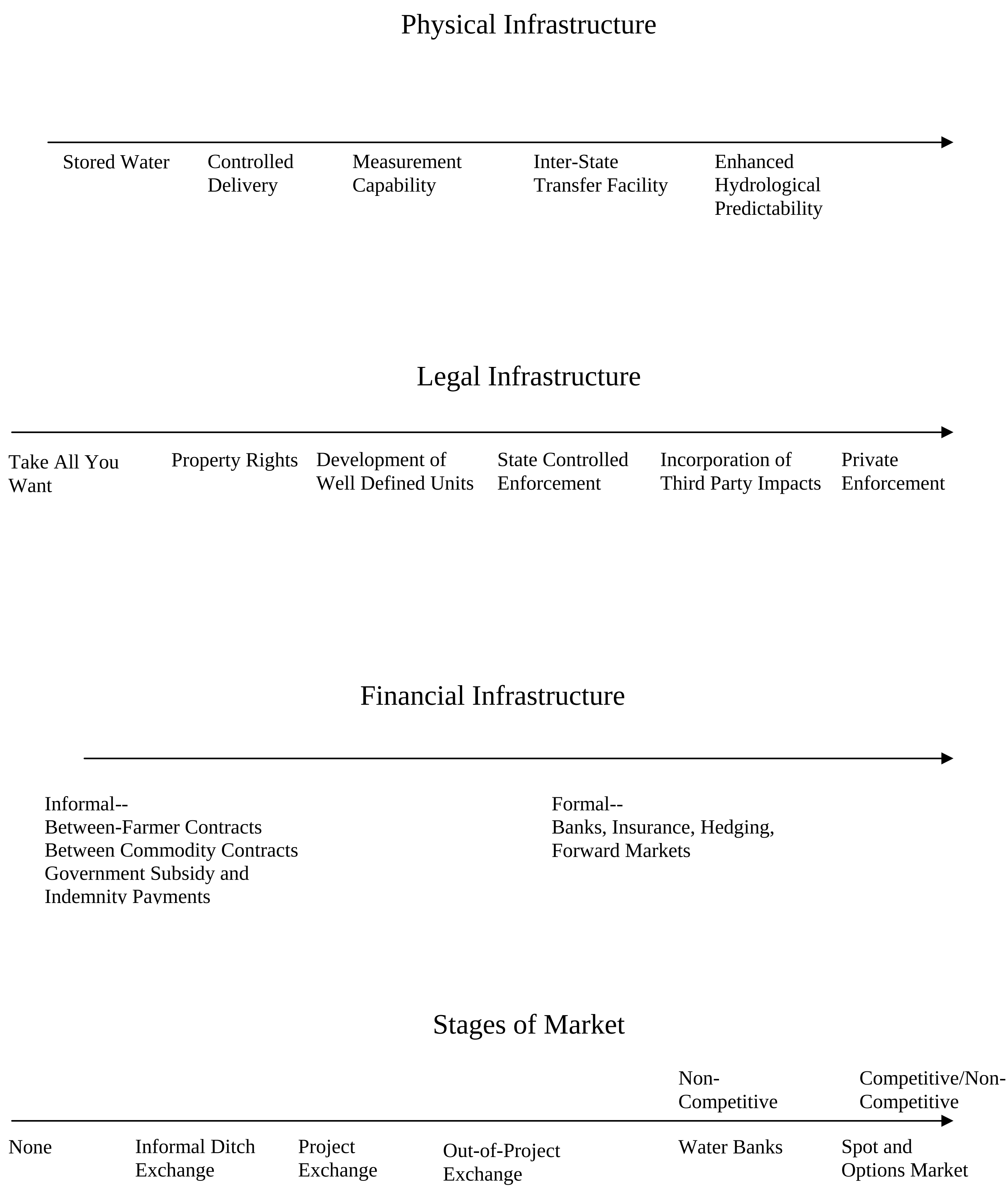

Figure 2: Evolution of Water Market through Feedbacks

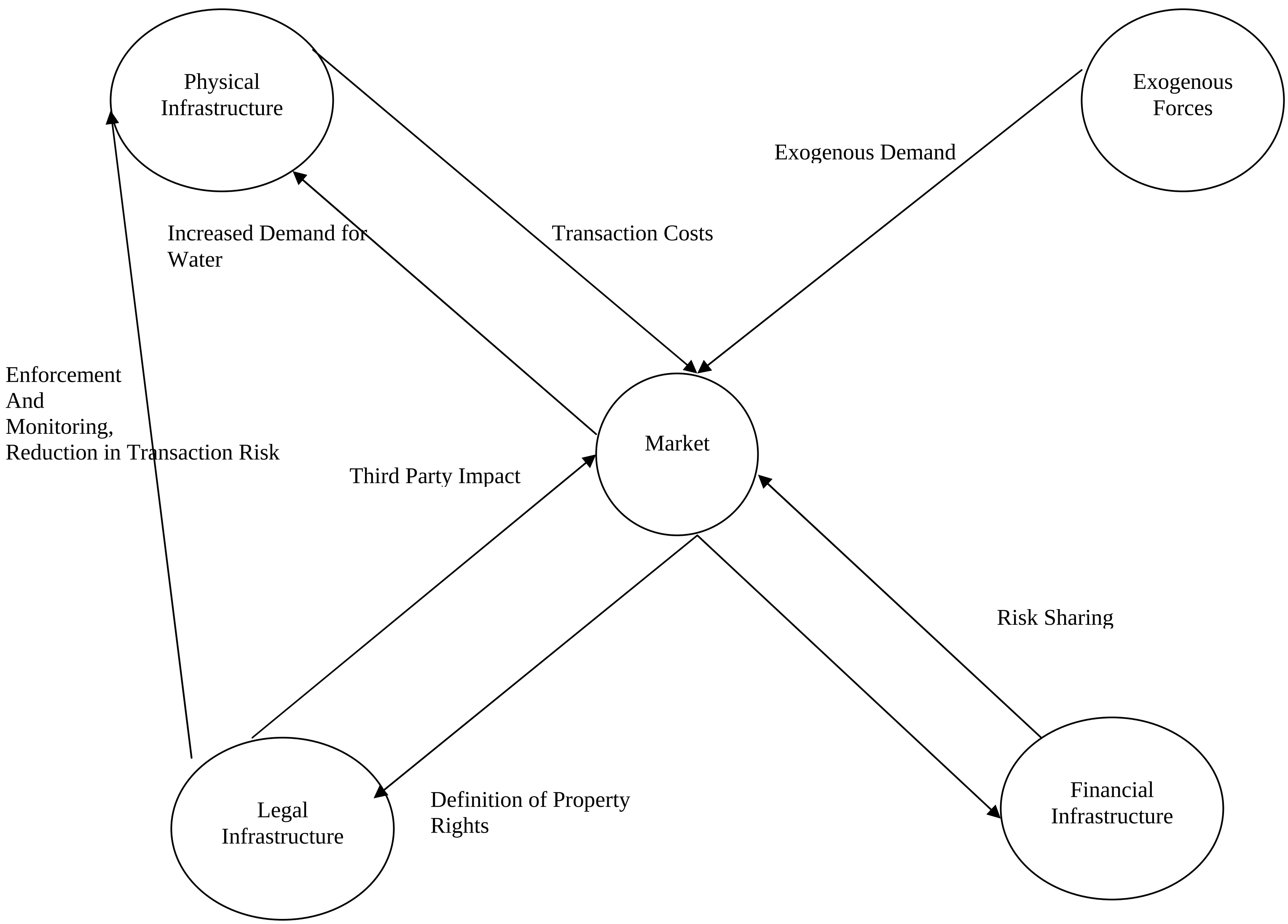

Figure 3: Determination of Option Value and Exercise Price

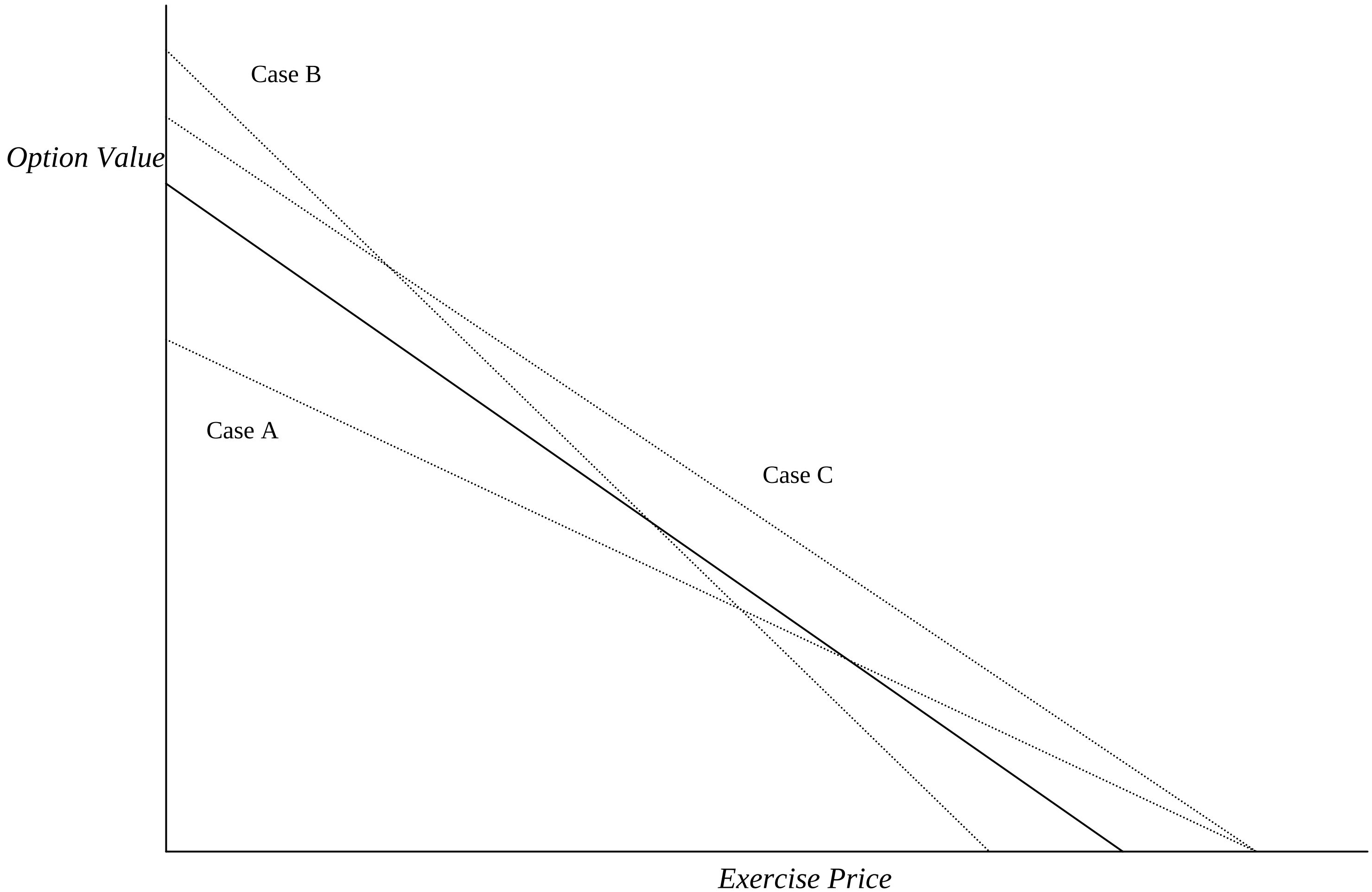

Figure 4: Profits from water Sales in Option and Spot Markets