UPSTREAM MARKET POWER IN WATER TRANSFERS

by

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DEDICATION

To my family

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ABSTRACT

Water transfers are generally considered beneficial when both parties in the transaction have different marginal values of water use. In most cases transfers are negotiated between buyers and sellers in a bilateral monopoly setting. Imperfections in water markets create opportunities for buyers or sellers to benefit from asymmetric bargaining ability and market power. This thesis models the negotiation process for water transfers between agricultural irrigation districts and urban municipal providers using bargaining theory. By looking at the outcome of a transfer contract as the result of a bargaining game, I am able to derive comparative statics on the effects of market power and bargaining ability on prices and quantities. The comparative statics are then tested empirically using data from western water transfers during the period from 1990-2004. The empirical evidence in support of the theoretical predictions is mixed.

CHAPTER 1

THESIS INTRODUCTION

Transfers of water between agricultural and urban users serve as mechanisms to deal with urban population growth and the accompanying increases in urban water demand. Growing urban water demands have caused divergence in the marginal values of water used between urban and agricultural entities. Agricultural-urban transfers therefore have the potential to result in welfare gains for both buyers and sellers. While the difference in marginal values might not be as large, agricultural-agricultural transactions also have the potential to result in more efficient resource allocations. However, the textbook gains from trade model is based on the assumption that water transfers occur in perfectly competitive markets. Many water professionals avoid using the phrase 'water markets' because of the lack of well defined markets with numerous buyers and sellers.[1] Most water transfers can therefore be considered as individually negotiated spot market agreements. When markets are thin, contract terms are influenced by both market power and asymmetric bargaining ability. In a bargaining context, the lack of sufficient outside options for either buyers or sellers is a form of market power. Exogenous market characteristics therefore have the potential to dramatically influence negotiations.

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[1] While the term is generally avoided, my use of 'water markets' here refers to markets with imperfect competition.

Given the scope for imperfect competition, the outcome of a transfer should be considered as the outcome of a bargaining game. This thesis has two major contributions. First, water transfers between users are formally modeled as bargaining games. The bargaining models generate empirically testable comparative statics regarding the effects of bargaining ability and market power on prices and quantities. Second, the price effects of upstream market power are tested empirically with data from agricultural-urban transactions in nine western states from 1990-2004. I first estimate price, quantity, and contract type equations separately by OLS and probit maximum likelihood. I then estimate a three equation simultaneous system which models price, quantity, and the binary decision of whether the transaction should be a short-term lease or a permanent purchase. While no formal results are presented, the empirical component also consists of a discussion of other possible modeling techniques that were explored.

This thesis consists of four remaining chapters. Chapter 2 lays a foundation for the theoretical and empirical models by discussing how water transfers are likely to be influenced by imperfect competition. I discuss several historic transfers which were affected by monopoly power, monopsony power, or both. Discussing imperfect competition in actual transfers makes the need for game theoretic models of the bargaining process apparent. Chapter 3 presents several models of bargaining for transfers between water users. I focus mainly on an asymmetric Nash bargaining model where an irrigation district and municipal provider bargain over price and quantity. The possibilities of uncertainty in urban demand and rural supply are also considered. I then derive comparative static results on the effects of bargaining power and outside options on negotiated prices and quantities. The comparative statics are the source of testable implications for the empirical models. Chapter 4 contains empirical tests of the implications derived in the previous chapter. The data consist of 143 transactions in seven western states during 1990-2004. The dependent variables of interest are price and quantity, which are the two endogenous variables in the bargaining models. The transactions include both short-term leases and permanent purchases of water. While not modeled theoretically, the empirical procedures must account for the potential endogeneity of the buy/lease decision. I do this by estimating a system of three equations using full information maximum likelihood (FIML). Chapter 5 discusses implications and conclusions. This final chapter also discusses the implications of the theoretical and empirical results for water transfer policies.

CHAPTER 2

OVERVIEW OF WATER TRANSFERS

Water transfers are complex economic arrangements that often involve both legal and environmental restrictions. The contracting process is therefore complex when compared to the simple contracts that tend to dominate in agriculture. Varying legal environments are a first source of complexity for transfers. In most parts of the Western United States water allocation is governed by the prior appropriation doctrine. Allocation by prior appropriation requires an initial user to establish possession of a property right to water by staking a claim to a reasonable amount of water to be used for beneficial purposes. The right is then secured when diversion occurs, hence the emergence of the phrase ‘first in time, first in right’. Senior appropriators are those holding originally established rights. Junior appropriators are conversely those holding more recently established rights. The endowments of senior rights holders are satisfied first when water supplies are limited. It is during these times that the allotments of junior rights holders are likely to be insufficient to satisfy their demands. Agricultural water users are often holders of senior rights. Urban and environmental users are more likely to hold junior rights. Transfers out of agriculture and to urban and environmental uses therefore have the potential to result in consistent increases in the quantity of water allocated to urban and environmental purposes, which are often the highest valued uses of water.

There are many characteristics of water transfers which could prevent transactions from resulting in the outcome with fully developed, or perfectly competitive, markets. The remainder of this chapter first presents an overview of the many factors which are cited in the literature as barriers to transfers. A discussion of these barriers is necessary in order to place the current work within the literature on the economic and institutional factors influencing water markets. I then turn to a discussion of the potential for market power and asymmetric bargaining ability as factors causing the outcomes of transfers to diverge from the perfectly competitive outcome. Finally, I discuss some historic transfers which were affected by imperfect competition.

2.1 Common Barriers to Transfers

Transfers of water between users have been limited by several factors. Economists have argued that various barriers prevent the number of transactions from being socially optimal (Young, 1986). One obvious barrier is the limitations in the infrastructure required to transfer water between users. It is often infeasible to transfer water between geographically separate users without a fully developed system of conveyance facilities. However, when the transacting parties rely on the same source of water (e.g. a river with a common dam), water sales are not limited by infrastructure. The transfer of a right simply allows the buyer to increase their diversions from that source. While lack of adequate conveyance facilities has been a historic problem, physically transferring water between users has become less problematic as the systems of conveyance facilities in western states have become more advanced.

One of the most commonly cited barriers to agricultural to urban transfers is their potential adverse effects on rural agricultural communities (Howe et al., 1990; Nunn and Ingram, 1988; Taylor and Young, 1995; Hanak, 2005). Land fallowing is a common way of conserving water to be transferred. Rural communities often oppose transfers on the basis that the local economy will be adversely affected by the associated decrease in agricultural production. Such pecuniary externalities are a common source of debate over transfer proposals. For instance, local input suppliers oppose transfers based on the notion that allowing transfers will reduce the demand for their products. Other members of rural communities hold similar beliefs regarding the negative economic impacts of transfers. Howe, Lazo, and Weber (1990) use an input-output model to estimate the economic effects of an agricultural to urban transfer in the Arkansas River Valley of Southeastern Colorado. They find the net loss of income in the state to be $53 per acre-foot (AF) transferred. The authors then explain that this is a rather small amount when compared to the cost savings (from foregone expansion in capacity) to the municipal provider. Taylor and Young (1995) also find that foregone benefits from agricultural production were moderately low for transfers in Southeastern Colorado. An impact analysis by Charney and Woodard (1990) finds that the local economic impacts to an Arizona county of fallowing agricultural land in order to transfer water have the potential to be substantial when including fiscal impacts.

Regardless of the relatively low costs of transfers on agricultural communities, some counties have instituted laws restricting out of basin groundwater transfers from rural agricultural communities. Hanak (2005) presents an empirical model which tests the efficacy of such restrictions on exports of groundwater from California counties. The export ordinances can take a variety of forms, but generally allow for county governments to oversee groundwater transactions. For instance, some ordinances could require greater levels of environmental review in order to transfer water. The expectation is that export restrictions will increase transaction costs and reduce the quantity of water transferred out of agriculture. Hanak's results indicate that export restrictions have the expected negative and statistically significant effect on water exports. The California case thus indicates that local counties of origin succeed in their attempts to limit water transfers. Future transfers are likely to be inhibited by local ordinances that restrict transfers based on concerns over pecuniary externalities.

The problem of lost return flows presents a true externality issue for agricultural to urban transfers. Downstream users of surface water are dependent upon return flows from upstream users. An out of basin transfer by an upstream user therefore has distributional effects on downstream users. When downstream uses are agricultural, the rights of other agricultural users are threatened by upstream out of basin transfers. If the proposed transfer is large, the problem is amplified when the downstream use is environmental or recreational (Anderson and Johnson, 1986). In this case the transfer has negative impacts on many environmental users rather than just a single agricultural operation. Decreased return flows therefore represent an additional issue for water policymakers.

Transaction costs represent a final barrier to transfers. Water transfers are often characterized by relatively high transaction costs (Young, 1986; Saliba, 1987). Various barriers arise when completing the steps necessary to transfer water. For instance, legal requirements are often burdensome on both buyers and sellers. In addition, it is costly to search for trading partners and to negotiate the terms of an agreement (Colby, 1990). The optimal allocation of the resource between users could be inhibited in markets where transaction costs are high. However, the existence of negative third party effects resulting from transfers makes high transaction costs a potential factor to offset the external costs of transfers. Ignorance of third party effects causes the level of transfer activity to be greater than optimal. It is possible that high transaction costs could offset this effect (Colby, 1990). Thus, transaction costs could cause water users to transfer amounts closer to socially optimal levels when transfers have negative third party effects.

Up to this point I have briefly discussed the common features which prevent water markets from becoming fully developed. These include infrastructure limitations, third party impacts, water quality issues, and transaction costs. Bilateral monopoly and asymmetric bargaining ability also have the potential to prevent transfers from achieving socially efficient outcomes. I next turn to a discussion of imperfect competition in markets for water.

2.2 The Potential for Bilateral Monopoly and Asymmetric Bargaining Power in Water Transfers

Given that agriculture accounts for a majority of water use in the western states, it serves as the major supplier for transfers to other users (Hutson et al., 2004.). Growing municipal demands have made agricultural to urban transfers common. At the same time, the number of participants in water markets is often small. There are usually only a small amount of irrigation districts within reasonable geographic proximity to serve as suppliers to a particular municipal entity. In addition, irrigation districts being located in primarily rural areas creates market power for municipalities which are in reasonable geographic proximity to the district. It is worth noting that reasonable geographic proximity is highly variable across space. The phrase really refers to the development of conveyance facilities for transfers. Transfers of water long distances are more feasible in some states where conveyance facilities are well developed. Energy costs are a significant component of conveyance costs. Thus, high energy costs also make conveyance costly for long distance transfers. When markets are characterized by few buyers and sellers, the terms of a transaction are the result of a bilateral bargaining process. The exact nature of the bargaining process is critical in determining which party enjoys a greater share of the gains from the agreement.

The existence of imperfect competition in water markets can be partially explained by three factors. First, the number of potential sellers is limited by the nature of the appropriative doctrine. Holders of junior rights may not be desirable sellers for municipalities. Junior rights are affected by uncertainty in the water supply and therefore less desirable to municipalities seeking assured supplies. Second, water rights holders are heterogenous in their entitlements. For instance, the Imperial Irrigation District of Southern California, which is the largest agricultural irrigation district in the nation, has a right to divert approximately 3.1 million acre-feet (AF) annually. The Metropolitan Water District, which is the largest municipal provider in the region, diverts approximately 550,000 AF annually. There is then a large variability in the endowments of other smaller districts and municipalities in the area. Some smaller districts may not have sufficient endowments to transfer to larger municipal providers. Heterogeneity in the sizes of buyers and sellers therefore further limits the scope of the market. Third, burdensome legal restrictions make participation in transfers undesirable for some potential buyers or sellers. Transaction costs imposed by legal requirements introduce additional costs of reaching an agreement. Only buyers and sellers which stand to gain above the expected legal costs of transferring water will participate in transactions.

In addition to the pure market power effect, transfers are affected by asymmetries in bargaining ability. Participants in a water transfer are unlikely to possess the same skills at the bargaining table. Participants with past buying or selling experience are likely to be more familiar with the complex legal requirements needed to transfer water. This familiarity would allow the participant to react and respond to offers faster than a buyer or seller with limited or no past experience. A buyer or seller with increased bargaining power would be expected to use this to their advantage in order to capture a greater share of the gains from agreement. Thus, both asymmetric bargaining ability between buyers and sellers and market power have the potential to cause contract outcomes to diverge from those which would be expected in perfectly competitive markets.

Many previous studies do not consider the effects of imperfect competition and asymmetric bargaining ability on transfers. (Vaux and Howitt, 1984; Weinberg, 2002; Ballestero, 2004). Modeling transfers as occurring in fully developed and perfectly competitive markets does not allow for the possibilities of asymmetric bargaining power, strategic behavior, and bilateral monopoly. These features can have substantial impacts on the outcome of transfer contracts.[1] Predicting the outcome of negotiations over transfer contracts should thus involve models which account for asymmetric bargaining power and imperfect competition.

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[1] There are several terms which could be negotiated when determining the outcome of a contract to transfer water. When referring to the outcome of a contract, I am referring to negotiated price and quantity.

Some studies have modeled bilateral negotiations for water transfers. Saleth, Braden, and Wayland Eheart (1991) develop bargaining rules in order to guarantee an efficient outcome in transfers between agricultural users. Their model is applicable to a situation where a limited number of irrigation districts negotiate over the distribution of a fixed water endowment. Not surprisingly, they find bargaining rules to be more important in leading to efficient outcomes when the degree of market concentration is greater. The specific bilateral monopoly problem is noted by Lekakis (1998), who models the allocation of irrigation water between Greece and Bulgaria as a bilateral monopoly problem. Models of multi-lateral negotiations also have implications for water management. Richards and Singh (1997.) model negotiations for water as a two stage cooperative bargaining process first between countries and second within countries. The authors point out that in the Western United States, their model is most applicable to two level bargaining between states and then between heterogenous parties within the respective states. A notable example of such a process would be the negotiations between states for access to Colorado river water. The inter-state negotiations are then followed by negotiations between different user groups within each state. Multilateral negotiations are not considered in the present work. Nonetheless, future work could address these issues by including government, environmental, or affected community groups as players in the bargaining game.

The literature on imperfect competition in water markets is fairly limited and comes to no clear and concise conclusions on the effects of imperfect competition and asymmetric bargaining ability on the outcomes of contract negotiations. The bargaining models presented here provide a cogent characterization of imperfect competition in water markets. The upcoming empirical models quantify the effects of upstream market power on transfer agreements. Before getting to theoretical and empirical models, I briefly discuss some historic transfer agreements.

2.3 Some Historic Transfers

Before moving into theoretical and empirical models of bargaining for water, it is instructive to give an overview of some past transfers which were influenced by asymmetries in bargaining power and market power. This initial empirical content provides a basis for the theoretical models in the upcoming chapter. Knowledge of past transfers which occurred in bilateral monopoly market setting gives support to the idea of modeling water transfers as bargaining games.

2.3.1 Owens Valley - Los Angeles

The most historic transfer of water between agricultural and urban users is undoubtedly the large-scale transfer between the city of Los Angeles and farmers in the Owens Valley around the turn of the 20^{th} century. The city of Los Angeles experienced rapid economic and demographic growth during the later part of the 19^{th} century. The Los Angeles River, which was the water supply of the city at the time, was insufficient to satisfy the needs of the rapidly growing city. Employees of the Los Angeles Department of Water and Power (LADWP), led by director William Mulholland, were forced to seek an alternate source of water. The Owens Valley, a primarily agricultural region located approximately 250 miles to the northeast of the city, seemed to be a prime source of the needed water. The 120 mile long Owens River was the predominant water source of the valley. Valley farmers used a portion of the river's flow for irrigation, with the remainder flowing into the Owens Lake. The only two issues to be solved for the city were obtaining the diversion rights and constructing an aqueduct to move the water between the two locations. The former was accomplished through land purchases from valley farmers. During the period from 1905-1934 the city purchased 145,867 acres of agricultural land in the valley (Libecap, 2006.). The purchases also included the riparian water rights associated with land ownership. By 1908 the city had begun construction on a 250 mile aqueduct that would bring water south from the valley. Construction was completed and the first water flowed down the aqueduct in 1913.

While a detailed discussion of the historical significance of the Owens Valley - Los Angeles transfer is beyond the scope of this thesis (for more detailed discussions see Hoffman (1981.), Walton (1992.), and Reisner (1997.)), it is useful to note some further aspects of the transfer. The Los Angeles Aqueduct was the major water source for the growing city during the 20th century. By 1930 the Owens Lake was completely dry. Today approximately half of the city's water supply comes from the Owens Valley.[2] The transfer has evolved into a century-long controversy and is the most frequently cited case by those weary of agricultural-urban transfers. The controversy has involved several cases of destruction of parts of the aqueduct by angry residents of the valley. While the valley is currently a top recreational destination, some even argue that the environmental and economic damages caused to the valley are insurmountable.

More importantly, asymmetric bargaining ability and market power had substantial effects on the negotiations between the city and valley landowners. The position of the city as the only large-scale buyer of agricultural land created monopsony power for the city in negotiations with landowners. Landowners attempted to counteract the buyer market power by organizing into pools and selling through these collusive arrangements. One would expect landowners who organized into pools (collective entities) to receive higher prices as a result of the increased bargaining power through the group arrangements. Libecap (2006.) finds that farmers in pools did receive higher prices from the city in the *land market.* However, when converting the land prices to a price per unit of water, Libecap finds no evidence that being in a pool leads to higher prices in the *water market.* Nonetheless, the city being a sole buyer and the attempted collusion by the sellers in the valley made bilateral monopoly a significant component of negotiations between the two parties.

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[2] LADWP website. http://www.ladwp.com/ladwp/cms/ladwp004409.jsp. Accessed 5/29/06.

2.3.2 PVID-MWD Land Fallowing Agreement

Similar to the rapid development in the city of Los Angeles during the early part of the 20th century, the last twenty years have been characterized by large population growth in the suburban communities surrounding Los Angeles. Many of these communities are indirectly reliant upon the Metropolitan Water District (MWD) for their water supplies. MWD is an upstream wholesaler of water to various local municipal providers throughout Southern California. MWD is and will likely to continue to be a major player in Southern California water transfers.

Increasing urban demands and declining profitability of irrigated agriculture instigated negotiations for a land fallowing agreement and transfer between MWD and the Palo Verde Irrigation District in 1986. The Palo Verde Irrigation District (PVID) provides Colorado River Water to farmers in the area of Blythe, which is a small community of approximately 30,000 in the Southeastern part of California. Due to conflicting demands regarding price escalation, the initial negotiations stalled (Haddad, 2000.). Negotiations were resumed in the early 1990's and an agreement was eventually reached in 1992. The test land fallowing agreement involved voluntary participation on the part of farmers. Participating farmers agreed to fallow a portion of land in exchange for a fixed one time payment and an additional annual per-acre fee.

The final contract (signed in 2004) is a 35 year land fallowing agreement. PVID farmers participate voluntarily in exchange for a two part payment from MWD. The first part is a one time sign up fee of $3,170 per fallowed acre. The first part of the payment is given to the farmer once they agree to participate in the program. The second part is an annual payment per acre fallowed of $602. The annual payment is made as long as the land remains in the program. Not surprisingly, the contract includes a maximum acreage fallowed in the entire district in any contract year. The maximum annual fallowed acreage is 26,500. The program is controversial as it explicitly uses land fallowing as a mechanism to conserve water and transfer to municipal users.

The agreement between PVID and MWD was negotiated in a bilateral monopoly setting. The heterogenous farmers of PVID were represented in negotiations by the district. The bargaining process thus involved two parties bargaining over the terms of a contract for land fallowing and water transfer. The initial negotiations experienced breakdown, which is common in bilateral monopoly agreements. While the terms of the PVID and MWD contract are clearly more complicated than a simple price-quantity deal, the bargaining over contract terms represents an example of bilateral negotiations for water.

2.3.3 2003 Water Transfer Agreement between IID and SDCWA

The water transfer agreement between the Imperial Irrigation District (IID) and San Diego County Water Authority (SDCWA) is one of the largest and most dynamic transfer contracts ever signed. The agreement was signed in October of 2003 as part of the larger Quantification Settlement Agreement (QSA) between IID, MWD, SDCWA, and Coachella Valley Water District (CVWD). The QSA aims to reduce California's Colorado River water use such that the state will no longer exceed its annual allotment of 4.4 million AF (SDCWA, 2005a). Another stated goal of the QSA is to allow for environmental restoration of the Salton Sea of Southeastern California (SDCWA, 2005b).

The specific agreement involves the transfer of irrigation water. The water is to be conserved through improvements in the efficiency of the agricultural irrigation system. The contract regards land fallowing as an acceptable conservation mechanism for only the initial periods of the contract. The length of the current agreement is 75 years. The price and quantity of water to be transferred were negotiated to follow dynamic schedules. The quantity began at 30,000 AF in 2004 and is scheduled to increase following a set schedule until reaching the maximum annual quantity of 200,000 AF. The price schedule increases over time from an initial price of $250 per AF. Both parties, however, have the opportunity to alter the price schedule according to pre-negotiated formulas after the fifth year of the contract(SDCWA, 2005a).[3]

The negotiations for the QSA involved complicated noncooperative interactions between the various stakeholders. One difference between the previous agreements

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[3] The QSA and water transfer agreement have additional details which may be of interest to some readers. Copies of the actual contracts can be viewed at http://www.iid.com/water/transfer.html (accessed 6/01/06).

and the QSA is that it was negotiated multilaterally rather than bilaterally. Multilateral negotiations have even more potential for strategic behavior and breakdowns than bilateral negotiations. Actual QSA negotiations broke down several times over the multi-year negotiating process. Eventually, signing of the agreement was facilitated by a threat from the Department of the Interior to reduce the Colorado River allotment of IID if no agreement could be reached. The federal intervention shows that other Colorado River states had interests in California reducing its dependence on Colorado River water.

2.4 Summary

The three past transfers in Southern California were discussed to demonstrate the possibilities of unequal bargaining power, imperfect competition, and strategic behavior having effects on the outcomes of water transfers. The three chosen examples have also demonstrated the complexity of many large-scale water transfer agreements. The bargaining models presented in the following chapter will abstract away from some of these details in order to present a clear framework for the determination of transfer price and quantity when contracts are negotiated bilaterally. While these transfers all happened to be in the same region, one should note that many smaller-scale transfers between agricultural and urban users have been negotiated in other western states. These negotiations have taken place in relatively thin markets. Thus, the three historic transfers in California and other transfers affected by bilateral oligopoly are best modeled using game theoretic models of bargaining. The upcoming two chapters focus on developing bargaining models for water transfers and empirically testing the implications of the models.

CHAPTER 3

BARGAINING MODELS

Game theoretic models for water transfers are surprisingly rare in the literature. Since transfers are frequently negotiated between concentrated parties, the absence of game theoretic models for transfers begs questions about the generation of empirically testable predictions. In order to generate testable predictions on the impacts of market power on negotiations, this chapter develops some simple bargaining models for water transactions. Models in this chapter also have some other implications which provide interesting avenues for future empirical work. I start by briefly reviewing the bargaining literature and then describing the variables and parameters. The simple models are then set up and solved. The chapter concludes by summarizing the empirically testable predictions.

The theoretical literature on bargaining between two parties over the division of a given surplus is well developed. The seminal work of Nash (1950; 1953) represents the first approach to modeling bargaining. Nash introduced a static solution to the bargaining problem where a unique solution is obtained based on a set of desirable axioms. The only setback of this cooperative solution is that the potential dynamics of the bargaining problem are ignored. Nash's bargaining game does not explicitly model the process of offers and counteroffers. This drawback has not inhibited the

Nash solution from being common in the theoretical economics literature. Nash bargaining models are not only simple to implement, but they guarantee a unique solution to the bargaining problem that is satisfactory to relevant axioms. Thus, the Nash bargaining solution has been widely used. The wide variety of applications of the Nash solution include bargaining between employers and employees over wage contracts (McDonald and Solow, 1981), bargaining between members of a household (Manser and Brown, 1980), and bargaining over horizontal integration between competing firms in the hog industry (Just et al., 2005).

Noncooperative games model the bargaining process as a dynamic game of offers and counteroffers. Rubinstein (1982) first modeled the bargaining game as a sequential process between two players. Noncooperative models cover extensively the impacts of time preference and impatience on the bargaining outcome. Noncooperative models are sometimes found more desirable because of their description of the bargaining game as a game of offers and counteroffers. In general, noncooperative games are far more difficult to implement than cooperative games.

Binmore, Rubenstein, and Wolinsky (1986) provide useful insights regarding the similarities between Nash's axiomatic solution and Rubinstein's noncooperative solution. First, if the lengths of the bargaining periods are small, then the Nash solution approximates the dynamic non-cooperative solution. Second, when the probability that negotiations will fail is made negligible, the two solutions also converge. Under these circumstances the Nash solution can be used to sufficiently describe noncooperative negotiations between players.

It is now apparent that there are two different frameworks which can be used in order to model bargaining between irrigation districts and municipal providers over contract terms for a water transfer. There are undoubtedly some elements of dynamics and delay costs for water transfers. In cases where drought conditions are extreme, the costs of delaying an agreement can be quite high for municipal providers. This would suggest implementation of Rubinstein's alternating offers model. However, there is evidence that the solutions of cooperative models can converge to those of noncooperative models under certain circumstances. The theoretical models of this chapter will rely on mostly cooperative game theory. By doing so, I am able to derive simple comparative static results that can be easily taken to the available data.

3.1 The Basic Setup

I consider a single irrigation district(hereinafter 'the district') that negotiates over price and quantity with a single municipal provider(hereinafter 'the provider').[1] The district is assumed to have an exogenously determined right to divert $\bar{X}$ acre-feet of water in a given time period.[2] The district chooses between selling x acre-feet to the

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[1] As was stated earlier, the empirical models rely on data for both agricultural-urban and agricultural-agricultural transactions. Therefore, the buyer need not always be a municipality. Nonetheless, the buyer will be referred to as such. The structure of the payoff function in the models will be sufficiently general such that it describes any type of buyer with a quadratic benefit function for purchased water.

[2] Quantity rationing is the common water allocation mechanism in United States agriculture (Moore and Dinar, 1995). For instance, the Imperial Irrigation District holds the right to divert

provider and applying $\bar{X} - x$ to crops. The price of agricultural output is denoted by P. The irrigation efficiency, or the share of applied water absorbed by crops is denoted as h, where $h \in (0, 1)$. Let c be the constant per-unit water application cost.[3] Agricultural production is characterized by a joint production function $f(e)$, where $e = h(\bar{X} - x)$. The term e is the effective water absorbed by crops. The function satisfies the standard requirements such that $f_e > 0$ and $f_{ee} < 0$, where subscripts denote partial derivatives.

The profits of the irrigation district when an agreement is reached are

$$\pi = Pf(h(\bar{X} - x)) + wx - c(\bar{X} - x). \tag{3.1}$$

When no agreement is reached the district uses $\bar{X}$ acre-feet and obtains profits of π_d, which are

$$\pi_d = Pf(h\bar{X}) - c\bar{X}. \tag{3.2}$$

Combining (3.1) and (3.2) and simplifying, the gains from trade of the district are

$$\pi - \pi_d = Pf(h(\bar{X} - x)) - Pf(h\bar{X}) + wx + cx. \tag{3.3}$$

Equation (3.3) indicates that the gains from trade are decreasing in agricultural

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3.1 million acre-feet each year from the Colorado River.

[3] Users of surface water are likely to experience constant marginal application costs. However, groundwater users are more likely to have increasing cost functions due to increased energy costs of pumping at lower well depths. The model could be easily extended to groundwater with the addition of such a cost function.

prices and increasing in transfer price. The last term in (3.3) is the benefit from foregoing application costs on each unit of water that is sold to the municipal provider. The district clearly stands to gain more from trading when the costs of agricultural water use are larger.

The provider is considered to be a regulated utility with an objective to maximize consumer surplus subject to a break-even constraint. The final inverse demand curve faced by the utility is assumed to be linear of the form $P(x) = \alpha - \beta x$. The final demand is a residual demand where $P(x)$ is the segment of total demand in excess of current capacity. The marginal value of the first unit of water purchased by the utility is then represented by α. The regulatory constraint requires the revenue from sales to urban consumers to be equal to the cost of the transfer.[4] The exogenous disagreement payoff of the buyer is described as V_d, where V_d is an increasing function of the number of other potential sellers in the market. In other words, the buyer stands to gain more from stalling the present negotiations when supply side competition is more fierce. It is worth noting that V_d includes more than just the number of other potential *agricultural* sellers in the market. When disagreement occurs, municipal users could rely on other user types as sources for transfers. The provider could rely on effluent reuse, urban conservation, or additional supply contracts could be pursued from state or federal agencies.[5] The

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[4] Alternatively, the municipal provider could be allowed a rate of return on capital and operating expenses. These expenses could result from the costs of treating water to make it suitable for municipal uses. The final price would then be the transfer price plus the allowable rate of return. The structure of the bargaining solution would be unaffected, so the simpler case is maintained.

[5] This is also the case with the irrigation district. The district may have options other than allo-

downstream objective function is thus,

$$V - V_d = \alpha x - \frac{1}{2}\beta x^2 - wx - V_d. \tag{3.4}$$

Clearly, the payoff to the downstream utility is increasing in α and decreasing in w, β, and V_d.

3.2 Integrated Outcome

As a basis for comparison, it is useful to first characterize the vertically integrated solution where the district and provider are one entity. Under this scenario, the relevant decision is the choice of x that optimizes the sum of profits from agricultural and municipal uses. Formally, the vertically integrated entity chooses x according to the optimization problem,

$$\max_x Pf(h(\bar{X} - x)) - c(\bar{X} - x) + \alpha x - \frac{1}{2}\beta x^2. \tag{3.5}$$

The first order condition yields,

$$x_{VI} = \frac{\alpha - hPf_e + c}{\beta}. \tag{3.6}$$

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cating the entire endowment to agriculture when no water is sold to the provider. The bargaining model could be altered to include other types of disagreement payoffs of both buyers and sellers.

The expression for the quantity to be allocated to municipal uses under vertical integration, x_{VI}, is not a closed form expression. A particular functional form for the agricultural production function would need to be assumed in order to express x_{VI} in closed form.

In reality, it is rare for a district and provider to be an integrated entity. The integrated outcome is nonetheless important because it achieves the first-best quantity that maximizes the value of the resource between the two competing uses. The expression in (3.6) thus represents the pareto optimal quantity to be allocated to municipal uses. It is important to start with this quantity as a basis of comparison for the quantities negotiated under different bargaining games.

3.3 Sequential Game

The relationship between the district and provider is somewhat similar to the relationship between an upstream manufacturer and a downstream retailer. The district acts as a monopoly supplier of water to the downstream provider. The provider then passes along the purchased water to urban customers, which can be thought of as final consumers. The textbook double marginalization phenomenon occurs in this context when the downstream provider is also a monopoly in the market for municipal water. However, public water utilities are often regulated and thus unable to enjoy monopoly markups. Since the objective of the provider is to maximize consumer surplus rather than monopoly profits, double marginalization does not occur because the provider is unable to charge a price above w to urban customers. All of the potential rents of the provider from the transaction are eliminated by regulation.

I consider a simple two-stage game where in the first stage the district determines the transfer price to charge to the provider. Given the actions of the district in the first stage, the provider determines how much water to purchase in the second stage. The regulatory constraint requires that the transfer price be equal to the price charged by the provider to urban customers. As usual, the game is solved for a Nash equilibrium by backwards induction.

In the second stage, the provider chooses the optimal x for the given w chosen by the district in the first stage. This amounts to maximizing (3.4) with respect to x. Doing so results in $x = (\alpha - w)/\beta$. Returning to the first stage, the district maximizes profits by choosing the optimal w when taking into account the anticipated second stage actions of the provider. This results to maximizing (3.3) with respect to w, of course when accounting for the second stage quantity choice of the provider. Or more formally, the first stage choice of the district is to

$$\max_{w} Pf\left(h\left(\bar{X} - \frac{\alpha}{\beta} + \frac{w}{\beta}\right)\right) - c\left(\bar{X} - \frac{\alpha}{\beta} + \frac{w}{\beta}\right) + w\left(\frac{\alpha}{\beta} - \frac{w}{\beta}\right). \tag{3.7}$$

The first order condition is

$$\frac{\partial \pi}{\partial w} = \frac{hPf_e - c - 2w + \alpha}{\beta} = 0. \tag{3.8}$$

The transfer price for the sequential game, w_s, is then

$$w_s = \frac{\alpha + hPf_e - c}{2} \tag{3.9}$$

and the quantity is

$$x_s = \frac{\alpha - hPf_e + c}{2\beta}. \tag{3.10}$$

The sequential game results in a quantity that is less than the first-best efficient quantity. Giving the district price setting power in the first stage allows a high price to be set initially. The higher price in the first stage causes the provider to reduce the quantity purchased in the second stage. The distortion away from the first-best efficient quantity would be further amplified if the provider were allowed to act as a monopoly in the market for water. Forcing the provider to be regulated causes the sequential game to essentially reduce to the standard monopoly solution. One could also consider a sequential game where the first stage involves price setting by the provider and the second stage involves a quantity choice by the district. The solution of this game would be the standard monopsony solution. However, solving by backwards induction would require a particular functional form for the production function of the district. I therefore do not formally solve for the monopsony outcome.

The outcome of a bargaining game is expected to be somewhere in between the outcomes of the two sequential games. Bilateral monopoly models often involve determinate quantities with prices determined by the relative bargaining power of the two players (Stuart, 1979; Blair et al., 1989). The sequential games explicitly give a first mover advantage to one of the parties. For water transfers it is not clear whether this advantage is owned by either districts or providers. For some transfers a greater share of bargaining power might be enjoyed by districts. Providers might possess the bargaining advantage for certain other transfers. Up until now the differences in bargaining power between the two players have not been addressed. An asymmetric Nash bargaining model allows me to explicitly parameterize the players' bargaining powers.

3.4 Nash Bargaining Model

I use the asymmetric Nash bargaining solution where the payoff of each party is weighted by their bargaining power parameter. Let γ be the bargaining power of the district and $1-\gamma$ the bargaining power of the provider. As usual, the district and provider bargain over price and quantity. The symmetric Nash Bargaining solution requires the maximization of the product of the two parties gains from trade. The asymmetric solution weights the payoff of each player by their bargaining power parameter. Hence, the asymmetric Nash product is written as

$$N = (\pi - \pi_d)^{\gamma}(V - V_d)^{1-\gamma}. \tag{3.11}$$

After substituting from (3.3) and (3.4) the bargaining problem becomes

$$\max_{w,x} \left(Pf(h(\bar{X}-x)) - Pf(h\bar{X}) + wx + cx\right)^{\gamma} \left(\alpha x - \frac{1}{2}\beta x^2 - wx - V_d\right)^{1-\gamma}. \tag{3.12}$$

When assuming a strictly interior solution with positive gains from trade for both parties the first order conditions yield,

$$x_N = \frac{\alpha - hPf_e + c}{\beta} \tag{3.13}$$

and

$$w_N = \gamma\left(\alpha - \frac{1}{2}\beta x - \frac{V_d}{x}\right) + (1-\gamma)\left(\frac{Pf(h\bar{X}) - Pf(h(\bar{X}-x)) - cx}{x}\right). \tag{3.14}$$

The derivations of (3.13) and (3.14) are given in Appendix A.

The quantity resulting from Nash bargaining is identical to the integrated quantity in (3.6). Pareto efficiency is a requirement imposed by cooperative bargaining games (Osborne and Rubenstein, 1990.). Therefore, the quantity is such that no change can increase the gains from trade of both players. The cooperative bargaining model does not induce any deviation in quantity away from the first-best quantity from the joint welfare-maximization problem. The sharing of gains from trade must then be determined by the outcome of price negotiations.

The optimal price in (3.14) is a weighted function of the maximum and minimum feasible prices for the provider and district, respectively. The maximum feasible price for the provider is obtained by setting their payoff function equal to zero and solving for price, thus leaving the first term in (3.14). The same algebraic procedure yields the minimum feasible price for the district, the second term in the equation. The price is weighted by the relative bargaining powers of the players. As the bargaining power of the municipal provider approaches zero($\gamma \rightarrow 1$), the price converges to the maximum feasible price. Conversely, when the bargaining power of the irrigation district approaches zero($\gamma \rightarrow 0$) the price converges to the minimum feasible price. When the parties have equal bargaining power ($\gamma = 1/2$) the price is the mean of maximum willingness to pay and minimum willingness to accept.

The results of the Nash bargaining game are somewhat standard to bilateral monopoly problems. The quantity traded is independent of bargaining power and price. The optimal quantity is the first-best quantity that arises from the maximization of joint gains from trade. The optimal quantity traces out the set of pareto efficient quantities along the contract curve. However, since the provider is a regulated utility whose objective is to maximize consumer surplus of its customers, the quantity in the Nash game is twice as large is it would be if the provider held monopoly power in the downstream market. The Nash quantity is therefore identical to the quantity traded in the competitive model. The price is however determined by the relative bargaining powers of the buyer and seller. The price thus determines the distribution of gains from trade. These results are common in studies of bilateral monopoly (Blair et al., 1989; Stuart, 1979).

3.5 Comparative Statics of Nash Solution

The quantity under Nash bargaining in 3.13 can be differentiated implicitly in order to analyze the effects of exogenous parameter changes on the quantity of water traded. Differentiating implicitly and solving for $\frac{\partial x^*}{\partial(\cdot)}$ generates some testable implications which will be outlined at the end of the current chapter.

The comparative statics on the quantity traded are given in Table 3.5. Many of the results are intuitive. As the residual demand curve shifts outward (α increases) more is traded. As the residual demand pivots outward (β decreases) more is traded. Increasing costs of applying water to agriculture, which could arise from increasing pumping costs or increasing electricity costs, results in greater quantities traded. Also, larger districts with greater endowments (larger $\bar{X}$) are expected to sell more.

Table 3.1: Comparative Statics of Quantity under Nash Bargaining

Parameter	$\frac{\partial x^*}{\partial(\cdot)}$	Sign
α	$\frac{1}{\beta - h^2 P f_{ee}}$	+
c	$\frac{1}{\beta - h^2 P f_{ee}}$	+
β	$\frac{hPf_e - \alpha - c}{\beta(\beta - h^2 P f_{ee})}$	-
$\bar{X}$	$\frac{-h^2 P f_{ee}}{\beta - h^2 P f_{ee}}$	+
P	$\frac{-hf_e}{\beta - h^2 P f_{ee}}$	-
h	$\frac{-Pf_e(1+EMP)}{\beta - h^2 P f_{ee}}$	A
γ	0	0

The effect of agricultural prices on quantity is unambiguous. As one would expect, the quantity transferred decreases with agricultural prices. High agricultural prices make irrigated agriculture more profitable and transfers to alternate uses less desirable. Farm support programs which directly support agricultural prices therefore have the effect of discouraging transfers to municipal uses. State and federal agencies have taken numerous steps to promote agricultural to urban transfers as mechanisms to deal with increasing urban demands. Coupled farm support programs are direct barriers to water transfers out of agriculture.

State and federal agencies have also looked at increases in agricultural irrigation efficiency as a way to conserve water in order to transfer to alternate uses. It has been shown that irrigation technology subsidies may have the countervailing effect of increasing applied water use (Huffaker and Whittlesey, 2000, 2003). Earlier work by Caswell and Zilberman (1986) indicates that improvements in irrigation efficiency only conserve water for certain magnitudes of the elasticity of the marginal product with respect to effective water use (EMP). The EMP is defined as,

$$EMP = f_{ee}\frac{e}{f_e}. \tag{3.15}$$

More specifically, when the absolute value of the EMP is greater than unity($EMP < -1$), increases in efficiency conserve water. The reverse is true when the marginal product is inelastic ($EMP > -1$). The results of the Nash bargaining model tend to solidify the results of Caswell and Zilberman. The entry in Table 3.5 indicates that increasing irrigation efficiency only leads to increases in quantities transferred to municipal uses when $EMP < -1$. Caswell and Zilberman point out that the EMP is likely to be smaller (in absolute value) when land quality is poor and wells are deeper. While a full discussion is beyond the scope of this thesis, federal programs which are designed to subsidize improvements in irrigation efficiency in hopes of encouraging transfers to alternate uses may only have their desired effects under certain circumstances.

The effect of drought on quantity is seen through changes in both α and $\bar{X}$. On the one hand, drought causes municipal water needs to increase, therefore leading to an increase in α. Water availability to agricultural irrigation districts is decreased during drought. This decrease in $\bar{X}$, when combined with the increase in α, indicates that drought has a potentially ambiguous effect on quantity. I further examine this issue in the upcoming empirical models.

Similar comparative statics can be derived for the transfer price. A straightforward way to derive the comparative statics of price is to differentiate (3.14) while taking note that x is a function of the exogenous parameters in a bargaining equilibrium. Table 3.2 contains the comparative statics obtained from this method. The signs of the comparative static derivatives are mostly ambiguous. Some ambiguities result from competing effects on profits under both trading and not trading. For instance, agricultural prices affect the district payoff under both agreements and disagreements. The main sources of ambiguities are the differing magnitudes

Table 3.2: Comparative Statics of Price under Nash Bargaining

Parameter	$\frac{\partial w^*}{\partial(\cdot)}$	Sign
α	$\gamma(1 - \frac{\beta}{2}\frac{\partial x^*}{\partial \alpha} + V_d x^{-2}\frac{\partial x^*}{\partial \alpha}) + (1-\gamma)\left[\frac{hPf_e - c - W_u}{x^*}\frac{\partial x^*}{\partial \alpha}\right]$	A
c	$\gamma(\frac{-\beta}{2}\frac{\partial x^*}{\partial c} + V_d x^{-2}\frac{\partial x^*}{\partial c}) + (1-\gamma)\left[\frac{x^* hPf_e - Pf(h\bar{X}) + Pf(h(\bar{X}-x))}{x^{*2}}\frac{\partial x^*}{\partial c} - 1\right]$	A
β	$\gamma\left[\frac{-x^*}{2} - \frac{\beta}{2}\frac{\partial x^*}{\partial \beta} + V_d x^{-2}\frac{\partial x^*}{\partial \beta}\right] + (1-\gamma)\left[\frac{hPf_e - c - W_u}{x^*}\frac{\partial x^*}{\partial \beta}\right]$	A
$\bar{X}$	$\gamma(\frac{-\beta}{2}\frac{\partial x^*}{\partial \bar{X}} + V_d x^{-2}\frac{\partial x^*}{\partial \bar{X}}) + (1-\gamma)\left[\frac{hPf_e - c - W_u}{x^*}\frac{\partial x^*}{\partial \bar{X}} + \frac{hP(f_{h\bar{X}} - f_e)}{x^*}\right]$	A
P	$\gamma(\frac{-\beta}{2}\frac{\partial x^*}{\partial P} + V_d x^{-2}\frac{\partial x^*}{\partial P}) + (1-\gamma)\left[\frac{hPf_e - c - W_u}{x^*}\frac{\partial x^*}{\partial P} + \frac{f(h\bar{X}) - f(e)}{x^*}\right]$	A
h	$\gamma(\frac{-\beta}{2}\frac{\partial x^*}{\partial h} + V_d x^{-2}\frac{\partial x^*}{\partial h}) + (1-\gamma)\left[\frac{hPf_e - c - W_u}{x^*}\frac{\partial x^*}{\partial h} + \frac{P(\bar{X}f_{h\bar{X}} - (\bar{X}-x)f_e)}{x^*}\right]$	A
γ	$WTP_{max} - WTA_{min}$	+
V_d	$\frac{-1}{x^*}$	-

Notes: W_u is shorthand for WTA_{min}

and directions of the changes in the disagreement prices with respect to changes in parameters. Finally, asymmetries in bargaining ability contribute to ambiguities. The comparative static derivatives are linear combinations of the relative bargaining power of the players. As either player gains a stronger bargaining advantage, some results are predicted to move in their favor. For example, as the bargaining power of the district approaches unity and the disagreement payoff of the provider goes to zero, $\frac{\partial w^*}{\partial P}$ approaches a positive value.

The only definite signs in the table are for the effects of changes in the relative bargaining power of the players and the market power of the sellers. The positive sign on $\frac{\partial w^*}{\partial \gamma}$ indicates that an increase in the bargaining power of the district(decrease in that of the provider) has the ceteris paribus effect of increasing price. The result is generally not surprising, but has implications for agricultural to urban water transfers. Many transfers occur in environments with asymmetric bargaining power. The effect is to cause prices to diverge from those that would be observed in perfectly competitive markets. The complicated nature of water transfer contracts and the substantial number of legal requirements to be satisfied make negotiating experience and ability important assets at the bargaining table. Bargaining power can also be measured by the time it takes a player to evaluate and react to offers by the other player (Binmore et al., 1986).

The theoretical price effects of supply side market power are as expected. As the number of outside purchasing options of the buyer decreases (V_d decreases), the seller in the transaction possesses a greater share of the market and enjoys an increase in market power. Since the sign of $\frac{\partial w^*}{\partial V_d}$ is negative, prices are expected to increase. The result is not surprising. The important note is that market power and asymmetric bargaining ability have only price effects when contracts are negotiated cooperatively. Quantity effects are also present in noncooperative games. The price effects allow the player with the bargaining advantage to capture a greater share of the gains from trading the resource.

3.6 The Effects of Uncertainty

Up until now I have made two simplifying assumptions regarding the certainty of both agricultural water endowments and urban demand for additional water. It has been assumed that both are non-stochastic. It seems plausible to consider negotiated agreements where either or both are uncertain. In many cases water rights of irrigation districts are quantifiable only up to a share of annual available supply. The endowment of a district is therefore a random variable that depends on annual climate. The demand for water by urban municipalities is often also random and dependent upon climate. Under these circumstances there may be incentives for a provider to seek out contingency contracts where transfers are only executed when the provider is in need of the negotiated quantity of water. I now turn to models which incorporate these aspects of uncertainty. Unfortunately, the empirical implications of the uncertainty models are not tested in the following chapter. Therefore, readers interested solely in the link between the theoretical and empirical models may wish to skip to the testable implications.

3.6.1 Demand Side

I consider a specific type of uncertainty where the intercept of the urban residual demand curve is random. The urban demand curve shifts inwards or outwards with variations in the quantity of water available to the provider. I assume that α is distributed uniformly on the support $[\underline{\alpha}, \bar{\alpha}]$. Assuming risk neutral players who bargain on price and quantity and obtain an interior solution with strictly positive values of both, I obtain the familiar solutions,

$$x_0 = \frac{E\alpha - hPf_e + c}{\beta} \tag{3.16}$$

and

$$w_0 = \gamma\left(E\alpha - \frac{1}{2}\beta x - \frac{V_d}{x}\right) + (1-\gamma)\left(\frac{Pf(h\bar{X}) - Pf(h(\bar{X}-x)) - cx}{x}\right), \tag{3.17}$$

where E is the expected value operator and thus $E\alpha = \frac{\bar{\alpha}+\underline{\alpha}}{2}$.

The only substantial difference between (3.16) and (3.13) is the addition of the expected value of the residual demand intercept. The district and provider now bargain on the efficient quantity, taking into account expectations about α. The price equation (3.17) under uncertainty is also similar to (3.14), with the only change being the replacement of α with $E\alpha$. Given the previous comparative statics it is intuitive and fairly easy to show that as the distribution of α shifts to the right($\underline{\alpha}$ increases, $\bar{\alpha}$ increases, or both), the quantity transferred increases.

A slightly more complicated type of uncertainty includes the possibility of drought and the potential emergence of contingency contracts. Contingency contracts are often referred to as dry-year option contracts(DYOC). Many municipal providers are turning to DYOCs in order to minimize the probability of being left with purchased water that is not needed and must be stored or leased out to other entities (Michelsen and Young, 1993). Notable DYOCs have been agreed upon in Southern California, Oregon, and the Edwards Aquifer region of Texas. Consider a provider that is only in need of additional water during drought. In the previous case, if $\underline{\alpha} < 0$ then a realization of an α to the left of zero would be a case where water is not needed by the municipality. The likelihood of this event is given by $P\{\alpha < 0\} = \frac{-\underline{\alpha}}{\bar{\alpha}-\underline{\alpha}}$. Conversely, let θ be the probability of drought. Thus,

$$\theta = \frac{\bar{\alpha}}{\bar{\alpha} - \underline{\alpha}}. \tag{3.18}$$

I consider a contingency contract where the predetermined quantity is only transferred when a nonnegative α is realized ex-post. The contract is however negotiated ex-ante, thus the provider must still account for some uncertainty regarding the actual value of α. The expected payoff to the provider is then,

$$V = \theta(E(\alpha x|\alpha > 0) - \frac{1}{2}\beta x^2 - wx - V_d). \tag{3.19}$$

The payoff to the district consists of two parts. When there is agreement the district expects a payoff of,

$$\theta[Pf(h(\bar{X} - x)) - c(\bar{X} - x) + wx] + (1 - \theta)[Pf(h\bar{X}) - c\bar{X}]. \tag{3.20}$$

When no agreement is reached, the district uses the entire endowment in agriculture without uncertainty. The disagreement payoff of the district is thus $Pf(h\bar{X}) - c\bar{X}$. Summing the two terms gives the objective of the district,

$$\pi - \pi^d = \theta[Pf(h(\bar{X} - x)) - Pf(h\bar{X}) + cx + wx]. \tag{3.21}$$

Since θ is merely a constant in the maximization problem, the results of Nash bargaining are identical to those of (3.16) and (3.17), with just a minor change. The term $E\alpha$ must be replaced with the conditional expectation $E(\alpha|\alpha > 0) = \frac{\bar{\alpha}}{2}$. It is clear that the contingency contract results in an increase in the quantity of water transferred (relative to the standard contract with a random α) when there is a positive probability of there being no need for additional water by the provider($\underline{\alpha} < 0$). The contingency contract allows the provider to eliminate the risk of paying for unneeded water. The price effects of introducing contingency contracts are theoretically ambiguous and thus leave a potentially interesting empirical question. One might expect providers to pay a price premium for the opportunity to eliminate the risk of being stuck with an unneeded supply of water.[6]

3.6.2 Supply Side

An additional type of uncertainty affecting water transfers is the possibility that the endowment of the district is random. Water is allocated by the prior appropriation

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[6] Two part pricing is common in many option contracts. Buyers often pay a fixed fee and a marginal fee when the contract is exercised. I have not modeled this type of pricing structure.

doctrine in most parts of the Western U.S. The doctrine allocates water to users based on seniority. For the most junior appropriators there is uncertainty regarding whether their endowments will be fulfilled in years with limited supplies. Under this allocation mechanism information on the seniority of the right being transferred would be expected to have effects on contract outcomes.

I model supply side uncertainty in a similar fashion as demand side uncertainty. Let ϕ represent a random variable with a negatively skewed distribution on the unit interval, $[0,1]$. The density function is represented as $g(\phi)$. Negative skewness allows most of the mass of the distribution to be nearer to 1. Thus, in most years the district would obtain their full endowment. As previously, the players expect to realize $E\phi$, where $E\phi = \int_0^1 \phi g(\phi) d\phi$. Districts with senior rights would have values of $E\phi$ close to unity. Districts with junior rights would have values of $E\phi$ less than those with senior rights.

The expected gains from trade of the district with an uncertain endowment are

$$\pi - \pi_d = Pf(h(E\phi\bar{X} - x)) + wx + cx - Pf(hE\phi\bar{X}). \tag{3.22}$$

The results of the asymmetric Nash bargaining game are again of the same form as (3.16) and (3.17). The differences are that for supply side uncertainty $e = h(E\phi\bar{X} - x)$ and that district revenues under disagreement are $Pf(hE\phi\bar{X})$. Totally differentiating the quantity expression with respect to $E\phi$ and rearranging results in

$$\frac{\partial x^*}{\partial E\phi} = \frac{-h^2 P\bar{X} f_{ee}}{\beta - h^2 P f_{ee}} > 0. \tag{3.23}$$

The result is fairly intuitive. Districts with junior rights (lower $E\phi$) are expected to sell less water than districts with senior rights. Seniority allows districts to feel fairly comfortable in the quantity of water that will be available to them in a given year.

The surprising result is that I am unable to unambiguously determine the direction of the effect of seniority on negotiated prices. One would generally expect municipalities to pay a price premium for added insurance that the negotiated quantity can be delivered. Or, it is possible that the effects of rights seniority are totally manifested in the bargaining game through increasing quantities. The effect of rights seniority on transfer prices is an interesting avenue for future empirical research.

3.7 Testable Implications

This chapter has presented various bargaining models for water transfers. Many of the comparative static results serve as empirically testable predictions. These predictions are summarized as follows:

PREDICTION 1: More water will be transferred when urban populations grow ($\partial x^*/\partial \alpha > 0$).

PREDICTION 2: The quantity transferred decreases with the value of agricultural production ($\partial x^*/\partial P < 0$).

PREDICTION 3: Negotiated prices will be higher in regions where the disagreement payoff of buyers is smaller ($\partial w^*/\partial V_d < 0$).

PREDICTION 4: The effect of increasing irrigation efficiency on the quantity transferred is ambiguous ($\partial x^*/\partial h \ ? \ 0$).

PREDICTION 5: As the endowment of the seller becomes more certain ($E\phi \rightarrow 1$), more water will be transferred ($\partial x^*/\partial E\phi > 0$).

The remainder of the thesis uses two different approaches to test the first three predictions. My data does not allow for testing of predictions four and five. Obtaining micro-level data on irrigation efficiency and rights seniority would provide nice empirical complements to the tests of the other three predictions.

CHAPTER 4

EMPIRICAL APPLICATIONS

4.1 Links with Past Work

Previous empirical work on contracts for water transfers has addressed a number of issues, none of which include the effects of market power on outcomes of negotiations. The theoretical price effect of seniority in the bargaining model was shown to be ambiguous. Colby, Crandall, and Bush (1993) find that rights with earlier priority dates (senior rights) fetch a price premium when compared to junior rights. While the authors do not test the quantity effects of seniority, the theoretical results predict seniority to have a positive effect on quantities transferred (PREDICTION 5).

Brookshire et al. (2004) use instrumental variables techniques to estimate prices and quantities for transfers in New Mexico, Arizona, and Colorado. Consistent with my theoretical prediction, the authors find that quantities tend to be smaller in regions with highly valued agriculture (PREDICTION 2). The specific measure of the value of agricultural productivity in the region of the transaction is not explained. Nonetheless, the result is intuitively appealing and conforms to theoretical predictions.

Another recent study by Bjornlund and Rossini (2005) analyzes variation in both prices and quantities for transactions in Australia from 1993-2003. A finding relating to this thesis is the observed positive association between transfer prices and prices of agricultural commodities. While I was unable to determine the theoretical direction of the effect for the cooperative bargaining model, it was hypothesized that transfer prices would increase with agricultural commodity prices (PREDICTION 2). The results of Bjornlund and Rossini support this prediction.

My empirical focus is on the effects of upstream market power on price negotiations for water transfers (PREDICTION 3). Measuring the effects of structure on market outcomes has always been a major focus of the empirical industrial organization literature. Early Structure-Conduct-Performance (SCP) models set out to identify cross-sectional relationships between market concentration and measures of market performance, such as industry profits or price-cost margins (Bain, 1951; Weiss, 1974.; Schmalensee, 1989.). The function of SCP models is to determine the magnitude of the effect of supply-side concentration on variables measuring market performance, such as prices, margins, or profits. The common criticism against SCP models is the endogeneity of the explanatory variables used to measure market concentration. Entry/exit decisions by firms are determined by margins. Thus, empirical models which attempt to explain variation in market performance as a function of concentration suffer from simultaneity bias. The obvious corrective procedure would be to use instrumental variables methods to account for the endogeneity of market structure. However, an absence of sufficient instruments has made it difficult to obtain statistically robust results using simple econometric methods (Schmalensee, 1989.).

In some ways, my empirical methods follow the traditional SCP approach. Using data on transactions in several western states, I construct two measures of seller market power. I use both the number of irrigated farms in the county of the seller and the average acreage per irrigated farm. Upstream market power is greatest in areas with fewer and larger irrigated farms. It is in these areas that the outside options of buyers negotiating with more powerful farmers and irrigation districts are fewer. In terms of the formal model, V_d is lower in such areas. The expected effect is therefore an increase in price.

The relationship between concentration of agricultural operations and prices for water transactions does not suffer from the common endogeneity problem. Entry/exit decisions of farmers are based on profitability of agriculture and are likely unaffected by individually negotiated water transfer prices. Second, the price for a specific transaction is the result of spot market negotiations. Water transfers do not occur in well defined markets. The concentration of agricultural production is therefore exogenous to the results of negotiations for a particular transfer.

In this chapter I estimate various different models. I start by estimating price, quantity, and contract type equations independently. Since the data are on both short-term leases of water and permanent sales of water rights, both models account for the endogeneity of the lease/ownership decision. While the bargaining models do not model the lease/ownership decision, it is important to recognize its potential endogeneity and use appropriate empirical methods. The next model estimates price, quantity, and lease/own equations simultaneously using full information maximum likelihood. I then discuss alternate estimation techniques where the buy/lease decision is controlled for using different methods.

4.2 Data

The water transfer data were obtained from back issues of the industry trade journals *Water Intelligence Monthly* and *The Water Strategist* (published by Stratecon Inc). Each year in February a list of transactions in western states for the previous year is published. These lists were used to identify identities of the buyers and sellers, prices, and quantities for a total of 143 agricultural-urban and agricultural-agricultural transactions during the period from 1990-2004. The states and number of transactions are California (59), Texas (51), Arizona (2), Washington (2), New Mexico (17), Nevada (2), Utah (4), Kansas (4) and Idaho (2). The final sample is a small subsample of the significantly larger sample of all transactions during the period. The process by which the sample was narrowed is described as follows. First, the sample was limited to agricultural-agricultural and agricultural-urban transactions. Second, while there are a substantial number of transfers in Colorado, it was decided that data on transfers in Colorado were insufficient for purposes of the study. Many of the transfers have both unidentified buyers and sellers. Further, many of the transfers also include unpriced services in addition to unit prices paid for water. Third, transactions were not used if the identities of both the buyers and sellers were not published. For these transactions it was not possible to determine counties in which the transactions occurred, which was necessary in order to collect the remaining variables in the dataset. Fourth, transactions were required to have complete data on price and quantity. Fifth, transactions in which other goods and services were tied in were eliminated. For instance, transfers of both water and land in exchange for payment were not included.

To make the explanation of the data collection process more concrete, I describe one transaction which was included and another which was excluded from the dataset. In the transactions review portion of the February 1992 issue of *The Water Strategist*, a transaction from Texas is listed as, "Laredo leases 2,300 AF of Rio Grande water from Hidalgo Co ID #2 at $15/af (page 5)." This transaction is included because it meets all the requirements listed above. However, in February 1993 issue, a transaction is listed as, "Metropolitan Water District agrees to line IID's and Coachella's All American Canal in exchange for 70,000 AF of conserved water (page 3)." This transaction is excluded as it violates the fifth requirement.

The descriptions of the variables used in the models are given in Table 4.1. All efforts were made to measure variables at the most appropriate micro-levels. Ideally, data should be aggregated such that the unit of observation is a feasible transaction region. The definition of a feasible transaction region varies across space as a result of different state laws restricting long distance transfers and varying levels of conveyance facilities. Thus, it is extremely difficult to define a feasible transaction region, let alone collect data at that level. Identifying the counties of buyers and sellers and aggregating variables at the county level was the most suitable way to measure micro-level economic and environmental variables in the areas of the transactions.[1] Using county level data is undeniably a matter of both convenience and practicality. Since the sellers in some transactions were individual irrigators or groups of irrigators, the identity of the seller could not be identified for all transactions.[2] County-level supply side variables were collected for buyer counties in these transactions. Most transactions occur within the same county. Thus, this method is not expected to introduce detrimental bias to the analysis. I further discuss data aggregation issues when checking the robustness of my main results against alternate aggregation procedures.

Descriptive statistics are then given in Table 4.2. The table also gives separate statistics for leases and purchases. 42% of the transactions are permanent sales. For leases, the PRICE variable is the real (year 2000 $) per acre price paid to the irrigation district or farmer. To make the comparison between lease and purchase prices comparable, I use a discounting factor of 5% in order to convert the one time purchase payment to an annual flow. For each purchase, the purchase price is multiplied

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[1] When buyers or sellers were located in more than one county (e.g. a large irrigation district) the mean value between the two counties was taken.

[2] When referring to individual irrigators, I am referring to sellers/lessees that are not agricultural water supply districts. In other words, these sellers/lessees are irrigators that transfer water independently of agricultural supply districts.

Table 4.1: Variable Descriptions

Variable	Description
Dependent Variables	
OWNERSHIP	= 1 if permanent purchase, 0 if short-term lease
PRICE	= Price per AF (discounted for permanent sales)
QUANTITY	= Quantity transferred in AF
Controls	
INDIVIDSELL	= 1 if seller is not an agricultural water supply district, 0 otherwise
AGBUYER	= 1 if buyer/lessee is agricultural user, 0 if municipal user
LANDVALUE	= Value per acre of ag. land and buildings in previous census year
BUYOTHER	= 1 if buyer made other purchase or lease during same year
GROUNDWATER	= 1 if transaction for groundwater, 0 otherwise
CALIFORNIA	= 1 if transaction in California, 0 otherwise
TEXAS	= 1 if transaction in Texas, 0 otherwise
Upstream Market Power	
IRRIGFARMS	= Number of irrigated farms (in hundreds) in the county of the seller during previous ag. census year
ACRESPERFARM	= Number of irrigated acres (in hundreds) per irrigated farm
Agricultural Value	
CROPVALUE	= Average value per acre of major crop in seller county
PRICEHAY	= Statewide average price (per ton) of all hay during year of transaction
Population Growth	
POP10YEAR	= 10 year projected population growth rate in buyer/lessee county[b]
DROUGHT	= -1 x Palmer drought severity index in buyer county during month of transaction

[a] Major crops were identified as the crop with the greatest acreage in the county during the most recent census year.

[b] POP10YEAR is the forecasted population growth rate between the two census years which precede and follow the year of the transaction. For instance, for a transaction in 1993, POP10YEAR is the growth rate in population between 1990 and 2000.

Note: All monetary variables converted to $ values in year 2000.

Table 4.2: Summary Statistics

	All Transactions	Leases	Purchases
Dependent Variables			
OWNERSHIP	0.42	-	-
	(0.50)	-	-
PRICE	71.70	73.99	68.53
	(110.65)	(136.66)	(59.08)
QUANTITY	4441.96	6555.93	1517.63
	(9083.76)	(11253.79)	(2755.45)
Controls			
INDIVIDSELL	0.43	0.22	0.73
	(0.50)	(0.41)	(0.45)
AGBUYER	0.34	0.57	0.03
	(0.48)	(0.50)	(0.18)
LANDVALUE	1953.62	2530.80	1155.19
	(1266.01)	(1276.86)	(688.98)
BUYOTHER	0.43	0.39	0.50
	(0.50)	(0.49)	(0.50)
GROUNDWATER	0.22	0.25	0.18
	(0.42)	(0.44)	(0.39)
CALIFORNIA	0.41	0.61	0.13
	(0.49)	(0.49)	(0.34)
TEXAS	0.36	0.36	0.35
	(0.48)	(0.48)	(0.48)
Upstream Market Power			
IRRIGFARMS	13.96	20.11	5.44
	(16.13)	(18.50)	(4.87)
ACRESPERFARM	1.83	1.97	1.65
	(1.53)	(1.41)	(1.67)
Agricultural Value			
CROPVALUE	1089.86	1448.14	594.27
	(1284.10)	(1455.19)	(771.46)
PRICEHAY	100.79	99.02	103.24
	(22.75)	(21.44)	(24.42)
Demand Shifters			
POP10YEAR	30.39	27.81	33.94
	(21.32)	(12.33)	(29.16)
DROUGHT	-0.13	0.06	-0.39
	(2.12)	(1.64)	(2.64)

Standard deviations in parentheses.

by 0.05. There remains substantial variability in both prices and quantities. Explaining dependent variables with unobservable heterogeneity can be problematic in cross-sectional data sets.[3] Taking natural logarithms of the continuous endogenous variables helps to control for outlier values of prices and quantities.

The control variables introduce additional information which is not in any of the bargaining models. The means of some of the binary control variables are descriptive of the data. 34% of transactions are agricultural-urban, while 22% of total transactions are for groundwater. Only 3% of permanent purchases are agricultural-agricultural, which shows that permanent sales tend to have urban buyers. Over 75% of the transactions in the sample occurred in California and Texas. Both states have large numbers of transactions with water being purchased/leased for both agricultural and municipal purposes.

The variables CROPVALUE and PRICEHAY are included in the models to test the prediction that smaller quantities are transferred when agricultural production is more valuable (PREDICTION 2). The unavailability of micro-level data on the crops grown by the actual seller in the transaction makes testing this prediction challenging. Since alfalfa hay is commonly produced in western states, its price is included to proxy for agricultural profitability. The CROPVALUE variable attempts to measure this at a finer level by measuring the per-acre value of the major crop in the county of the seller. Ideally, one would like to have a measure of the profitability

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[3] While I refer to the data as cross-sectional, it is truly neither cross-sectional or time series. The data has elements of both, but is obviously not a panel.

of all of the crops grown by the seller. Alternatively, county level data on farm support programs would provide an additional proxy for agricultural profitability in the area of the seller. Nonetheless, CROPVALUE and PRICEHAY are expected to be negatively associated with quantity.

The POP10YEAR and DROUGHT variables are meant to measure α in the bargaining model. POP10YEAR is expected to be positively associated with quantity transferred. Drought conditions are expected to increase demand and therefore have a positive association with quantities as well (PREDICTION 1).

The important variables for testing the impacts of upstream market power are IRRIGFARMS and ACRESPERFARM. The average number of irrigated farms is 1,396. Again, some counties have very small numbers of irrigated farms, with the minimum being 16.[4] Conversely, large counties in the Central Valley of California often have over 6,000 irrigated farms. The average number of acres per irrigated farm (ACRESPERFARM) measures the relative size of agricultural operations. The mean number of irrigated acres per farm is 183, with a minimum of 14 and a maximum of 649. Regions with fewer irrigated acres per farm are characterized by smaller-scale farm operations. Sellers in these areas are expected to be less powerful than in areas where farms with irrigation are larger. The outside options of buyers/lessees in regions with a small number of irrigated farms are fewer than in regions with greater numbers of agricultural operations. The expected effect of the increased upstream

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[4] This observation was in the Carson City Nevada Area; an area with generally low agricultural productivity. The next smallest value of IRRIGFARMS was 41.

market power on transfer negotiations in regions with fewer irrigated farms is to allow sellers to capture a greater share of gains from trading through price increases (PREDICTION 3). I expect regions with a fewer number of larger irrigated farms to be most plagued by upstream market power. Therefore, IRRIGFARMS is expected to have a negative effect on prices, while ACRESPERFARM is expected to have a positive effect.

4.3 Separate Estimation by OLS and Probit Maximum Likelihood

Reverting back to the theoretical results, the bargaining models determine prices and quantities as a function of various exogenous parameters. I have hypothesized that determination of whether the contract is permanent or short-term might be an additional endogenous decision made by buyers and sellers. Simultaneous determination of the three endogenous variables makes a standard simultaneous equations model seem desirable. However, if at the bargaining table the decisions are not made simultaneously, then errors between the three equations may be uncorrelated and simultaneous estimation may not introduce significantly more information.

As a start, I estimate the three equations independently. I attempt to take the Nash bargaining model to the data in a concise manner. According to (3.13), the negotiated quantity is the pareto efficient quantity that is a function of solely exogenous parameters and not a function of upstream market power variables. Nonetheless, one can test for noncooperative bargaining by including the market power variables in the quantity equation. In (3.14), the price is a function of exogenous variables as well as the quantity transferred. Therefore, I initially estimate the price equation by standard two stage least squares where the groundwater dummy variable is used as an instrument for quantity in a first stage OLS regression of quantity on the groundwater dummy and other exogenous variables. While a rich topic in the economic organization literature, the determination of contract type is not motivated by any theoretical model. Rather, I estimate the probit equation in a reduced form fashion by including all the exogenous variables as explanatory variables for the probit equation.

The results of separate estimation are given in Table 4.3. Other than to discuss the validity of instruments, no discussion will be devoted to the estimates on control variables. The groundwater dummy is used as in instrument for quantity in estimation of the price equation. Therefore, the results of the quantity equation in the table are also the first stage results for 2SLS estimation of the price equation. The estimate on the groundwater variable in the quantity equation shows strong positive association between groundwater and quantity transferred. The GROUNDWATER variable must also be exogenous in the price equation in order to be a sufficient instrument. It is unlikely that price negotiations have any impact on the type of water sold by agricultural entities. In almost all cases the type of water to be sold is predetermined and therefore exogenous to negotiations on price. The groundwater variable is therefore a good candidate as an instrument for quantity in the price equation.

The estimates on the upstream market power variables both have the expected signs. The price effect of the variable ACRESPERFARM is however insignificant from zero. The magnitude of the estimate on IRRIGFARMS is sizeable, indicating that increasing the number of farms by one hundred has the approximate effect of decreasing price by 1.7%. The signs of the estimates support prediction three, however their statistical imprecision makes the support weak. The quantity effects of IRRIGFARMS and ACRESPERFARM are interesting. The cooperative bargaining model predicted market power effects on quantity to be null. The results show that transactions tend to be smaller in areas where there are more farms. Transactions are larger in regions with larger farms. Combining the two estimates indicates that more water is transferred in regions with more upstream market power, which is not predicted by standard microeconomic theory.

The variables CROPVALUE AND PRICEHAY do not have the expected signs in the quantity equation. Measures of the value of agricultural production were expected to be negatively associated with quantity transferred. Measuring the value of agricultural production is difficult at the micro level.

The estimated impacts of drought on transfer quantity is essentially null. In the previous chapter, it was noted that drought may cause urban demands to increase and rural supplies to simultaneously contract. It is thus not surprising that the empirical results show no statistically significant impact of drought on quantity.

Table 4.3: Estimated Parameters from Separate Estimation

	Dependent Variable		
Independent Variable	ln(PRICE)	ln(QUANTITY)	OWNERSHIP
	(2SLS)	(OLS)	(MLE)
Controls			
CONSTANT	2.62042**	4.5759***	2.4241
	(2.17)	(4.09)	(1.02)
ln(QUANTITY)	0.1660		
	(0.83)		
INDIVIDSELL	0.4550**	-0.0059	1.3850**
	(2.09)	(0.01)	(2.41)
AGBUYER	0.0359	1.0464**	-1.5345**
	(0.11)	(2.30)	(2.22)
LANDVALUE	-	-	-0.0010**
			(2.20)
BUYOTHER	0.0943	-0.1186	0.1645
	(0.62)	(0.40)	(0.32)
GROUNDWATER	-	0.9412**	-1.4526**
		(2.56)	(2.09)
CALIFORNIA	0.0896	1.6640**	-4.4456***
	(0.19)	(3.14)	(3.6220)
TEXAS	-0.3528	0.5206	-2.9244***
	(1.42)	(1.12)	(2.64)
Upstream Market Power			
IRRIGFARMS	-0.0173*	-0.0363**	-0.1028*
	(1.76)	(2.57)	(1.64)
ACRESPERFARM	0.0170	0.3065***	-0.7111***
	(0.20)	(2.77)	(3.12)
Agricultural Value			
CROPVALUE	-0.0000	0.0003*	-0.0000
	(0.02)	(1.89)	(0.10)
PRICEHAY	0.0035	0.0013	0.0159
	(0.87)	(0.16)	(0.90)
Demand Shifters			
POP10YEAR	-0.0072**	0.0081	-0.0038
	(1.94)	(1.14)	(0.25)
DROUGHT	0.07**	-0.0073	-0.1959
	(1.98)	(0.11)	(1.57)
Number of Observations	143	143	143
R^2	0.30	0.41	
McFadden's R^2			0.65

Absolute values of t-ratios in parentheses. Asterisks indicate statistical significance at the 10%(*), 5%(**) and 1%(***) levels. McFadden's R^2 is calculated as $1 - (lnL/lnL_r)$, where lnL_r is the log-likelihood from estimation with only a constant term.

Finally, my model predicted a positive relationship between population growth and quantity transferred. While the coefficient on POP10YEAR has the correct sign, it is insignificant at reasonable levels. Forecasted population growth is only a suitable measure for growth in water demand for municipal buyers. Considering that the data also contain transfers between agricultural users, there may be an interaction between it and the buyer type dummy. One would expect the marginal effect of population on quantity to be positive for agricultural-urban transactions only. Furthermore, the estimated coefficient on DROUGHT is statistically indistinguishable from zero. Estimating the equations separately fails to provide convincing evidence in support of prediction one.

In the price equation, the sign on POP10YEAR is counterintuitive and the estimate is significant at the 5% level. The estimate on the variable DROUGHT however conforms to intuition and is significant from zero. The estimated effect of drought is that a unit increase in the Palmer index leads to roughly a 6.9% increase in price.

4.4 Three Equation System

Joint negotiation of price, quantity, and contract type creates the possibility of correlation between error terms of the three equations. When errors between the three equations are correlated, efficiency can be improved by estimating the equations simultaneously as a system. Such a system is nontraditional in the sense that the third equation has a binary dependent variable. Nonetheless, if the errors between the three equations are significantly correlated, then simultaneous estimation is desirable over separate estimation.

The three equations are set up according to the Nash bargaining model as are they were for separate estimation.[5] For a particular observation the vector of endogenous variables, $\mathbf{y}_i$ is $[y_{1i}, y_{2i}, y^*_{3i}]'$, where y_{1i} is the logarithm of PRICE, y_{2i} is the logarithm of QUANTITY, and y^*_{3i} is the unobserved latent variable describing the propensity for water to be permanently transferred. The observed binary variable, y_{3i}=OWNERSHIP, is equal to 1 if $y^*_{3i} > 0$ (permanent purchase) and 0 if $y^*_{3i} < 0$ (lease). The vectors of independent variables explaining price, quantity, and contract choice are $\mathbf{x}_{1i}$, $\mathbf{x}_{2i}$ and $\mathbf{x}_{3i}$, respectively. The vectors of exogenous parameters to be estimated are $\boldsymbol{\beta}_1$, $\boldsymbol{\beta}_2$, and $\boldsymbol{\beta}_3$. Quantity is included in the price equation where the groundwater dummy is again used as instrument. I also let the propensity to permanently transfer water influence both price and quantity. Therefore, the unobserved latent variable y^*_{3i} is included on the righthand side of both the price and quantity equations. It may seem desirable to include the actual observed binary variable, y_{3i}, as an intercept shifter instead of the latent unobserved variable y^*_{3i}. However, models with mixtures of the latent variable and observed binary variable are generally inconsistent and in need of further restrictions for estimation (Heck-

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[5] The only difference is that the dummy variable for transactions in Texas is not included in the system. After discounting prices for permanent purchases, standard errors for Texas and California dummies grew unrealistically large. The dummy variables for transactions in Texas was therefore omitted.

man, 1978; Maddala, 1983.). I opt for the simpler system which can be estimated using traditional maximum likelihood methods. The three equations to be estimated can be written in structural form as,

$$\Gamma \mathbf{y}_i = \mathbf{x}\boldsymbol{\beta}_i + \mathbf{u}_i, \tag{4.1}$$

where $\mathbf{x}\boldsymbol{\beta}_i = [\mathbf{x}_{1i}^{'}\boldsymbol{\beta}_1, \mathbf{x}_{2i}^{'}\boldsymbol{\beta}_2, \mathbf{x}_{3i}^{'}\boldsymbol{\beta}_3]'$, $\mathbf{u}_i = [u_{1i}, u_{2i}, u_{3i}]'$ and

$$\Gamma = \begin{bmatrix} 1 & -\alpha_3 & -\alpha_1 \\ 0 & 1 & -\alpha_2 \\ 0 & 0 & 1 \end{bmatrix}. \tag{4.2}$$

In order for the system to be identified, valid instruments must be used for quantity in the price equation and the buy/lease latent variable in the price and quantity equations. As was previously mentioned, the groundwater dummy is used as an instrument for quantity in the price equation. I use the variable LANDVALUE as an instrument for the buy/lease latent variable. The previous probit results showed that LANDVALUE has a negative and significant effect on the likelihood of a permanent transfer. Further, there is no reason to believe that agricultural land values are influenced by negotiations for water transfers, therefore indicating exogeneity of agricultural land values in the price and quantity equations. With these instruments and the exclusion restrictions in the $\boldsymbol{\Gamma}$ matrix, the system is exactly identified. The reduced form system is,

$$\mathbf{y}_i = \Gamma^{-1}(\mathbf{x}\boldsymbol{\beta}_i + \mathbf{u}_i). \tag{4.3}$$

The structural errors between the three equations are considered to be distributed tri-variate normal with zero means and covariance matrix of,

$$\text{Cov}(\mathbf{u}_i) = \Sigma = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{12} & \sigma_{22} & \sigma_{23} \\ \sigma_{13} & \sigma_{23} & 1 \end{bmatrix}. \tag{4.4}$$

As usual, the variance of the error term in the probit equation is normalized to unity. The vector of errors in reduced form is $\Gamma^{-1}\mathbf{u}_i = [v_{1i}, v_{2i}, v_{3i}]'$. The reduced form errors also have tri-variate normal distribution with zero means. The covariance matrix of reduced form errors is,

$$\text{Cov}(\mathbf{v}_i) = \Gamma^{-1}\Sigma\Gamma'^{-1} = \begin{bmatrix} s_{11} & s_{12} & s_{13} \\ s_{12} & s_{22} & s_{23} \\ s_{13} & s_{23} & 1 \end{bmatrix}. \tag{4.5}$$

For a particular observation the log-likelihood can be written as,

$$L_i = [\text{Prob}(y_{3i} = 1|y_{1i}, y_{2i})\phi_2(y_{1i}, y_{2i})]^{y_{3i}}[\text{Prob}(y_{3i} = 0|y_{1i}, y_{2i})\phi_2(y_{1i}, y_{2i})]^{1-y_{3i}}, \tag{4.6}$$

where ϕ_2 is the marginal bivariate density of y_{1i} and y_{2i}. After further simplifications, which are detailed in Appendix B, the log-likelihood for all N observations is,

$$\begin{aligned} lnL \quad = \quad & \sum_{i=1}^{N} y_{3i} ln \left[\Phi \left(\frac{\mathbf{x}_{3i}^{'}\boldsymbol{\beta}_3 - a_1 v_{1i} - a_2 v_{2i}}{(1 - \frac{\rho_{13}^2 + \rho_{23}^2 - 2\rho_{13}\rho_{23}\rho_{12}}{1-\rho_{12}})^{1/2}} \right) \right] \\ & +(1 - y_{3i}) ln \left[\Phi \left(\frac{-\mathbf{x}_{3i}^{'}\boldsymbol{\beta}_3 - a_1 v_{1i} - a_2 v_{2i}}{(1 - \frac{\rho_{13}^2 + \rho_{23}^2 - 2\rho_{13}\rho_{23}\rho_{12}}{1-\rho_{12}})^{1/2}} \right) \right] \\ & + ln \left[\phi_2(v_{1i}, v_{2i}) \right], \end{aligned} \tag{4.7}$$

where Φ is the standard normal cumulative distribution function, ρ_{ij} is the correlation between reduced form errors for equations i and j, $a_1 = \frac{\rho_{13}-\rho_{23}\rho_{12}}{\sqrt{s_{11}}(1-\rho_{12}^2)}$, and $a_2 = \frac{\rho_{23}-\rho_{13}\rho_{12}}{\sqrt{s_{22}}(1-\rho_{12}^2)}$. Maximization of (4.9) with respect to $\boldsymbol{\beta}_1$, $\boldsymbol{\beta}_2$, $\boldsymbol{\beta}_3$, α_1, α_2, α_3, σ_{11}, σ_{12}, σ_{13}, σ_{22}, and σ_{23} gives the desired parameter estimates.

The results of estimating the structural parameters in (4.1) are given in Table 4.4.[6] Overall, simultaneous estimation appears to result in less explanatory power than separate estimation. Similar to separate estimation, the results do not provide evidence in support of predictions one and two. The signs on the upstream market

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[6] The standard errors of parameter estimates are computed using the outer product of the gradient vector (Berndt et al., 1974). Approximation of the Hessian matrix by numeric second derivatives are is an alternate option. See Calzolari and Panattoni (1988) for further details.

variables are consistent with the results from separate OLS estimation. However, unlike OLS estimation, the estimates are not individually statistically significant. Further, a Wald test of the joint significance of IRRIGACRES and ACRESPERFARM fails to reject the hypothesis that the two variables have no joint effect on prices ($\chi^2 = 0.73$, p-value = 0.69).

The purpose of estimating the equations simultaneously is to improve efficiency due to correlation between errors of the equations. Of the three error covariances, the covariance between errors of the quantity and buy/lease equations (σ_{23}) is the only estimate that is statistically significant at standard levels. However, a Wald test of the joint significance of the covariance terms fails to reject the hypothesis that the error covariances are all zero ($\chi^2 = 18.63$, p-value = 0.00). The significance of the estimated covariances between errors of the quantity and buy/lease equations is however the main factor driving the joint significance of the covariance estimates. A separate Wald test for σ_{12} and σ_{13} fails to reject the null hypothesis of no joint effect ($\chi^2 = 0.46$, p-value = 0.79). Potential efficiency gains from estimating equations simultaneously appear to be most substantial for the quantity equation.

Estimating the equations simultaneously by maximum likelihood does not produce statistically robust results. The system approach to estimation is computationally expensive and fails to confirm theoretical predictions. The results have implications for the empirical contributions of this thesis. It is difficult to separate out the price, quantity, and contract type effects of the exogenous factors from

Table 4.4: Estimated Parameters from Simultaneous Maximum Likelihood Estimation

	Dependent Variable		
Independent Variable	ln(PRICE)	ln(QUANTITY)	OWNERSHIP
Controls			
CONSTANT	4.6364**	4.6866***	-1.1331
	(2.43)	(2.88)	(0.61)
INDIVIDSELL	0.4672	-0.3414	1.3100**
	(1.14)	(0.54)	(2.29)
AGBUYER	0.6131	0.8470	-1.3990
	(1.30)	(1.22)	(1.23)
LANDVALUE	-	-	-0.0012
			(1.45)
BUYOTHER	0.0375	0.1290	0.5809
	(0.17)	(0.26)	(1.03)
GROUNDWATER	-	0.5707	-0.5599
		(1.12)	(0.86)
CALIFORNIA	1.2686	1.6805	-2.2728
	(1.40)	(1.16)	(1.30)
Upstream Market Power			
IRRIGFARMS	-0.0168	-0.0318	-0.0588
	(0.63)	(1.33)	(0.69)
ACRESPERFARM	0.0349	0.2815	0.5305
	(0.15)	(1.04)	(1.34)
Agricultural Value			
CROPVALUE	0.0001	0.0003	0.0006
	(0.27)	(1.29)	(0.52)
PRICEHAY	-0.0002	0.0009	0.0215
	(0.03)	(0.06)	(1.09)
Demand Shifters			
POP10YEAR	-0.0071	0.0017	0.0024
	(1.25)	(0.17)	(0.12)
DROUGHT	0.0784	-0.0433	-0.1795
	(1.05)	(0.49)	(0.94)
Endogenous Variables			
ln(QUANTITY)	0.1988	-	-
	(0.49)		
BUY/LEASE LATENT	-0.1193	0.0071	-
	(0.70)	(0.03)	
Error Covariances			
σ_{12}	0.6982	-	-
	(0.67)		
σ_{13}	-0.3543	-	-
	(0.63)		
σ_{23}	-1.5488***	-	-
	(4.33)		
Number of Observations	143		
Log-likelihood	-442.172		

Absolute values of t-ratios in parentheses. Asterisks indicate statistical significance at the 10%(*), 5%(**) and 1%(***) levels.

the Nash bargaining model. The link between the buy/lease choice and price and quantity appears to be a confounding factor in separate estimation.

4.5 Other Models

Econometric models with endogenous binary variables are often estimated using switching regression techniques. Correlation between error terms of the probit equation and equation of interest creates an endogeneity problem with the binary explanatory variable. The switching regression is advantageous because it allows for endogeneity to be controlled for in a computationally simple fashion. In addition, separate parameter vectors for the two regimes are estimated. Simultaneous equation models can also be estimated using a combination of two-step switching regression methods and instrumental variables (Lee et al., 1980; Maddala, 1983.).

The results from the three equation system showed that there is only significant correlation between error terms of the quantity and probit equations. Nonetheless, I further explored the theoretical implications of the bargaining models by estimating switching regressions explaining both prices and quantities. The quantity equation was estimated using the standard two-step estimation procedure introduced by Heckman (1979). The price equation was then estimated using the instrumental variables switching regression of Lee et al. (1980). For all cases, the coefficients on the upstream market power variables were not statistically different from zero. The estimated parameters on the inverse mill's ratios (estimated covariances between errors) were also indistinguishable from zero; thus indicating that an endogenous switching model is possibly unnecessary.

Another possibility is to estimate the price and quantity equations after dividing the sample into purchases and leases. Or, the equations could be estimated with the inclusion of a binary buy/lease explanatory variable. Both approaches were explored and the estimates on the upstream market power variables were usually of the wrong sign and statistically insignificant. These results raise interesting concerns regarding the link between upstream market power and contract type. It is possible that rather than through prices or quantities, upstream market power is enjoyed by farmers through negotiations on contract type. If this is the case, then models where the buy/lease decision is not appropriately controlled for will suffer from omitted variable bias. The theoretical effects of imperfect competition on contract type for water transfers is an interesting area where future work could be done in order to generate empirically testable implications.

4.6 Comments on Robustness of Upstream Market Power Results

This chapter has presented and discussed various econometric models explaining prices, quantities, and contract type for water transfers. The bargaining models of Chapter 3 generated a main testable implication of interest. That is, water transfers are influenced by market power, and sellers benefit from upstream market power during price negotiations.

The purpose of the models was to test the prediction about upstream market power and prices. Overall, the econometric evidence in support of the prediction is weak. Separate estimation by OLS shows that farmers that are fewer in number are able to negotiate for higher prices. The direction of this effect is the same when estimating the equations simultaneously by maximum likelihood. However, the statistical precision of the estimate is far less. Finally, controlling for the buy/lease decision by splitting up the sample or using switching regression models causes the estimated effects of upstream market power variables on contract prices to be close to null. In these cases the argument could be made that market power impacts negotiations on contract type which certainly influences price. A theoretical model of the relationship between market power and contract type may be needed in order to refine empirical studies which attempt to model prices, quantities, and contract type.

CHAPTER 5

IMPLICATIONS AND CONCLUSIONS

In this thesis I have expanded on a well-known characteristic of water transfers in western states. That is, the form of economic organization for water transfers is not the traditional market as it is described by classical economic theory. The limited number of market participants creates incentives for opportunistic behavior by buyers and sellers. The strategic element of transfers is often mentioned but not explicitly modeled in theoretical or empirical studies. The impacts of market imperfections on transfer negotiations are potentially large. The increased reliance of policymakers on transfers as means of reallocating water between users becomes questionable if the outcomes of negotiations are expected to diverge from first-best jointly optimal outcomes. I have considered the issue of imperfect competition in water transfers from both a theoretical and empirical perspective. Both the theoretical and empirical results have implications for water management.

Further, I have adapted an industrial organization (IO) framework in markets for water. While theoretical and empirical IO has evolved to markets for other natural resources, this study is one of the initial studies to take an IO approach to modeling water transfers. Given that future studies using IO tools in natural resource economic models are becoming more common, this thesis is expected to be followed by other studies using IO models to examine natural resource issues.

5.1 Theoretical Implications

The simple theoretical models presented in Chapter 3 served two main purposes. First, the results of the bargaining models led to some empirically testable predictions regarding asymmetric bargaining ability and market power in water transfers. Second, by looking at water transfers using simple game theoretic models, some expected decision rules regarding outcomes of negotiations were derived. It was shown that negotiated prices and quantities may diverge substantially from those which would be observed in perfectly functioning markets. A comparison of the noncooperative and cooperative games shows how the quantity of water to be traded between two concentrated parties is critically dependent on the scope of cooperation between the two parties. In the noncooperative game, both price and quantity are affected by the degree of oligopoly or oligopsony power. In the cooperative game, both asymmetric bargaining ability and market power result in only price effects. As the degree of cooperative behavior increases, the negotiated quantity approaches the first-best joint maximizing quantity. The sharing of gains from trade is determined by the relative bargaining power and the disagreement payoffs of the players. Encouraging cooperative behavior is needed if transfers are desired as a means of efficiently reallocating water between users.

Uncertainty is an important issue influencing negotiations for water. Municipal buyers have uncertain demands which are dependent on stochastic weather conditions. Under the prior appropriation system the endowments of agricultural sellers are also uncertain. It was seen that when both buyers and sellers are risk neutral, the distribution of municipal demands has the expected effects on bargaining outcomes. It was also shown that larger transfers are expected to be negotiated when sellers hold senior rights. Buyers looking to purchase large amounts are thus more likely to succeed in negotiations when bargaining with senior rights holders.

The bargaining models with uncertainty also have implications for dry-year option agreements. Option contracts are emerging as mechanisms for buyers in long-term agreements to minimize the risk of being stuck with an unneeded water supply in wet years. Option contracts are predicted to be agreements for larger quantities as a result of reduced risk to buyers. When buyers are risk averse option contracts are one mechanism which can eliminate welfare losses from transactions during years when additional supply is unneeded.

5.2 Empirical Implications

There seems to be a continual interest in how various economic, legal, and environmental variables will affect negotiations for water transfers. Past work has tested several different hypotheses regarding transfer prices. The effects of market structure and imperfections on market outcomes is a classic question from the empirical industrial organization literature. It is a question that has yet to be applied to the case of water. I have attempted to fill this gap by testing some of the theoretical results using a very traditional approach. The theory showed that thinner markets on the supply side have the effects of reducing disagreement payoffs of buyers and leading to higher prices. The empirical evidence shows that sellers in areas with fewer irrigated farms are better off during negotiations for prices. Buyer participation in transfers may be reduced in regions where insufficient competition on the supply side allows for sellers to capture greater amounts of gains from trading.

While the results are significant in separate OLS estimation, I have shown that they are generally not incredibly robust to alternate specifications. It seems that there is an interesting dynamic between market power in transfers and duration of contracts that could be confounding the simple relationship between prices and upstream market power variables. Further work with more elaborate data sets could provide nice checks of the robustness of the results to alternate ways of controlling for the buy/lease decision.

A major empirical implication that has went untested thus far is the effect of irrigation efficiency on the quantity of water transferred from agricultural to urban users. The surprising prediction that irrigation efficiency has an ambiguous impact on quantity is a nice testable prediction for future work. An imperfect but suitable method of testing this prediction would be the use of aggregate data at the state or county level where the number of transfers or quantity of water transferred out of agriculture is regressed on measures of efficiency in the irrigation system. This approach is not micro-level analysis. However, it may be the most suitable given the absence of micro-level data on transfers and irrigation efficiency.

5.3 Policy Implications

Most agree that increased reliance is being placed on transfers in order to reallocate water and best manage the existing supply. New supply projects are uncommon as they are both economically and environmentally infeasible. Transfers are therefore encouraged in order to transfer resources to higher valued uses. Water managers are interested in what steps can be taken in order to further encourage participation in transfers. A simple decision rule that allows for determination of contract terms in settings with asymmetric bargaining ability and market power allows policymakers to investigate the impacts of various policy mechanisms to negotiations. Understanding the impacts of policies on negotiations helps to understand what can be done in order to encourage participation in negotiations by either buyers or sellers.

The comparative statics of the Nash bargaining model result in some immediate policy implications. It was shown that installing improved irrigation technology in agriculture does not guarantee more water to be transferred to alternate uses. Instead, the direction of this effect is crucially dependent on agricultural production technology. In areas with unproductive soils, the positive marginal effect on total productivity of increasing water use will outweigh the welfare gains from transferring. Policymakers must be careful when constructing policies which encourage improvements in irrigation technology with the hopes of increasing amounts transferred to other users. In the United States the Environmental Quality Incentives Program (EQIP) provides cost-sharing payments to farmers installing more efficient irrigation systems. The stated objective of allowing for conserved water to be transferred to other users is brought into question when the marginal product of effective water use in agriculture is less responsive to increases in effective water use. The efficacy of the program is this specific objective is likely to vary by region.

The Nash bargaining model predicted quantity transferred to be strictly decreasing in agricultural prices. Policies which specifically support agriculture through direct supports on commodity prices have the additional effect of discouraging transfers to other users. Policies which support agriculture through decoupled payments do not discourage transfers. The countervailing effects of policies which encourage transfers and policies which support agriculture through payments which are tied to production are clear. Fully encouraging transfers requires farm support programs which do not directly subsidize agricultural prices.

Water policymakers are becoming increasingly concerned with how to allocate existing supplies during drought. My empirical results show that drought does not influence quantity transferred due to competing effects on urban demands and agricultural supplies. However, drought does lead to increases in prices. The ambiguous effect on quantity and the increase in price indicate that agriculture may not be the best supplier for municipalities during drought. Also, policymakers placing increased reliance on larger agricultural-urban transfers during drought may be making poor decisions.

The empirical results on market power indicate that participation in transfers may become infeasible for buyers in regions with limited numbers of potential sellers. State agencies have already attempted to encourage the further development of perfectly functioning markets. In the early 1990's the state of California instituted an emergency drought water bank where the state served as an agent to facilitate transfers. Simplifying the transfer process leads to decreased costs of negotiation and allows for transfers to become economic for buyers and sellers which were previously unwilling to participate. Encouraging participation by both buyers and sellers leads to transfers being affected less by imperfect competition. Eliminating market imperfections is necessary if transfers are going to be relied upon to reallocate water. Policies which reduce bargaining costs and encourage participation are desirable to allow for markets to become more competitive.

5.4 Limitations and Final Comments

This thesis has presented theoretical and empirical evidence on the effects of market power on negotiations for water. The limitations of the study serve as potential directions for future research. The theoretical models can be expanded in order to describe a variety of different economic environments. I have relied on mostly cooperative bargaining theory to model water transfers. Noncooperative bargaining games which explicitly model negotiations as a sequence of offers and counteroffers could offer insights for transfers where the scope for cooperation is minimal. A comparison of predicted outcomes under cooperative and noncooperative bargaining games is an additional direction which would provide nice insights into the predicted impacts of noncooperative behavior on contract terms. I have also focused on a specific type of transaction where two players negotiate over only price and quantity. The models can be expanded to describe bargaining between multiple players over several contract terms. Transfers have numerous different stakeholders. Multilateral bargaining models would allow for participation in negotiations by affected third parties such as representatives of rural communities or advocates of using purchased water for environmental purposes. Additional contract terms could include third party compensation for reduced agricultural water use or the shares of purchased water to be allocated to different purposes by buyers. Contracts for water transfers are far more complex than simple contracts specifying price and quantity. Further theoretical work could allow for endogenous determination of these various contract terms.

The study does have some empirical limitations. First, as was stated earlier, the data are not perfect for testing the theoretical implications. Ideal data would be aggregated at the geographic level that is best described as a feasible transaction region. Also, many of the parameters from the theoretical models have imperfect proxies in the empirical models. These issues are common in empirical studies on contracting. Second, the data used did not allow for empirical tests of oligopsony power. The theory predicts that buyers in rural areas with a limited number of competing municipal entities will negotiate for lower prices. Further empirical work could include simple tests for oligopsony power by looking at the impacts of buyer concentration on prices. Transfer negotiations being spot market negotiations eliminates some of the econometric problems associated with empirical tests for market power. The only remaining question is how to measure buyer concentration. An appropriate variable would be similar to the use of the number of irrigated farms in the area as a measure of upstream competition. While it is obvious that measuring downstream competition may not be as simple, empirical tests of oligopsony power in water transfers would add to the growing list of factors causing transfer outcomes to diverge from first-best socially optimal outcomes. Third, recent work by Hanak (2005) suggests that groundwater export restrictions are an important determinant of the quantity of water transferred in California. Ignoring such restrictions is not likely to have caused significant omitted variable bias in the regressions in Chapter 4. First, only twelve transactions are for groundwater in California. Second, the emergence of restrictions would have to be correlated with other explanatory variables for bias to occur. There does not seem to be any reason to expect that the emergence of export restrictions would be heavily correlated with any of the variables in the two models.

The literature in empirical industrial organization has become saturated with empirical tests of market power. In this thesis I have used a traditional empirical method to measure the effects of upstream market power on spot market water transactions. Simple theoretical results were tested for both permanent transfers and short-term leases of water. I have provided some initial empirical models which look at the idea that water transfers are affected by imperfect competition. Further work can be supplementary by verifying robustness and looking at oligopsony power in water transfers.

APPENDIX A

DERIVATION OF NASH SOLUTION

The two first order conditions for maximizing (3.12) are

$$\begin{aligned}\frac{\partial N}{\partial x} &= \gamma(\pi-\pi_d)^{\gamma-1}(-hPf_e+w+c)(V-V_d)^{1-\gamma} \\ &\quad +(1-\gamma)(V-V_d)^{-\gamma}(\alpha-\beta x-w)(\pi-\pi_d)^{\gamma}=0 \qquad \text{(A.1)}\end{aligned}$$

and

$$\frac{\partial N}{\partial w}=\gamma(\pi-\pi_d)^{\gamma-1}(x)(V-V_d)^{1-\gamma}+(1-\gamma)(V-V_d)^{-\gamma}(-x)(\pi-\pi_d)^{\gamma}=0. \qquad \text{(A.2)}$$

By rearranging $\frac{\partial N}{\partial w}=0$, I obtain

$$(\pi-\pi_d)^{\gamma-1}(V-V_d)^{-\gamma}x[\gamma(V-V_d)-(1-\gamma)(\pi-\pi_d)]=0. \qquad \text{(A.3)}$$

The assumption of a strictly interior solution with positive gains from trade for both players indicates that the above equality can only hold true if the bracketed term is zero. I then have the result that the gains from trade of the two players are proportional to their bargaining power parameters:

$$\frac{\pi - \pi_d}{V - V_d} = \frac{\gamma}{1-\gamma}. \tag{A.4}$$

Rearranging $\frac{\partial N}{\partial x} = 0$ similarly results in

$$(\pi - \pi_d)^{\gamma-1}(V - V_d)^{-\gamma}[\gamma(-hPf_e + w + c)(V - V_d) + (1-\gamma)(\alpha - \beta x - w)(\pi - \pi_d)] = 0. \tag{A.5}$$

Since the first term is nonzero, the above equality only holds true if the bracketed term is zero. Substituting from (A.4) leaves

$$(1-\gamma)(\pi - \pi_d)[(-hPf_e + w + c) + (\alpha - \beta x - w)] = 0. \tag{A.6}$$

Again the equality only holds true if the second term is zero. Rearranging gives the quantity expression:

$$x_N = \frac{\alpha - hPf_e + c}{\beta} \tag{A.7}$$

In order to get w^*, (A.4) can be expressed as

$$(1-\gamma)[Pf(h(\overline{X} - x)) - Pf(h\overline{X}) + wx + cx] = \gamma\left[\alpha x - \frac{1}{2}\beta x^2 - wx - V_d\right]. \tag{A.8}$$

Solving for w^* results in

$$w_N = \gamma \left(\alpha - \frac{1}{2}\beta x - \frac{V_d}{x} \right) + (1-\gamma) \left(\frac{Pf(h\overline{X}) - Pf(h(\overline{X} - x)) - cx}{x} \right), \tag{A.9}$$

which is the expression given in (3.14).

A.1 Second Order Conditions

The maximization problem in (3.12) requires strict concavity of the Nash product with respect to variables w and x. Formally, the second order condition is satisfied if the Hessian matrix, $\mathbf{H}$, is negative definite. The Hessian matrix is

$$\mathbf{H} = \begin{bmatrix} N_{xx} & N_{xw} \\ N_{xw} & N_{ww} \end{bmatrix}, \tag{A.10}$$

where subscripts again denote partial derivatives. Negative definiteness requires $N_{xx} < 0$, $N_{ww} < 0$, and $N_{xx}N_{ww} - N_{xw}^2 > 0$. The second order derivatives are

$$\begin{aligned} N_{xx} &= \gamma(\gamma-1)(\pi-\pi_d)^{\gamma-2}(-hPf_e + w + c)^2(V - V_d)^{1-\gamma} \\ &+ \gamma(\pi-\pi_d)^{\gamma-1}h^2Pf_{ee}(V-V_d)^{1-\gamma} + \gamma(\pi-\pi_d)^{\gamma-1}(-hPf_e + w + c) \\ &\cdot (1-\gamma)(V-V_d)^{-\gamma}(\alpha - \beta x - w) - \gamma(1-\gamma)(V-V_d)^{-\gamma-1}(\alpha - \beta x - w)^2 \\ &\cdot (\pi-\pi_d)^{\gamma} - \beta(1-\gamma)(V-V_d)^{-\gamma}(\pi-\pi_d)^{\gamma} + \gamma(1-\gamma)(V-V_d)^{-\gamma} \\ &\cdot (\alpha - \beta x - w)(\pi-\pi_d)^{\gamma-1}(-hPf_e + w + c), \end{aligned} \tag{A.11}$$

$$N_{ww} = x^2\gamma(\gamma-1)(\pi-\pi_d)^{\gamma-1}(V-V_d)^{-\gamma}\left[\frac{V-V_d}{\pi-\pi_d}+\frac{\pi-\pi_d}{V-V_d}+2\right], \tag{A.12}$$

and

$$\begin{aligned} N_{xw} &= (\pi-\pi_d)^{\gamma-1}(V-V_d)^{-\gamma}[\gamma(V-V_d)+\frac{V-V_d}{\pi-\pi_d}x\gamma(-hPf_e+w+c) \\ &+ x\gamma(1-\gamma)(\alpha-\beta x-w)+(\gamma-1)(\pi-\pi_d)+x\gamma(1-\gamma)(\alpha-\beta x-w) \\ &\cdot \frac{\pi-\pi_d}{V-V_d}+x\gamma(\gamma-1)(-hPf_e+w+c)]. \end{aligned} \tag{A.13}$$

Using the first order condition that $\alpha-\beta x-w = hPf_e-w-c$, N_{xx} is the sum of six negative terms and is hence negative itself. Since γ is in the unit interval and gains from trade of both parties are assumed to be strictly positive, N_{ww} is also negative. It is assumed that the final condition be satisfied such that the Nash product is strictly concave in price and quantity.

APPENDIX B

LOG-LIKELIHOOD FOR 3 EQUATION SYSTEM

For all n observations the likelihood function is the product of (4.8),

$$L = \prod_{i=1}^{n} [Prob(y_{3i} = 1|y_{1i}, y_{2i})\phi_2(y_{1i}, y_{2i})]^{y_{3i}} [Prob(y_{3i} = 0|y_{1i}, y_{2i})\phi_2(y_{1i}, y_{2i})]^{1-y_{3i}}. \tag{B.1}$$

Taking logarithms leaves,

$$\begin{aligned} lnL &= \sum_{i=1}^{n} y_{3i} ln[Prob(y_{3i} = 1|y_{1i}, y_{2i})\phi_2(y_{1i}, y_{2i})] \\ &\quad +(1 - y_{3i}) ln[Prob(y_{3i} = 0|y_{1i}, y_{2i})\phi_2(y_{1i}, y_{2i})]. \end{aligned} \tag{B.2}$$

After further simplifications we have,

$$\begin{aligned} lnL &= \sum_{i=1}^{n} y_{3i} ln[Prob(y_{3i} = 1|y_{1i}, y_{2i})] + (1 - y_{3i}) ln[Prob(y_{3i} = 0|y_{1i}, y_{2i})] \\ &\quad +ln[\phi_2(y_{1i}, y_{2i})]. \end{aligned} \tag{B.3}$$

Since the reduced form error terms are linear combinations of the endogenous variables, exogenous variables, and parameters, (B.3) can be expressed as,

$$\begin{aligned} lnL &= \sum_{i=1}^{n} y_{3i} ln[Prob(y_{3i}^* > 0|v_{1i}, v_{2i})] + (1 - y_{3i}) ln[Prob(y_{3i}^* < 0|v_{1i}, v_{2i})] \\ & +ln[\phi_2(v_{1i}, v_{2i})]. \end{aligned} \tag{B.4}$$

Noting that $v_{3i} = u_{3i} = y_{3i}^* - \mathbf{x}_{3i}^{'}\boldsymbol{\beta}_3$, (B.4) can be written as

$$\begin{aligned} lnL &= \sum_{i=1}^{n} y_{3i} ln[Prob(v_{3i} > -\mathbf{x}_{3i}^{'}\boldsymbol{\beta}_3|v_{1i}, v_{2i}] + (1 - y_{3i}) ln[Prob(v_{3i} < -\mathbf{x}_{3i}^{'}\boldsymbol{\beta}_3|v_{1i}, v_{2i}] \\ & +ln[\phi_2(v_{1i}, v_{2i})]. \end{aligned} \tag{B.5}$$

Estimation requires the mean and variance of the conditional distribution of v_{3i} given v_{1i} and v_{2i}. Letting ρ_{ij} be the correlation between reduced form errors of the ith and jth equations, the conditional mean is (see Greene 2003., p.871-872) $a_1 v_{1i} + a_2 v_{2i}$, where $a_1 = \frac{\rho_{13} - \rho_{23}\rho_{12}}{\sqrt{s_{11}}(1-\rho_{12}^2)}$ and $a_2 = \frac{\rho_{23} - \rho_{13}\rho_{12}}{\sqrt{s_{22}}(1-\rho_{12}^2)}$. The conditional variance is,

$$Var(v_{3i}|v_{1i}, v_{2i}) = \left(1 - \frac{\rho_{13}^2 + \rho_{23}^2 - 2\rho_{13}\rho_{23}\rho_{12}}{1 - \rho_{12}^2}\right) \tag{B.6}$$

After normalizing and taking advantage of the symmetry of the normal distribution, (B.5) reduces to the log-likelihood expressed in (4.7).

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