IRFAN YOUSUF TAREEN
Forecasting Irrigation Water Demand: An Application to the Flint River Basin
(Under the direction of MICHAEL E. WETZSTEIN)

Limited supply of water in the Flint River Basin necessitates a method for allocating this supply. An efficient allocation of water requires estimating the current and future demands for water. A major component of this demand is agriculture. In this dissertation a method for forecasting Georgia agricultural water demand for corn, cotton, peanuts and soybean by county is developed. Developing such a forecasting method requires estimating crop irrigated acreage response based on physical, economic and institutional determinants and applying the estimates of crop acreage by county to the Blaney-Criddle formula to estimate water demand. The empirical estimates are based on 31 Georgia counties which approximate the Flint River Basin.

Expected utility maximization is the theoretical underpinning of this analysis. The producer maximizes expected utility by allocating the total amount of irrigated acreage available among competing enterprises. Given the assumption of risk aversion and an acreage constraint, the resulting empirical model of irrigated acreage is a function of profits, variance-covariance of profits and the total irrigated acreage in a county. Profits capture the substitution effect among crops and total irrigated acreage captures the expansion effect in acreage response. Econometric estimation of the parameters of acreage response model suggests producers primarily base their acreage allocation decision on mean expected returns of their crop.

Based on the econometric estimation, irrigated acreage and water demand is forecasted through to year 2010. Changes in water demand as a result of reduction in irrigated acreage is measured using both a conventional physical and the econometric model. The conventional physical models do not consider the substitution and expansion effects in determining agricultural water demand. In contrast, the econometric model considers these effects. The difference in the estimates of water demand is called slippage. This study has attempted to identify the presence of slippage and the pitfalls associated with not considering substitution and expansion effects in measuring changes in water demand. This analysis indicates a 13% slippage caused by disregarding the role of prices and total irrigated acreage.

In considering the dynamic substitution and expansion effects in acreage allocation, policy makers may be better equipped to assess the net change in water demand. Greater precision in estimating agricultural water demand is required for developing future policies considering supply allocation. For example, in the Flint River Drought Protection Act instead of the expected 130 million gallons a day (mgd) as a direct result of this Act the actual reduction based on this analysis is only 113 mgd. Thus, failure to make adjustment as suggested in this dissertation would lead to erroneous policy analysis.

INDEX WORDS: Acreage Response Models, Corn, Cotton, Flint River Basin, Forecast, Irrigation water demand, Peanuts, Slippage, Soybean

FORECASTING IRRIGATION WATER DEMAND: AN APPLICATION TO THE FLINT RIVER BASIN

by

IRFAN YOUSUF TAREEN

B.S., Lock Haven University, 1991

B.A., Lock Haven University, 1991

M.S., The University of Georgia, 1995

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IRFAN YOUSUF TAREEN

Approved:

Major Professor:	Michael E. Wetzstein
Committee:	Jimmy R. Bramblett Lewell F. Gunter Jack E. Houston Chung L. Huang

Electronic Version Approved:

Gordhan L. Patel
Dean of the Graduate School
The University of Georgia
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ممی اور پاپا کے نام
جن کی محبت نے مجھے رستہ دکھایا
اور
جن کی تربیت نے مجھے قابل بنایا

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CHAPTER 1

INTRODUCTION

Background

Irrigation is the artificial supply of water to land. In agriculture, irrigation may be used to augment precipitation, extend a growing season or enable farming in dry seasons or regions. Generally throughout the world, farmers rely on precipitation for crop production. However, irrigation is required in crop production wherever precipitation amounts to less than ten inches a year (Karadi, 1998). In regions with an annual precipitation of only ten to 20 inches, some crops may be grown by dry-land farming methods, but larger and more dependable yields can be obtained through irrigation. Even in regions with adequate annual rainfall, irrigation may be necessary if the seasonal distribution is such that a dry period comes during the growing season. Supplemental irrigation is also desirable in regions that are subject to short droughts even though the total rainfall during the growing season may be adequate. Consequently, irrigation is practiced by more than half the farmers in the world.

Methods of irrigation depend on local conditions, including topography, crops to be irrigated, the nature and location of the water supply and drainage characteristics of the soil. For these reasons, modern irrigation methods vary widely, but they fall into one of five general categories: flooding, furrow irrigation, subirrigation, sprinkling and drip irrigation (Karadi).

In the flooding method, water covers the surface of the irrigation plot continuously and is contained there by small dikes or ridges. The fields to be irrigated are usually divided into smaller basins. Water is released from field ditches through siphons or by cutting temporary gaps through the earthen ridge of secondary ditches. After filling a basin with water, the farmer removes the siphons or closes the gap and repeats the procedure at the next basin.

Many crops are irrigated by furrows, which are ditches between ridges on which the crops are planted. The water, coming from laterals, is admitted to each furrow by cutting away a small earthen dike, thus opening a gap. When the water in each furrow has reached the desired level, the supply is cut off by reclosing the dike. Water seeps into the soil and feeds the roots of the plants. Compared to flooding, this method is more expensive to build and to operate. It can be justified, however, for high-value crops such as vegetables.

If soil conditions are favorable and the groundwater table is near the surface, subirrigation or underbed irrigation is used. Here water is delivered to the field in ditches and allowed to seep into the ground to maintain the desired groundwater level to feed the roots of plants. Compared with the flooding method, the amount of irrigation water is reduced significantly, but given direct exposure of the roots, subirrigation also requires water with low salt content. This approach is effective for delicate plants, such as strawberries, small fruits and vegetables, because it keeps the tops of the plants dry, which helps to prevent spoilage through rot or mildew.

The sprinkler method is in some ways the most convenient and efficient irrigation system. Most types of sprinklers require piping and pumps. The water can be placed exactly where it is required, and the flow rate can be regulated more accurately than in other systems. Sprinklers can also be used effectively on rough and hilly land without smoothing and grading. There are several types of sprinklers, some much like lawn sprinklers. Units can be portable, permanent or semipermanent. Rotary sprinkler systems are widely used in the United States. They consist of sprinklers mounted on a radial pipeline supported by towers. The towers are mounted on two wheels or small trucks for movement across a field. The pipeline is slowly rotated about a central pivot by electric motors at each tower or, in self-propelled systems, by water pressure actuators. A single system can irrigate an area of 24 to 260 acres. This has been the preferred method of irrigation in Georgia. In 1998, approximately 57% of Georgia farmers used sprinkler irrigation techniques like the center pivot system.

In drip or trickle irrigation, a perforated plastic pipe is laid on the ground. The perforations are designed to release a controlled amount of water near the roots of plants. The method minimizes water losses due to both evaporation and deep seepage below the root level. It is practiced mainly in areas where water supplies are limited.

Factors that affect farmers' decisions related to irrigation include expected crop price, water cost (mostly initial cost of installing the irrigation system, and then some costs associated with operating those systems), risk perception, expected yield response, role of government programs designed to minimize risk to farmer income and water availability. Irrigation management requires an understanding of irrigation technologies, soil-plant-water processes and economic factors affecting the choice of crop planted.

Irrigation is a historic technique that has aided farming around the world. Although irrigation has evolved through time, there have been significant changes in irrigation technology over the last 50 years (Boggess et al., 1993). In addition to the introduction of new technologies such as sprinkler and drip irrigation, there have been improvements made in water pumping and conveyance technologies.

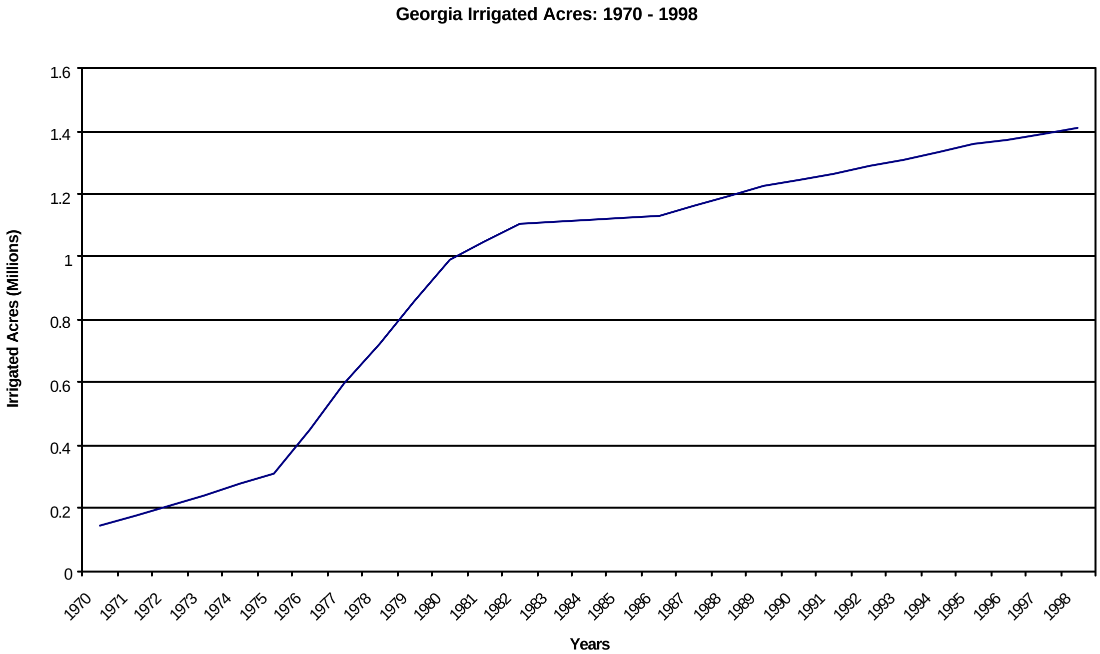
Irrigation dates back to about 5000 BC, when the Egyptians first used irrigation techniques. One of their first major irrigation projects was built in about 3100 BC during the reign of Menes, founder of the first dynasty. Ruins of elaborate irrigation projects built 2,000 to 4,000 years ago can still be found in many countries of the Middle East. The Marib Dam in Yemen, built in about 500 BC to store water for a large irrigation system, was in operation for more than 1,000 years. A large irrigation project in the Sichuan province of China dates to the third century BC and is still in use.

Agricultural irrigation flourished in the Western Hemisphere more than 2,000 years ago. The Incas in Peru developed an advanced agricultural civilization based on irrigation. About AD

1200, the Hohokam Indians in Arizona constructed extensive systems. Ditches in the Salt River Valley of Arizona, built around 1400 AD, are in use today. Mormon settlers in Utah established the first large-scale irrigation project in the United States in 1847. As other settlers moved into the West, many irrigation works were built. The early ones were small and crude, but later associations of farmers and commercial firms built more sophisticated ones. In 1868, the federal government entered the field with the construction of works to provide water for the land on the Mojave Indian Reservation in Arizona. By 1900, about 9.5 million acres were being irrigated in the west (Karadi). With the passage of the National Reclamation Act in 1902, the government began to finance projects that were too large for individuals, groups or even states. Today most large irrigation projects are initiated and directed by national governments. By 1980, products from irrigated land accounted for over a third of the total value of agricultural output in the U.S. (Day and Horner, 1987).

Historically, the southeastern U.S. has been considered water abundant, with farmers relying heavily on precipitation for crop production. A possible source to study water use in Georgia are the irrigated acres. It is difficult to assess agricultural water use in Georgia directly, because there are few, if any, records of water use. However, there is relatively a better time series of irrigated acres available. Examining recent history of agricultural water use in Georgia reveals that through most of 1970s there were sharp increases in irrigated acreage that continued well into the 1990s (Figure 1.1).

One possible explanation of this phenomenon is that credit agencies began requiring farmers to irrigate a proportion of their land to minimize the downside risk associated with a poor yield. Another explanation is that, historically, irrigated production of corn, soybeans and peanuts has been found to be more profitable in most



Source: USDA-NRCS

Figure 1.1. Georgia Irrigated Acreage: 1970 - 1998

cases in Georgia relative to nonirrigated production (Moss and Saunders, 1982; Mackert et al., 1980). This is evidenced by dramatic changes to acreage under irrigation for these three commodities. In the ten year period, between 1970 and 1980, the acreage rose from 30,418, 38,227 and 795 to 410,241, 271,323 and 133,695 acres in corn, soybean and peanuts, respectively (Proceedings of the 1999 Georgia Water Resources Conference). Additionally, Tew notes that it is the expectation of profits rather than the absolute levels of profits that makes irrigation a desirable technology. With the 1990s being a decade of declining price supports, there was a motivation for bringing a larger amount of land under irrigation to enhance the expectation of profits.

According to a study by the U.S. Department of Agriculture - Natural Resource Conservation Services (USDA - NRCS), Georgia agriculture, with its 7,500,00 acres of farmland (over 37% planted for crops) is the major consumptive water user in the state. Despite the large consumption, it is unknown precisely how much water agriculture uses on a county by commodity basis. This level of disaggregation is desirable, because information on a crop by county basis facilitates a better understanding of agricultural water demand. Crop by county information identifies the variation in water demand owing to unique soil, climate and market conditions in a county. Furthermore, information on a commodity level fine tunes the agricultural water demand projections in face of changing government commodity programs and profitability for different crops. In absence of this information, policy proposals and decisions regarding what and how much to irrigate are made under incomplete, and potentially inaccurate, information.

A recent water summit in Southwest Georgia emphasized the problems associated with policy making under incomplete information. Engineers and economists were like-minded on the desire for additional information regarding agricultural water use in the state. The participants at the water summit agreed that more temporal and site-specific information is required for understanding Georgia's future agricultural water demands. Site-specific temporal information is especially required in vulnerable areas, both in terms of water quantity and quality. With regards to water quantity, it is important to assess the effect of withdrawals on competing users of the watershed. In Southwest Georgia, where the Flint River is inextricably linked with the ground water tables, the issue of water quality is also a critical one.

As a specific example of rising pressure on agricultural water demand, the Alabama-Cossa-Tallapoosa (ACT) and Apalachicola-Chattahoochee-Flint (ACF) River Basins in Alabama, Florida and Georgia may be considered. The ACT-ACF River Basin are comprised of 62 Georgia counties, 34 Alabama counties and 6 Florida counties. In 1992, the Governors of Alabama, Florida and Georgia and the Assistant Secretary of the Army for Civil Works signed a Memorandum of Agreement (MOA) establishing a partnership to address interstate water resource issues and promote coordinated systemwide management of water resources.

A key part of this process was conducting a comprehensive study of the ACT and ACF River Basins which concluded in 1997. According to the study, the total agricultural water withdrawals from the ACT-ACF River Basins were approximately 400 million gallons per day (mgd) in 1992. Of the 400 mgd water, Georgia farmers used 72% of the total, while farmers in Alabama and Florida accounted for 21% and 7%, respectively. They also forecasted a 40% increase in agricultural water demand between 1992 and 2000 in the tri-state area.

As evidenced in the USDA-NRCS study, the greater pressure on the water resources in the tri-state area of Alabama, Florida and Georgia is the root cause of ensuing water negotiations amongst these states. Examining relatively recent history, the three-year-long drought in Georgia, 1997 through present time, has resulted in greater uncertainty in agricultural yield. This uncertainty has accentuated the need for agricultural water use in Georgia. Current demands for water from Georgia's neighboring states and from within Georgia are creating conflicts which cannot be easily addressed.

Negotiations and studies to achieve an equitable allocation of water among these states have been going on for about 10 years. It appeared that the settlement process was heading to federal courts because of a failure to reach an agreement in 1999. However, the lessons of water litigation from the western U.S., and more recently, from Colorado, Kansas and Nebraska over the Republican River Compact may serve as a disincentive against litigation. The Republican River Compact was designed in 1943 to improve efficiency of water use and remove potential water conflicts in the region. The Compact has resulted in limited success. Recently, Colorado, Kansas and Nebraska sued and counter-sued each other over issues of water flow and inclusion of ground water in the definition of water rights. According to the last court decision in favor of Kansas, the judge assessed damages to be paid by Colorado in the order of $66 million for lost economic activity, lost yields and resulting loss in Kansas state and local tax revenue from 1965 onwards (Norton, 2000). In view of such a law suit, Georgia and Florida have considered mediation as a better alternative. Consequently, in late October 2000

Dr. Talbot D'Alemberte, president of Florida State University, was selected as the mediator to assist with the ACF portion of the River Basin between Georgia and Florida. These mediation attempts are steps towards a potential ACF Compact between Alabama, Florida and Georgia.

To better understand agricultural water demand in the context of cropping mix in the ACF River Basin, this analysis focuses closely on a 31-county region in Georgia which approximates the Flint River Basin (see figure 1.2). The counties, comprising the Flint River Basin, contain a representative crop mix for the state and consumed approximately 51% of the irrigation water in the state of Georgia in 1995.

Problem Statement

A dependable water supply is vital to the well-being and economic development of the state. Proposals to develop water resource projects and to protect water uses for municipal and industrial purposes in North Georgia have created serious problems among other water user groups in the state.

There is a lack of information on agricultural water use. Policy makers do not have a clear understanding of the past, present and future water demands by farmers. An understanding of historical agricultural water use patterns in Georgia is imperative to improved decision-making and policy development that will influence agricultural water use. Although efforts have been made to bridge the knowledge gap, there still remain numerous problems to date associated with estimating agricultural water demand in Georgia. This dissertation will address four main problems: limited data sources, absence of an economic model of agricultural water demand, lack of link between the economics and engineering models of agricultural water use, and dynamics of agricultural water demand.

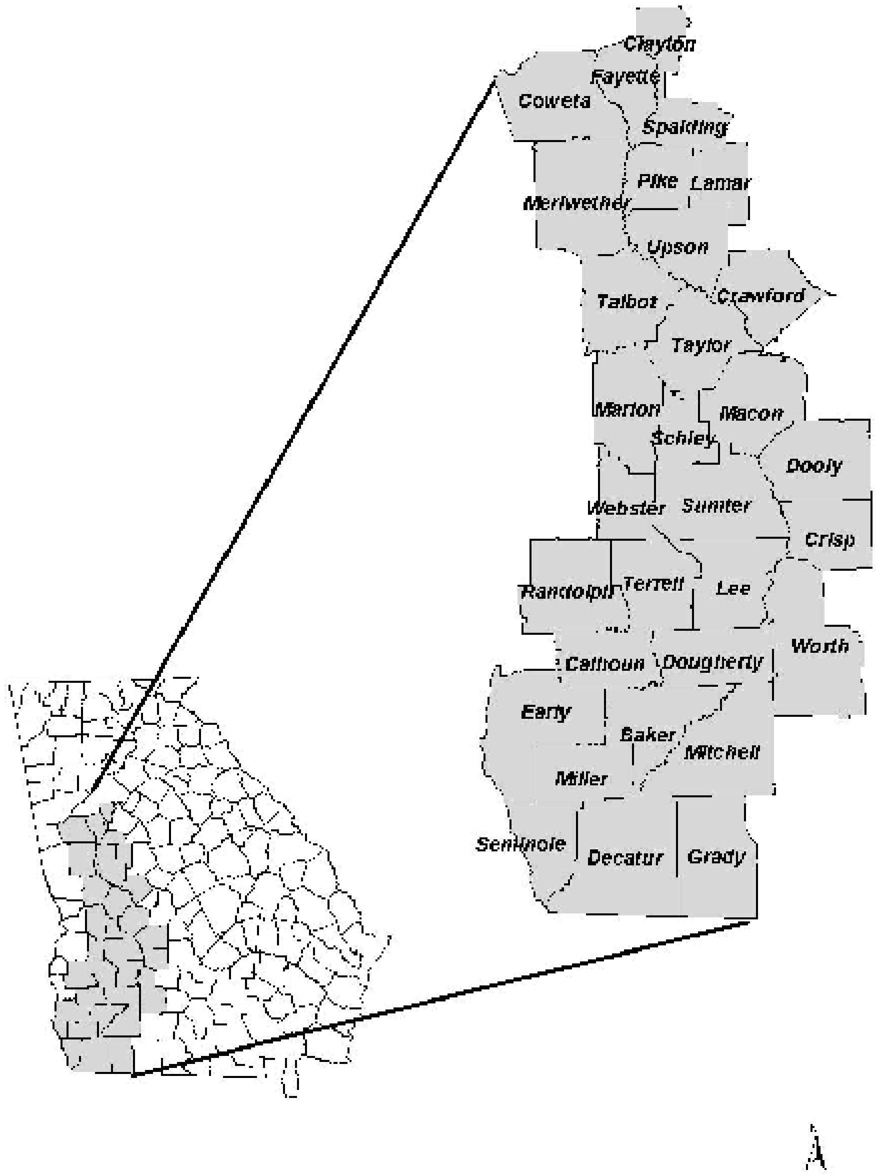


Figure 1.2. Georgia Counties Approximating the Flint River Basin.

The first problem associated with estimating agricultural water demand is the limitation of available data sources. The first potential sources of information are the estimates made by county extension agents on irrigation patterns on a county basis. These are aggregated to reflect measures of irrigation behavior for a given crop for the state or total irrigation in the entire county for all crops combined. Using these data, however, irrigated acreage cannot be broken down on a county by crop level and, therefore, site-specific irrigation patterns remain unknown. There is also a tendency for the agents to mis-estimate the irrigated acreage. A possible source of under estimation may be under counting the orchards that are irrigated. The open area irrigation systems, accounted through aerial photo observation, may be unobservable when under tree cover in the orchards.

A second potential source of information is the irrigation permit data base that exists for Georgia and is managed by the Environmental Protection Department (EPD). This data base was established in the late 1980s and EPD required farmers using over 100,000 gallons per day to apply for these irrigation permits. Presently, the data base has information on approximately 18,000 producers reporting their intended irrigated acres with certain irrigation systems. This source could have been used to disaggregate the acreage by counties. However, to guarantee a bigger share of water, there is a tendency of farmers to over-report the area to be irrigated, frequently to an extent exceeding the physical limits. The other limitation is that irrigation systems are not static and may be moved from, say, one pond to the other and used to irrigate more or less area than claimed in the permit application. Thus, there is not a clear link between the permit and irrigated acreage. Consequently, these limitations may render the claimed irrigated acres by county in Georgia a dubious figure.

The third potential source of data are the USGS estimates of agricultural water use for the years 1980, 85, ‘87, ‘90 and ‘95. The USGS estimates define all water use, such as agricultural, municipal and thermoelectric, in the state of Georgia. They attempt to parse the agricultural component of the estimates into ground water and surface water as well as into livestock and other agricultural commodities. This is done by using the two data sources mentioned above, namely the EPD irrigation permit data base and the irrigation survey conducted by the county extension agents. In using these two data sources, the USGS estimates carry over the problems associated with them.

Thus, presently available potential sources to quantify irrigation water use and to forecast water demand in Georgia are insufficient. Furthermore, with regards to the second problem of interest, current models of agricultural water use have an engineering slant and examine only the physical parameters, such as weather. Forecasting water demand requires economic and institutional variables, such as expected profits and role of government programs.

Models based on physical parameters estimating water requirements for different agricultural commodities were based on the Blaney-Criddle (BC) formula. Blaney and Criddle found that the amount of water consumptively used by crops during their normal growing season was closely correlated with mean monthly temperatures and daylight hours. They developed coefficients that can be used to convert the consumptive use data for a given area to other areas for which only climatological data are available. The net amount of irrigation water necessary to satisfy consumptive use is found by subtracting the effective precipitation from the consumptive water requirement during the growing or irrigation season.

Attempts have been made to update the BC formula by more precise measures of Georgia water application rate. The first study of this type in Georgia was by the U.S. Geological Survey (USGS) and was called *Benchmark Farms Study* (Fanning, 1995). For the 1995-96 growing season, USGS randomly selected and studied 200 irrigation systems in a 32 county area in Southwest Georgia. Their intent was to build a monitoring network for the entire state and to improve irrigation estimation techniques based on the B-C formula (Fanning, 2000). The study was conducted by strapping monitors to the irrigation system to measure water use by measuring the time the systems operated and calculating the application rate. This was aimed at better approximating the application rates, which were used as a measure of water use. Results from the study are not available to date.

Presently, a similar study is ongoing by the University of Georgia-Agricultural Engineering (UGA-AE) department examining 400 sites for three years. In examining a larger number of farms over the entire state and focusing on the center pivot irrigation system, the study by UGA-AE is intended to provide relatively precise measures of the application rates. The estimates of application rates are to serve as a proxy for water demand. This will be a contribution to the existing engineering models for water demand put forth by the USGS .

Another study conducted by the University of Georgia-Center for Remote Sensing and Mapping Science (UGA-CRMS). This study aimed at further improving the estimates of irrigation water application rate by using remote sensing devices. The study took place in the lower Flint River Basin with the aid of low level photography to get an accurate measure of agricultural irrigated acres in the study area.

The studies by USGS, UGA-AE and UGA-CRMS are very valuable in providing a bench mark for water use. However, these studies have a limited temporal scope and are also limited in only examining the physical relationships. Demand for water is driven by several economic factors. The decision to irrigate a given crop depend in turn on several factors, such as the market price a producer expects for the crop, the cost of irrigation, the downside risk associated with not irrigating, the effect of government support programs on prices and total irrigable land available. A thorough examination of water demand in agriculture must, therefore, entertain these economic factors in addition to the physical relationship examined by the above two studies. Furthermore, the physical models, in disregarding the economic forces driving the choice of crop to be planted, are susceptible to slippage in forecasting water demand. Slippage, in the context of water demand, refers to reduction in irrigated acreage for which there is no corresponding reduction in water use (Ericksen, 1976).

The demand for irrigation water is a derived demand evolving from the value of agricultural product produced. A key variable, price of water, required to estimate agricultural demand for water directly is zero in Georgia. Thus, irrigation water demand may not be modeled directly and requires certain physical and economic determinants. The planted acres of the crop are the major determinant for the derived demand for water.

Water application by farmers is made on a per acre basis and is a function of the crop planted to those acres. The appropriate modeling strategy is one that examines the changes in the cropping mix patterns committed to irrigation as the economic and institutional parameters of the problem, such as profitability of different crops and availability of total irrigated acreage. In the literature, such models are referred to as acreage response models. An acreage response model is simply a model that traces changes in the acreage due to changes in the economic parameters. An acreage response model is the primal representation in the duality based approach of supply response. Primal representation offers greater possibilities for using knowledge generated by the production sciences which, in turn, permits using the identification limits of available data to better understand producer's behavior. Another desirable characteristic of acreage response models is their independence from the subsequent weather conditions. Thus, acreage response models are theoretically consistent with farmer's decision making framework. Furthermore, a site-specific acreage response model, based on county by commodity data, is considerably more useful than one on an aggregate level, such as the state. Currently available irrigation data is on a state level and must be parsed on a county by crop level.

To summarize the problems, while efforts have been directed toward better understanding the spatial dimension of Georgia's irrigation issues, the temporal element is missing from this discourse. Historical knowledge of economic and institutional factors aid future projection of acreage allocation. Currently available information in Georgia is solely based on physical models and is thus inappropriate for forecasting. Accurately forecasting water demand requires a consideration of physical, economic and institutional determinants. Data presently available for analysis are also limited because they are highly aggregated.

River Basin planners are required to forecast agricultural water demand in each of Georgia's 14 river basins. Their plans are based on limited information as described above. A method for forecasting Georgia agricultural water demand for commodities on a county basis will be of import to the river basin planners. A temporal and site-specific acreage response model is aimed at linking water demand with cropping patterns. In linking water demand with cropping patterns, the acreage response model will complement the findings of the physical models. It will also improve the information base for future policy work in a changing economic climate for Georgia agriculture. The desire for county and commodity specific water demand by planners and policy makers leads to the following objectives.

Objectives

The main objective of this study is to develop a method for forecasting Georgia agricultural water demand for corn, cotton, peanuts and soybeans on county level basis. Specifically, developing such a forecasting method requires

1. Deriving a method for disaggregating available state level data to a county and commodity level.
2. Employing this disaggregated data for estimating crop irrigated acreage response based on physical, economic and institutional determinants.
3. Applying the estimates of crop acreage by county to the B-C formula for forecasting the quantity of water demanded for a given choice of crop by county.
4. Conducting a sensitivity analysis given changes in the economic and institutional conditions.

Procedures

Objective 1 is achieved by combining state and county level data in such a way that county by crop estimates of irrigation sum up to the available total irrigation by county. Objective 2 is accomplished by developing an econometric acreage response model based on economic theory of expected utility maximization. For objective 3, parameter estimates from this econometric model are used in the B-C formula for forecasting irrigation water demand. Finally, sensitivity analysis is conducted on the parameters of the acreage response model to trace the effects of alternative prices, weather and institutional arrangements.

CHAPTER 2

REVIEW OF RELATED LITERATURE

Agricultural economists' interest in modeling agricultural commodity response stems from employing elasticity estimates in policy analysis and forecasts under government intervention. Existing literature contains a large number acreage response models relative to supply response models for estimating crop production. An acreage response model is the primal representation in the duality based approach of supply response. Primal representation offers possibilities for using knowledge generated by the production sciences which, in turn, permits using the identification limits of available data to better understand producer's behavior. Furthermore, the acreage commitment timing of the farmers renders an acreage response model appropriate for the current analysis. This chapter provides the connections in the literature of models of acreage response and forecasting.

Acreage Response Literature

Estimating acreage response has resulted in numerous articles since the seminal work by Nerlove (1956) on partial adjustment and adaptive expectations models of prices. The basic Nerlovian framework has been extended in several ways. Some of these studies incorporate the role of government programs (Houck and Ryan, 1972; Morzuch, Weaver and Helmberger, 1980; Duffy, Richardson and Wohlgenant, 1987; Shideed, White and Brannen, 1987; McIntosh and Shideed, 1989; Chembezi and Womack, 1992; Massow and Weersink, 1993). Other studies consider alternative expected market price in the model where suggestions include a simple one-period lag (Duffy et al., 1987), the higher of a geometric lagged function of the previous seven years' market price or current weighted support price (Shumway, 1983), futures prices (Gardner, 1976; Morzuch, et al., 1980) and a combination of the cash and futures prices (Chavas, Pope and Kao, 1983). The Nerlove model has also been extended by considering the role of risk in acreage allocation (Just, 1974; Lin, 1977; Traill, 1978; Nieuwoud, Womack and Johnson, 1988; Chavas and Holt, 1990; Pope and Just, 1991; Duffy, Shalshali and Kinnucan, 1994; Krause, Lee and Koo, 1995). Risk typically enters the model through an agent optimizing expected utility (EU). In case of normally distributed returns, the expected utility criteria is completely specified by the expected value and variance of returns. The expected value-variance (EV) rule is based on the proposition that, if the expected value of the choice A is greater than or equal to the expected value of choice B, and the variance of A is less than or equal to the variance of B, with at least one strict inequality, then A is preferred to B by the decision maker.

Since its development by Markowitz in 1952 as a portfolio selection tool, the EV model has been a popular method of ordering choices into efficient and inefficient sets. The EV set is defined as the choices or sets of choices that provide the minimum variance for alternative levels of expected returns. The efficient set is considered to contain the preferred choice for a well-defined set of producers. In contrast, the inefficient set does not contain the preferred choice.

A justification for the EV approach was shown by Tobin (1958) that expected utility maximizing decisions are always members of the EV set when choices are represented by various combinations of a risky and a safe asset. The resulting choice set has no choices that are excluded from the EV set. Meyer (1985) has since shown that Tobin's condition is a special case of a more general condition requiring linear combinations of random variables.

The EV approach is justified on the basis of four conditions: (1) quadratic utility, (2) normality, (3) choices involving a single random variable and (4) choices involving linear combinations of the random variables. None except condition (4) characterize most empirical situations. Quadratic utility implies that marginal utility becomes negative beyond some monetary outcome and that the investor being modeled is characterized by increasing absolute risk aversion. Few random variables take on symmetrically distributed values ranging from negative to positive infinity as implied by normal distribution. Perhaps most importantly, decision situations concern choices involving more than one risky asset.

These shortcomings of conditions underlying the EV approach have made its justification in empirical analysis dependent on the ability to approximate results obtained with a more general EU models. Porter (1973) showed that the EV sets of randomly constructed stock portfolios were consistent with EU models with the exception of portfolios having small expected values and variances. Tsiang (1972) demonstrated that various restrictions on skewness could yield a close correspondence between EV and EU results. Levy and Markowitz (1979) showed similar effects of EV analysis as an effective approximating approach to portfolio selection. Moreover, the appropriateness of quadratic utility has been defended as a second-order Taylor series approximation to all risk averse utility functions. Thus the debate involving EU and EV models as decision tools has largely focused on the approximating capacity of the EV models.

Acreage response models incorporating risk effects have been modeled for individual commodities without regard to the system-wide impact of these response models (Traill, 1978; Just, 1974; Pope, 1982; Chavas and Holt, 1990; Krause, et al., 1995; Coyle, 1999). In other words, total acreage constraints have not been incorporated into model specifications as they have been for other agricultural supply models (Chambers and Lee, 1986). Since acreage decisions are made among competing commodities, a systems framework is the appropriate modeling technique. Such a technique incorporates contemporaneous covariance of disturbances across the equations and yields efficient estimators. Some notable exceptions which examine acreage response with risk in a systems framework are studies by Bettendorf and Blomme, 1994; Barten and Vanloot, 1996; and Holt, 1999.

The cobweb theorem links supply reacting to the lagged price to demand reacting to the current price. One can generalize this idea to a set of interdependent markets. Bettendorf and Blomme (BB) and Barten and Vanloot (BV) generalize the cobweb theorem for eight agricultural products markets. The supply side is represented by an acreage allotment model, which describes the areas under cultivation for various crops in response to price expectations. The demand side is modeled as an inverse demand system. These two systems were estimated for historical data for Belgium in the early part of this century. Barten and Vanloot conclude that the strength of the response depends on substitution possibilities, which may be restricted in agriculture due to the lack of quality of the soil and lack of knowledge with the farmer on one hand and the specificity of consumer preferences on the other hand.

BB and BV developed a first-order differential acreage allocation model by using the basic mean-variance utility framework. The BB-BV model is consistent with certainty equivalent profit maximization and constant absolute risk aversion. The BB-BV specification is useful for estimating acreage response with time-series data but is limited when cross-sectional or panel data are used. Holt extends their analysis to deal with cross-sectional and panel data. Furthermore, the model as extended by Holt is useful for maintaining the theoretically useful properties of homogeneity, symmetry and adding-up.

A majority of the literature primarily focuses on the acreage response for a single commodity (Houck and Ryan, 1972; Morzuch, et al., 1980; Bailey and Womack, 1985; Duffy, et al., 1987; Ahouissoussi, McIntosh and Wetzstein, 1995; Govindasamy and Jin, 1998). There are relatively fewer studies of acreage response in multiproduct settings. One multiproduct study is by Binkley and McKinzie (1984).

Binkley and McKinzie specify a system of crop acreage demands to improve upon the single commodity studies. Single commodity studies are potentially incomplete since they fail to incorporate all alternative uses of land. Given land fixity, a system of equations provides information about the allocation of land to any one use and its substitutability to other uses.

Unlike the multiple equation models, single equation models fail to capture the interaction among error terms. Hence, a single equation model is limited in providing substitutability information, even if it were to include all alternatives. Despite considering behavioral matters such as convexity and linear homogeneity, there are serious limitations to the analysis conducted by Binkley and McKinzie. They fail to take account of separability, adding-up, duality and assumptions necessary for reciprocity in an acreage demand model. Furthermore, Binkley and McKinzie discuss symmetry conditions, but they apparently do not use or otherwise test for reciprocity in their empirical analysis. Concepts such as separability, adding-up, homogeneity and reciprocity are crucial assumptions regarding the underlying technology in a production function and deserve further explanation. Explanation of each of these concepts is provided in the following discussion before returning to more literature on multiproduct acreage response.

The notion of separability is used in terms of output and refers to the technical feasibility of aggregating groups of outputs. Separability is a measure of how the marginal rate of product transformation (MRPT) is independent between two outputs; i.e., the MRPT for one output is independent of the level of output of another output.

In production theory, adding-up restrictions are typically for imposition of homogeneity. Homogenous technologies are of interest, since they put specific restrictions on how the technical rate of substitution changes as the scale of production changes. This restriction is often seen in translog models. Models which use normalized quadratic functional forms (or any normalized model, such as the translog) will not have them, as the restriction is imposed by normalization.

Reciprocity refers to symmetry of the cross-partial derivatives. Symmetry is an artifact of assuming that your response can be modeled using a twice-continuously-differentiable function. According to Young's theorem, the second partial derivatives of any twice-continuously-differentiable function are invariant to the order of differentiation.

With respect to the literature on land allocation models, the shares allocated to each of the crops behave as probabilities. Not only the actual shares but the predicted shares are non-negative and sum to one. Several specifications can ensure that the shares sum to one, but the dual problem of adding-up and non-negativity requires highly non-linear equation systems to be used. This non-linearity is characteristic of logistic type functions. A possible model to fulfill the basic requirement is Theil's (1969) multinomial extension of the linear logit model. Colman (1979), Kraker and Paddock (1985) and Bewley, Young and Colman (1987) all use the strategy of specifying a system of crop acreage demands conditional on all crop output prices and total crop acreage using a multinomial logit model. The disadvantage of this strategy is that multinomial logit models tend to increase in complexity as the number of crops grows. Also, in these three articles, the authors fail to exploit the role of separability as a means of simplifying the model structure.

Multiproduct models of crop acreage response system have addressed model diagnostic issues such as multicollinearity by adopting highly restrictive functional forms. In doing so, these models have overlooked many cross-price effects. An alternative to these restrictive functional forms is adopting restrictions on coefficients implied by fundamental behavioral theory. An article by Coyle (1993) is an effort in this direction. Coyle presents an alternative approach to the specification of systems of crop acreage response. The two-stage aggregation model by Coyle is appropriate, given the assumption of weak separability between the enterprises. The system of individual crop acreage demands specified in Coyle's model relates demands to lags in adjustment of the overall crop rotation while preserving the simplicity for estimation of a lag in a single acreage variable. Derived demands of acreage for individual crops are specified as conditional on total crop acreage, and related separability and dynamic specifications further reduce the effects of multicollinearity in the system. In Coyle's framework, reciprocity restrictions and duality relations are also taken into account. In terms of behavioral consistency, this is a significant contribution over the previous work by Colman, Kraker and Paddock and Bewley, Young and Colman.

Forecasting Literature

Theoretically consistent elasticity estimates may be used in improving the forecast of input demand. However, little, if any, literature exists that deals with using elasticities to forecast irrigation water demand. To capture the unique response to a policy for a given commodity, an analyst may use several forecasting tools. Forecasting in general may be divided into two broad categories: structural econometric models and time-series models using the Box-Jenkins (1976) techniques. Research indicates that forecasting in agricultural economics may also be dichotomized in a similar fashion (Allen, 1994). Structural forecasting in agricultural economics dates back to the first econometric forecast for agricultural commodities by Moore in 1917. Using regression of cotton yield on rainfall and temperature in selected months, Moore outperformed the USDA models of forecast based on condition reports. The early years of econometric forecasting are characterized by single equation forecasting models. Sarle (1925) forecasted hog prices, Smith (1925) cotton acreage, and Hopkins (1927) cattle prices. One of the few early efforts of pure forecasting using a single equation was by Cox and Luby (1956), whose specifications for 6 and 12 month ahead price forecasts also relied on explanatory variables known non-stochastically at the time of forecasting. Dynamic structure is introduced to agriculture economics models by the adaptive expectations for prices developed by Nerlove (1958). Expected prices are modeled as an exponentially decaying function of past prices. Asakri and Cummings (1977) present an excellent review of this line of research.

Since the 1960s, there has been an interest in estimating time series models and comparing these models to their structural counterpart. In their earliest form, time series models aimed at deterministic trend extrapolation. An earlier application of time series methods in agricultural economics is the study of Australian wool prices by Jarret (1965). Schmitz and Watts (1970) forecast of wheat yield is the earliest application of time series methods to U.S. agriculture where they apply Box-Jenkins and exponential smoothing to annual data. Exponential smoothing, producing better out-of-sample forecasts, is deemed a winner in this comparison. However, unlike business forecasting, this standard has not been followed in the agricultural economics literature. Around the same time, there were efforts to explain the historical patterns via spectral analysis instead of forecasting (Rausser and Cargill (1970); Cargill and Rausser (1972); Hinchy (1978)). In the 1980s, a transfer function was used to study multivariate time series (Shonkwiler and Spreen, 1982). Bessler (1984) introduced vector autoregression (VAR) to agricultural economics despite criticism of over-parameterization and the fact that VAR is an atheoretical approach to modeling. In efforts to circumvent the undesired effects of over-parameterization, several articles were published. These articles are reviewed in Kaylen (1988).

In summary, acreage response models are a more direct method of estimating crop production than supply response. Such is the case because planting decisions are independent of the subsequent weather conditions and, therefore, acreage response models are theoretically consistent with farmer's decision making framework. Since the seminal work by Nerlove in 1956, there have been, and continue to be, numerous articles published in this area. The basic Nerlovian framework has been extended in several ways. Some of these studies incorporate the role of government programs, while other studies consider alternative expected market price in the model. The Nerlove model has also been extended by considering the role of risk in acreage allocation. However, until recently the limitation in acreage response studies has been the focus on the acreage response for a single commodity. There are relatively fewer studies of acreage response in multiproduct setting incorporating the effect of risk. Sparser still is literature on the role of risk in a multiproduct setting on a state or county level.

To summarize, forecasting literature may be divided into two broad categories: structural econometric models and time-series models using the Box-Jenkins techniques. Structural forecasting in agricultural economics dates back to the first econometric forecast for agricultural commodities by Moore in 1917. Dynamic structure is introduced to agricultural economics models by the adaptive expectations for prices developed by Nerlove. Since the 1960s, there has been an interest in estimating time series models and comparing these models to their structural counterpart. Around the same time there were efforts to explain the historical patterns via spectral analysis instead of forecasting. Since the 1980s, forecasting in agricultural economics may be characterized by Bessler's introduction of vector autoregression (VAR) models to agricultural economics. Despite criticism of overparameterization and VAR's atheoretical approach to modeling, it has been a well-accepted tool in the discipline.

Justification for Present Study

Most forecasting in agricultural economics literature has focused on prices and production (See Allen, 1994, for an excellent review of forecasting in agriculture articles). There is some literature for derived demand for agricultural inputs in general and irrigation water in particular (Shumway, 1973; Lynne, 1978; Apland, et al., 1980; Nieswiadomy, 1985; Kulshreshta and Tewari, 1991). Focus of much of this literature is agricultural production in the western United States (Gisser, 1970; Shumway, 1973; Connor, et al., 1989; Ogg and Gollehon, 1989). There is very little research done on irrigation water demand in the southeastern U.S. (Pierce, et al., 1984; Duffy, et al., 1994; Moss and DeBodisco, 1999; Houston, et al., 1999). Sparser still is research that considers forecasting irrigation water demand, either on a national or a regional level. The present study develops a method to forecast Georgia agricultural water demand for corn, cotton, peanuts and soybeans on a county basis. The method employs the irrigated acreage response to changes in the economic climate of Georgia on a county by commodity basis. The following chapter addresses the theoretical model development which closely follows the EV framework.

CHAPTER 3

ACREAGE RESPONSE: THEORETICAL MODEL

This chapter lays out the theoretical underpinnings for the empirical analysis. First, expected utility theory is defined for a general case. Second, the properties of a representative utility function are formalized using a Taylor series expansion. Finally, a theoretical model of acreage response is derived based on expected utility function of a farming enterprise.

The demand for irrigation water is a derived demand evolving from the value of agricultural products produced. Static and deterministic empirical models of water demand indicate adoption of modern irrigation technologies depends on price of water, labor, output level, output prices, soil slope, water holding capacity and climate (Caswell and Zilberman, 1985; Nieswiadomy, 1988; Negri and Brooks, 1988; Lichtenberg, 1989; Schaible *et al.*, 1990). These studies suggest that introduction of modern technology tends to use less water and increase yields, both effects are stronger with poorer land qualities.

The deterministic models are effective in assessing seasonal water demand and irrigation technology choices by risk neutral producers. However, given risk in yield and prices, there is uncertainty involved with the profits of an enterprise. Irrigation is an example of a risk-reducing technology. The decision to irrigate by a risk averse individual is appropriately modeled through techniques allowing the effects of risk in decision making models. The major analytic tool for solving decision problems under risk is the expected utility model. The expected utility theorem provides a complete theory of choice under uncertainty and is widely used by economists to formally describe individual decisions under risk. The expected utility hypothesis states that the individual assigns a utility value to each mutually exclusive activity with an associated probability distribution that is an outcome of a decision. The preferred choice has maximum expected utility. Bernoulli first formulated the expected utility theorem in 1738, when he postulated that an extra dollar has more value to a poor man than to a rich man. The concept was extended using a set of behavioral axioms by von Neumann and Morgenstern (1944). In an expected utility model, a representative agent maximizes expected utility subject to an endowment constraint. To understand the expected utility theory, a primer for general expected utility theory with its assumptions and limitations is discussed in the following section (Wetzstein).

The Elements of Expected Utility Theory

In making future investment plans, a representative firm will consider the probability of possible outcomes. In determining the probabilities of these outcomes, a firm may use a combination of both subjective and objective probabilities. A firm is then faced with choosing alternatives with uncertain outcomes by means of known probabilities. These risky alternatives are called states of nature or lotteries, *L*. A state of nature is a set of probabilities, summing to one, for each of the n outcomes. In general, a state of nature is a set of probabilities for all n outcomes.

There is a fundamental difference between commodities and states of nature. Commodities can be, and generally are, consumed jointly. An example is driving and listening to the radio. Alternatively, states of nature, by their definition of being mutually exclusive, cannot be consumed jointly. Either one state of nature exists or another, but two or more states of nature cannot coexist. The idea of being unable to jointly consume two or more states of nature is a fundamental assumption of many theories dealing with choice under uncertainty. This assumption may be summarized by the following independence axiom:

If L, L', and L" are alternative states of nature and D is the probability of the state of natures L and L' occurring, then L š L' if and only if DL + (1 - D)L" š DL' + (1 - D)L"

The preference a firm has for one state of nature, *L*, over another state, *L'*, should be independent from other states of nature, say, *L"*. This other state of nature *L"* should be irrelevant to a firm's choice between *L* and *L'*. In other words, what does not happen should not affect the level of preferences between two possible states of nature.

Based on this independence axiom, the utility function for choice under uncertainty is additive for consumption in each possible state of nature. For all possible states of nature, utility from consumption in one state of nature is added to the utility from consumption in another state. Such a utility function is called the expected utility function or also called the von Neuman-Morgenstern utility function. For two possible states of nature, 1 and 2, the expected utility function is

$U(\vec{x}_1, \vec{x}_2, D_1, D_2) = D_1U_1(\vec{x}_1) + D_2U_2(\vec{x}_2)$,

where U_1 and U_2 are utility functions associated with commodity bundles $\vec{x}_1$ and $\vec{x}_2$ consumed in states of nature 1 and 2, respectively, and D_1 and D_2 are the probabilities of the states of nature occurring. Note, $D_1 + D_2 = 1$. Expected utility is the weighted sum of the utility from consumption in the states of nature, where the weights are the probabilities of the states occurring. If only one of the states of nature occur, say state one, then $D_1 = 1$ and $D_2 = 0$, and the utility function reduces to $U(\vec{x}_1) = U_1(\vec{x}_1)$.

With uncertainty, the probabilities are $0 < D_1, D_2 < 1$, and the utility function represents the average or expected utility given the alternative possible states of nature.

In contrast, with certainty utility functions, which are ordinal measures of utility, expected utility measures utility on an interval scale. Thus, unlike certainty utility functions, the change in the marginal utilities of expected utility do represent changes in preferences.

Specifically, $MU_1 = MU/M\vec{x}_1 = D_1MU_1/M\vec{x}_1$,

represents the change in utility from a change to the consumption bundle $\vec{x}_1$. Thus, any monotonic transformation of the expected utility functions may not yield the same measure of firms preferences. The reason for this result is the independence axiom may be violated by a monotonic transformation.

A set of transformations which do not violate the independence axiom are increasing linear transformations (also called positive affine transformations). A positive linear transformation is written in the form

$V(U) = aU + b,\ a > 0.$

As an example, consider the following expected utility function:

$U(Rx_1, Rx_2, D_1, D_2) = D_1\, ln(Rx_1) + D_2\, ln(Rx_2).$

A linear transformation is then

$V(U) = aD_1\, ln(Rx_1) + aD_2\, ln(Rx_2) + b.$

The marginal utilities associated with this function are

$MU_1 = aD_1/Rx_1, \quad MU_2 = aD_2/Rx_2,$

which do not violate the independence axiom.

Expected utility is a convenient representation of firms' preferences when faced with uncertainty. This is why it is generally used throughout economic theory, yielding positive as well as normative implications. However, expected utility is not universal in offering reasonable explanations of firm behavior. In practice, there may exist paradoxes that seemingly invalidate the foundations of expected utility theory. An example of such paradoxes is the Allais Paradox. Under Allais Paradox, an individual is shown to prefer a sure return as compared to a lottery with a higher expected return. Another example is Machina's Paradox where, for instance, a disappointed fan who is unable to get tickets for the World Series game would rather go entirely without watching the baseball game, even on television. Watching the game on the television reinforces his disappointment. Thus, the disappointed fan ends up choosing an alternative with a lower expected return.

As these paradoxes illustrate, there are individual examples of preferences which violate the independence axiom, and thus, limit expected utility as a model of preferences. However, analogous to the Giffen Paradox, in the aggregate investigation of markets, expected utility can be assumed to represent preferences.

In the following section, properties and assumptions of a representative utility function are presented. They are followed by model development for a farming enterprise with von Neumann-Morgenstern preferences.

Properties of a Representative Utility Function

Several assumptions about individual preferences and the distribution of returns are made to simplify the expected utility model for empirical analysis. First, if returns are normally distributed, the decision maker can rank alternatives using only two parameters, expected value and variance, without concern to the higher moments of the distribution. The individual is assumed to behave as if he were an expected utility maximizer, and maximizing expected value, *ceteris paribus*, is an appropriate goal. Finally, the decision maker is assumed to be a risk averter; thus, the individual wants to minimize the dispersion of returns.

A Taylor series expansion of the utility of profits, $U(B_i)$, for the four crops of interest in the analysis (corn, cotton, peanuts and soybeans) about the expected value, $h = E[\mathbf{B}]$, is carried out to formalize the results of expected utility maximization. Prior to conducting a Taylor series expansion in a multivariate setting, some notation must be defined. A gradient vector, $G(\mathbf{B})$, is defined having components

$$G_i(\mathbf{B}) = MU(\mathbf{B})/MB_i, \qquad i = 1, \ldots, 4, \tag{3.1}$$

and a Hessian matrix $\mathbf{H}(\mathbf{B})$ is defined with components

$$H_{ij}(\mathbf{B}) = M^2U(\mathbf{B})/MB_i\, MB_j, \qquad i, j = 1, \ldots, 4 \tag{3.2}$$

The $G(\mathbf{B})$ is interpreted as a four-component vector and $\mathbf{H}(\mathbf{B})$ as a four by four matrix, both functions of $\mathbf{B}$.

Using the gradient and Hessian, the Taylor series for U can be written in the vector-matrix form as follows

$$U(\mathbf{B} + \mathbf{h}) = U(\mathbf{B}) + \mathbf{G}(\mathbf{B})^T\mathbf{h} + ½\,\mathbf{h}^T\,\mathbf{H}(\mathbf{B})\mathbf{h} + \ldots. \quad (3.3)$$

In this illustration, U is the fixed point of expansion in $\mathbf{U}^4$ and **h** is the variable in $\mathbf{U}^4$ with components h_1, h_2, h_3 and h_4.

By Young's theorem, the partial derivatives are invariant to the order of differentiation, so long as the partial derivatives are all continuous. In the special case of the Hessian matrix, if the second partial derivatives of U are all continuous, then H is a symmetric matrix; i.e.,

$H_{ij}(\mathbf{B}) = M^2 U(B)/MB_i\, MB_j = M^2 U(B)/MB_j\, MB_i = H_{ji}(\mathbf{B})$,

with

$$\mathbf{h}^T H_{ii}(\mathbf{B})\,\mathbf{h} = F_{ii} = Var(B_i), \quad (3.4a)$$

$$\mathbf{h}^T H_{ij}(\mathbf{B})\,\mathbf{h} = F_{ij} = Cov(B_i, B_j). \quad (3.4b)$$

The expected utility of a risky prospect can be expressed in terms of the mean and a series of higher moments of the associated probability distribution. The appropriate number of higher moments are determined by the complexity of the utility function, the desired accuracy of the approximation and the characteristics of the distribution of returns. However, the central limit theorem states that normally distributed returns are more likely than other types of distributions (Samuelson, 1970). Given the normal distribution can be completely specified by the first two moments, a functional form that incorporates only the first two moments is sufficient (Hogg and Craig, 1978).

An alternative assumption, which may be more applicable to agricultural situations because the normality of agricultural returns is not assured, is a quadratic expected utility function. Since the third, U''', and higher derivatives are zero for a quadratic function, higher moments of such functions are irrelevant and the first and second moment are sufficient to characterize the function entirely. Furthermore, given the assumption of risk aversion, the expected utility of profits, EU($\mathbf{B}$), is an increasing function of the first moment of expansion and a decreasing function of the second moment for the risk averse decision maker.

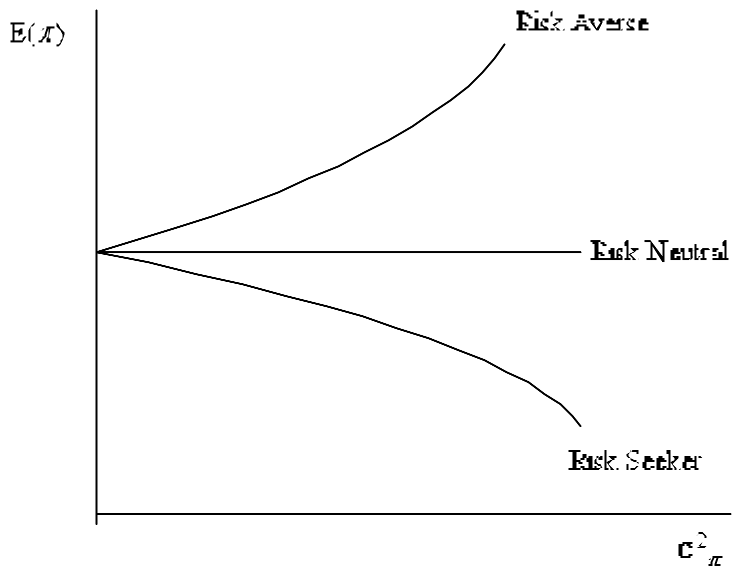


Figure 3.1. Indifference Curves for Risk Averse, Risk Neutral and Risk Seeking Individuals in an Expected Utility and Variance Space.

Figure 3.1 illustrates indifference curves for risk averse, risk seeking and risk neutral decision makers. Expected utility functions for an individual are typically categorized in three ways. An individual is said to be risk averse if for constant wealth, a certain sure outcome is always preferred to a lottery with the same expected value but some positive variance. An individual is risk neutral if he is indifferent between the certain outcome and the gamble and he is risk seeking if the lottery is preferred (Binger and Hoffman, 1997).

Indifference curves for the risk averse individual are convex with respect to the horizontal axis, which assumes that the direction of increasing expected utility is upward and to the left. Having identified the assumptions and properties of a representative expected utility function in general, one may now proceed with the development of the specific expected utility function for the farming enterprise.

Theoretical Framework for Irrigation Decision

There are two theoretical considerations for irrigated acreage decision making: expected utility maximization and agronomic consideration. First the expected utility maximization is laid out and then the agronomic considerations are incorporated in the theoretical framework for irrigation decision making.

Consider a farming enterprise in a given county engaged in producing n crops over A acres of irrigated land. Let A_i denote acres of i^{th} irrigated crop with a corresponding yield of Y_i per acre. Y_i is sold at the market price of p_i per unit of yield. The above activity results in the following revenue function, R, for the farm

$$R = \sum_{i=1}^{n} p_i Y_i A_i \tag{3.5}$$

Revenue *(R)* is a linear function of stochastic prices and yield. By assumption, the vector of prices $\tilde{\mathbf{P}} = p_1, ..., p_n$ and yield $\tilde{\mathbf{Y}} = Y_1, ..., Y_n$ are unobserved at the time of acreage allocation, R is a risky variable. Let the costs of the farming enterprise be defined as

$$C = \sum_{i=1}^{n} c_i A_i \tag{3.6}$$

with c_i as the variable cost of production per irrigated acre of the i^{th} crop. It is assumed that the total variable costs, C, for such an enterprise are known with certainty given input prices and per acre costs are known at the time of irrigated acreage commitment.

Constraints on the irrigated acreage require that all land is allocated to one of the *n* enterprises and that irrigated acreage does not exceed the total available acreage. These constraints may be represented as follows:

$f(\mathbf{A}) = 0,$

$$\sum_{i=1}^{n} A_{iy} = A_y, \tag{3.7}$$

where $f(\mathbf{A}) = 0$ is the production frontier representing the multiproduct multifactor technology of the firm. Variable A_{iy} denotes irrigated acres of i^{th} crop in a county and A_y are total irrigated acres available in the y^{th} county.

If the representative firm maximizes expected utility under competition, then the decision model is

$$\max_{\mathbf{A}} EU(\pi) = \max_{A_i} \{EU[(\sum_{i=1}^{n} \pi_i A_i)]\} \tag{3.8}$$

subject to the acreage constraints in equation (3.7). The per-acre profit accruing from the i^{th} crop is

$\pi_i = p_i Y_i - c_i$.

The formulation of (3.8) indicates that the acreage decision *A* is made under both price and production uncertainty. Both yields $\tilde{Y}$ and output prices $\tilde{P}$ are random variables with given subjective probability distributions. Consequently, the expectation operator (E) in (3.8) over the stochastic variables $\tilde{Y}$ and $\tilde{P}$ is based on the information available to the firm at planting time. The optimization model in equation (3.8) has direct economic implications for the optimal irrigation acreage allocation, A_i^*. If the firm is not risk neutral, the optimal acreage decision will depend not only on expected profits, but also on higher moments of the profit distributions. In case of normally distributed returns, the expected utility criteria is completely specified by the expected value and variance of returns. The expected value-variance (EV) rule is based on the proposition that, if the expected value of the choice A is greater than or equal to the expected value of choice B, and the variance of A is less than or equal to the variance of B, with at least one strict inequality, then A is preferred to B by the decision maker.

Since its development by Markowitz in 1952 as a portfolio selection tool in an optimization setting, the EV model has been a popular method of ordering choices into efficient and inefficient sets. The EV set is defined as the choices or sets of choices that provide the minimum variance for alternative levels of expected returns. The efficient set is considered to contain the preferred choice for a well-defined set of producers. In contrast, the inefficient set does not contain the preferred choice.

The EV approach is justified on the basis of four conditions: (1) quadratic utility, (2) normality, (3) choices involving a single random variable and (4) choices involving linear combinations of the random variables. None except condition (4) characterize most empirical situations. Quadratic utility implies that marginal utility becomes negative beyond some monetary outcome and that the investor being modeled is characterized by increasing absolute risk aversion. Few random variables take on symmetrically distributed values ranging from negative to positive infinity as implied by normal distribution. Perhaps most importantly decisions situations concern choices involving more than one risky asset.

These shortcomings of conditions underlying the EV approach have made its justification in empirical analysis dependent on the ability to approximate results obtained with more general EU models. As discussed in chapter two, Levy and Markowitz have demonstrated the appropriateness of an EV model as a second-order Taylor series approximation to all risk averse utility functions. Acreage response model in the present analysis is one such application of the EV theory being used in approximating expected utility as a function profits and variance-covariance of profits.

According to EV theory an increase in the profits of the i^{th} crop increases the expected utility of the producer. This drives the producers to add more irrigated acres of the i^{th} crop by substituting away from the j^{th} crop and vice-versa for all crops where i...j.
On the other hand, increases in the variance of the i^{th} crop increases risk and drives expected utility of the producer down. The producer, therefore, will reduce irrigated acreage of a crop with higher variance. However, increased variance of the j^{th} crop, with j...i, shows an increased risk associated with crop j. Reducing irrigated acreage of the j^{th} crop frees up resources to commit to crop i.

A negative correlation between two crops in a producer's portfolio reduces risk. A rising covariance between crops and i and j, with i...j, means more exposure to risk to a producer who has crops i and j in their portfolio. Expected utility maybe enhanced by reducing irrigated acreage of both i and j. However, according to portfolio theory with a rising covariance between crops j and k, with both j, k ...i, a producer may increase their expected their utility by reducing irrigated acreage of both j and k and committing resources to crop i.

Agronomic considerations, such as rotation, play an important part in irrigated acreage decision making. Crop rotation is the successive planting of different crops in the same field. Rotations may range between two and five years in length and generally involve a farmer planting part of his land to each crop in rotation (National Research Council). Rotations provide well-documented economic and environmental benefits to agricultural producers (Heady, 1948; Heady and Jensen, 1951; Power, 1987). Some of the benefits of rotation are inherent to all rotations; others depend on the crops planted and the length of the rotation; and others depend on the types of tillage, cultivation, fertilization and pest control practices used in the rotation (National Research Council).

Much of the literature on crop rotation refers to the rotational effect (Powers). This term is used to describe the fact that in most cases rotations will increase yields of a grain crop beyond yields achieved with continuous croppings with similar conditions. Many factors are thought to contribute to the rotational effect, including soil moisture, pest control and the availability of nutrients. It is generally agreed that the most important component of this effect is the insect and disease control benefits of rotations (Cook, 1986).

With regards to insect and disease control, rotation is used in Georgia against the potential of white mold and nematode. The typical rotation cycle is three years with alternating corn, cotton, peanut and soybeans planted. Specifically, cotton works against the infestation of nematodes. Rotating corn with soybean virtually eliminates the damage by corn rootworms.

According to University of Georgia Extension Services planting peanut after corn minimizes risk of nematodes to peanuts.

The solution to (3.8) results in the irrigated acreage allocation equation. The optimal choice of A is a function of the following variables and their estimated parameters : total irrigated acres (TIA) available, expected profits for each commodity, variance of these profits, and cross-commodity covariance of profits.

$A_i^* = f\,(\mathbf{B}, F_{ii}, F_{ij}, \text{TIA})$ œ i, j = 1, ... ,n. (3.9)

The acreage response model in 3.9 may be decomposed into two parts: substitution and expansion effects. In making decisions about irrigated acreage allocations, producers may compare the first and second moments of profits of alternative enterprises. Comparison of expected per acre profits, and the variance and covariances of recent profits of alternate enterprises, are assumed to drive the substitution among crops for a utility maximizing firm.

On the other hand, substitutions between irrigated crops have been accompanied by an overall increase in irrigated acreage over time. Changes in irrigation technology, costs of irrigation, irrigation policy, lender practices relative to irrigation, and producer’s assessments of future economic conditions in agriculture all may stimulate expansion or contraction of total irrigated acreage partly or wholly independent of year to year variations in relative expected prices, yields, and costs of a set of crops. That is, even if relative profits of a set of crops were expected to remain constant, changes in total irrigated acreage may occur, and changes in total irrigated acreage will be reflected in changes in the irrigated acreages of individual crops. These impacts, representing an expansion effect, are captured by the parameters of the total irrigated acreage variable included in each commodity equation. The derived irrigated acreage allocation function in equation (3.9) will be estimated in the following chapter.

CHAPTER 4

DATA: SOURCES, TRANSFORMATIONS AND PRELIMINARY ANALYSIS

Estimation of acreage response (equation 3.9) by crop and county requires data on irrigated acreage on a crop by county basis, and price, yields and cost. The purposes of this chapter are to identify specific data requirements for the analysis and available data sources, and to describe assumptions and techniques used in going from the available to the required data. The first section describes the required data, sources of available data and the methods and assumptions for imputing irrigated acreage by crop and county. The second section identifies data sources for prices, yields and costs. The data sources are summarized in Table 4.1. Finally, the third section concludes with the specification of the empirical model based on equation 3.9 and hypothesized relationships.

Acreage Data

With regards to acreage data, there are two major data sources for the analysis, University of Georgia - Cooperative Extension Service (UGA-CES) and the U.S. Department of Agriculture - National Agricultural Statistic Service (USDA-NASS). The state and county irrigation data came from the UGA-CES. A subset of these data are the state irrigated acreage of the i^{th} crop at time period t (SIA_{it}), which includes all commodity and recreational irrigation groups. Summing of these categories yields the state total irrigated acres at time period t, ($STIA_t$). These data are available for 1970, 75, 77, 80, 82, 86, 89, 92, 95, and 98. Another

Table 4.1. Data Sources

Variable	Data Span	Source
Acreage Data		
State Irrigated Acres by crop (SIA_{it})	1970, 75, 77, 80, 82, 86, 89, 92, 95, 98	UGA - Cooperative Extension Service
State Total Irrigated Acres all crop ($STIA_t$)	1970, 75, 77, 80, 82, 86, 89, 92, 95, 98	UGA - Cooperative Extension Service
Total County Irrigated Acres all crops (TIA_{yt})	1974, 78-82, 84, 86, 89, 92, 95, 98	UGA - Cooperative Extension Service
State Harvested Acres by crops (SHA_{it})	1970 - 1998	U.S.D.A. National Agricultural Statistics Service
County Harvested Acres by crops (CHA_{iyt})	1970 - 1998	U.S.D.A. National Agricultural Statistics Service
Profits Data		
Season Average Price by crops (SAP_{ti})	1970 - 2001	U.S.D.A. National Agricultural Statistics Service
Loan Rate/Target Price (LR_{it}/TP_{it})	1970 - 2001	Agricultural Statistics
Yield per acre by crop and county (Y_{iyt})	1970 - 1999	USDA National Agricultural Statistics Service
Variable Cost per acre by crop (c_{it})	1975 - 1999	U.S.D.A Economic Research Service
Cost and Price Index	1974 - 1998	Agricultural Statistics

irrigation data subset consists of total irrigatedacres for all commodities combined, by county at time t, (TIA_{yt}). Data for TIA_{yt} are available for the years 1974, 78 – 82, 84, 86, 89, 92, 95 and 98 and are reported in the annual publication called the Georgia County Guide.

All harvest data are from NASS. These data are available for 1970 through 1998 and were downloaded from the USDA - NASS web-site http://www.usda.gov/nass/. The data contain the commodity harvested acreage by county at time t, (CHA_{iyt}). The state commodity harvested acres (SHA_{it}) were obtained by summing over all the 159 Georgia counties.

Considering the strong linear trend in the available irrigation data (see Figure 1.1), data interpolation for the missing SIA_{it} and TIA_{yt} assumes that irrigation acreage increases or decreases linearly between two time intervals. The assumption of linearity for data in the missing years is a source of error, but it is difficult to quantify the error.

As seen in Table 4.1., the time intervals vary among the state and county level irrigation data sets, and it was necessary to have a common time period for all data sets. Therefore, the estimation proceeded for the 1974-98 time period imposed by the range of the TIA_{yt} data set.

The dependent variable in equation 3.9 (CIA_{iyt}) represents irrigated acreage of crop i on county y in year t. Given that data is only available on SIA_{it}, $STIA_t$, TIA_{yt}, SHA_{it} and CHA_{iyt}, there are two possible starting points to construct a proxy for CIA_{iyt},

1) assume that proportion of crop i that is irrigated is the same in county y as it is in the state. Algebraically,

$$CIA_{iyt} = (SIA_{it}/SHA_{it}) * CHA_{iyt} \quad (4.1)$$

2) assume that the proportion of irrigated acreage that is used in the production of crop i is the same in county y as it is in the state. Algebraically,

$$CIA_{iyt} = (SIA_{it}/STIA_t) * TIA_{yt} \quad (4.2)$$

Both alternatives 1 and 2 have advantages and limitations. Alternative 1 has an advantage of being conceptually linked with the observed crop mix in a given county. The conceptual problem with alternative 1 is that employing state proportion of each crop that is irrigated will likely underestimate the proportion of each crop that is irrigated in the river basin counties included in this study. Alternative 2 uses total irrigated acres in a county in its calculation and, therefore, accounts for higher levels of irrigation expected in river basin counties. The conceptual problem with alternative 2 in imputing the county by crop irrigation acreage is that this method is not linked with the crop mix in a county. The present analysis is based on alternative 2 with a modification to account for available county level crop mix data. This procedure is described as follows.

Data imputation is a two-stage process. The first stage assumes that the proportion of irrigated acreage devoted to a given commodity in each county is identical to the proportion of irrigated acreage devoted to that commodity at the state level. Algebraically,

$$CIA'_{it} = (SIA_{it} / STIA_{t}) * TIA_{yt} \text{, where} \tag{4.3}$$

CIA'_{it} = Unrestricted County Irrigated Acres of the i^{th} crop at time t,

The second stage uses a rule to insure that the irrigated acres estimate of the i^{th} crop in the y^{th} county does not exceed the harvested acres of the i^{th} crop in this county; i.e.,

$$CIA^{*}_{it} = \min (CIA'_{it}, CHA_{iyt}) \tag{4.4}$$

The modified alternative 2 emphasizes the importance of available data on total irrigated acreage by county and year, but seeks to minimize possible errors related to the crop mix by incorporating county level data on harvested acreage by crop and year.

Profits Data

A major contribution of this analysis is accounting for the influence of economic variables on water demand. Incorporating the profitability of competing farming enterprises requires information on prices and costs for a given enterprise. The data on prices, yields and costs were collected as follows.

Seasonal average price (SAP_{it}) for a crop is a simple average of the Georgia crop prices during the cropping season. SAP_{it} data are collected from 1970 - 99 editions of

Georgia Agricultural Facts, published annually by USDA-NASS. Yield data are collected for each of the 19 counties from *Georgia Agricultural Facts*. Yield enters the empirical model on a county basis to account for cross-sectional heterogeneity in terms of irrigated acreage. Government prices (GP_{it}) were proxied by the loan rate (LR) and target price (TP). GP_{it} for peanuts and soybeans do not have a target price and are, therefore, proxied using the LR_t. For corn and cotton, government prices at time t were defined as follows:

$$GP_{it} = \max (LR_{it}, TP_{it}). \qquad (4.5)$$

These data were collected from 1970-99 editions of the Agricultural Statistics published by USDA-NASS. There is an obvious omission of acreage restrictions in constructing the GP_{it}. The reason for excluding the acreage restrictions in constructing the government support price series is that the goal of this study is to examine acreage response for irrigated acres, and farmers typically set aside marginal dryland to qualify for participation in the program.

Variable cost of production data were collected from the USDA - Economic Research Service (USDA-ERS). The variable cost data are "historical," based on the actual costs incurred by producers in the southeastern U.S. during each year. These cost figures differ from the projection based budgets put forth by land-grant universities to assist farmers in planning. These actual measures of costs incurred are more relevant to the present analysis in considering profitability of competing enterprises. The data were downloaded from ERS website: http://www.ers.usda.gov/briefing/farmincome/costsandreturns.htm.

Generally a producer's revenue per unit of output i in year t will be higher of the government price, GP_{it}, described above and the market price for that output (Shumway). Although the government price for a given commodity should be known to producers before planting decisions are made, the market prices for crops to be planted will not be known in advance. Operator's planting decisions will therefore have to be based on expected revenue per unit.

Designate the ex post producers' price for commodity i in year t as the supply inducing price:

$$SIP_{it} = \text{Max}\ (GP_{it}\ ,\ SAP_{it}). \qquad (4.6)$$

where SAP_{it} is the seasonal average price for commodity i in year t. Expected supply inducing prices for producers making cropping decisions for period t were assumed to be a simple linear function of the announced government price for year t, the lagged supply inducing price and a time trend:

$$E[SIP_{it}] = \$_0 + \$_1\ GP_t + \$_2\ SIP_{i,t-1} + \$_3\ T, \qquad (4.7)$$

where $\$_0$, $\$_1$, $\$_2$ and $\$_3$ are parameters to be estimated with the price data. Equation 4.7 was estimated for each crop using ordinary least squares.

The second component of expected profits is the expected yield. Expected yield may be estimated by regressing yield on lagged yield and a time trend. Duffy *et al.* suggest that deriving expected yield in this manner should produce a better fit than regression on a trend. The trend variable in estimating yield allows for changes in production and irrigation technology. The OLS equation for estimating expected yield in the i^{th} crop in the y^{th} county at time t is as follows:

$$E[Y_{iyt}] = "_0 + "_1 Y_{t-1} + "_2\ T, \qquad (4.8)$$

where $"_0$, $"_1$ and $"_2$ are parameters to be estimated using the data on yield. Equation 4.8 was estimated for each crop using ordinary least squares.

The expression for expected profit, B_{it}, is defined as

$$E_{t-1}[B_{it}] \;=\; E_{t-1}[SIP_{it} * Y_{iyt}] - c_{it}..$$

Given covariance between yields and prices (Bohrnstedt and Goldberger), expected profits are calculated using:

$$E_{t-1}[B_{it}] \;=\; E_{t-1}[SIP_{it}]*E_{t-1}[Y_{iyt}] + Cov(SIP_i,\ Y_i) - c_{it}, \qquad (4.9)$$

where $Cov(SIP_i, Y_i)$ is the covariance between price and yield of the i^{th} crop.

Higher Moments of Expected Profits

In order to capture the risk aversion of the farmers, variance in profits for the crops was included in the model. The variance associated with profits for the three year period preceeding year t is defined as dispersion of observed profits about their mean, i.e.

$$\text{Var}\,(B_{it}) = F_{B_{it}} = \text{'}_{j=1}^{3}\; 8_j\,[B_{i,t-j} - E_t\,(B_{it})]^2,$$

where

$$E_t\,(B_{it}) = \frac{(B_{i,t-1} + B_{i,t-2} + B_{i,t-3})}{3},$$

is a three year moving average of observed profits and 8_1, 8_2 and 8_3 represents the weights from an adaptive expectations model similar to the one used in Chavas and Holt. An equally weighted scheme is assumed for the data with the three time periods weighted at 0.34, 0.33 and 0.33 for the first, second and third year, respectively. However, using variance directly in the estimation has a demerit that if a random variable has an upward trend its variance will increase due to scale effect even though its relative risk, i.e. variance standardized by the mean, may not be increasing. Using coefficient of variation eliminates scale effect. Coefficient of variation is calculated as follows:

$$\text{C.V.}\,(B_{it}) = F_{B_{it}} \,/\, E_t\,(B_{it}). \tag{4.10}$$

Covariance between any two crops, i and j, is included to account for the mechanism of risk-spreading by farmers via the portfolio effect in an expected value-variance (EV) setting. A negative correlation between two crops in a farmer's portfolio reduces the farmer's risk. It is expected, therefore, that in the equation for the i^{th} crop there will be a negative sign associated with the variable for covariance, evidencing that the farmer will commit more resources to the irrigated acres of the ith crop. However, in the same equation, comparing the covariance between other non- i crops and a reduced risk scenario suggests taking irrigated acres out of the production for the ith crop and commit them to some combination the other two crops. A positive relationship is the expected sign in this case. Covariance is calculated using the following equation

$$Cov(\pi_{it,jt}) = \sigma_{\pi_{it,jt}} = \sum_{k=1} \lambda_k [[\pi_{i,t-k} - E_t(\pi_{it})] [\pi_{j,t-k} - E_t(\pi_{jt})]],$$

where

$E_t(\pi_{it}) = (\pi_{i,t-1} + \pi_{i,t-2} + \pi_{i,t-3})/3$

$E_t(\pi_{jt}) = (\pi_{j,t-1} + \pi_{j,t-2} + \pi_{j,t-3})/3$

and $i \neq j$

Covariances are standardized, to eliminate the trend effect, as follows:

$$C.V.\ Cov(\pi_{it,jt}) = \frac{\sigma_{\pi_{it,jt}}}{E_t(\pi_{it}) + E_t(\pi_{jt})/2} \qquad (4.11)$$

Data summary statistics are presented in table 4.2. These are followed by the empirical model for estimating acreage response and hypothesized signs on the variables based on the EV theory and agronomic considerations as defined in chapter three.

The irrigated acreage span a large range. One possible explanation of the large range is the time period of the data. Relative to early 1970's there was rapid adoption of irrigation technology in the late 1970s through 1980s. Adoption was primarily driven by credit agencies requiring farmers to irrigate a proportion of their land to minimize the downside risk associated with a poor yield. Thus, a comparison of the early and late 1970's provides an explanation for the large data range.

Table 4.2. Summary Statistics: Variables used in the Regression Model

Variables	n[a]	Mean	Standard Deviation	Minimum	Maximum
Corn					
Irrigated Acres	475	6691.99	5125.80	77.81	27895.06
Price	456	2.71	0.43	1.73	3.17
Yield	456	87.39	22.83	40.49	135.66
Cost	475	120.44	45.12	44.36	196.45
Profit					
Mean	456	131.89	50.90	27.93	246.20
Variance	418	21.73	26.08	0.03	239.86
Cotton					
Irrigated Acres	475	4005.38	6391.95	0	36201.20
Price	456	0.67	0.11	0.41	0.77
Yield	456	597.78	143.50	317.25	830.86
Cost	475	234.50	83.93	82.57	344.79
Profit					
Mean	456	184.56	75.42	31.18	340.39
Variance	418	225.63	3538.52	-1544.43	72335.93
Peanut					
Irrigated Acres	475	7311.72	5553.28	92.79	25292.97
Price	456	0.27	0.07	0.14	0.35
Yield	456	2820.22	243.83	1987.92	3344.06
Cost	475	275.34	97.73	101.30	434.15
Profit					
Mean	456	463.57	107.43	235.18	701.49
Variance	418	23.66	29.55	0.04	159.81

Table 4.2. Continued

Variables	n[a]	Mean	Standard Deviation	Minimum	Maximum
Soybean					
Irrigated Acres	475	2135.63	2273.51	0	12939.66
Price	456	5.63	0.76	2.93	6.36
Yield	456	24.35	1.82	20.48	29.52
Cost	475	68.73	27.95	23.86	113.71
Profit					
Mean	456	67.48	16.29	24.53	97.93
Variance	418	14.82	23.56	-282.67	158.81
Cov Corn-Cotton	399	676.37	1968.22	-10005.96	7992.90
Cov Corn-Peanut	399	969.45	2144.73	-4523.65	10376.71
Cov Corn-Soybean	399	379.28	583.06	-2093.99	2430.93
Cov Cotton-Peanut	399	3169.37	7097.04	-16584.60	34782.35
Cov Cotton-Soybean	399	335.65	1360.24	-4929.09	7046.16
Cov Peanut-Soybean	399	873.50	1519.12	-3103.32	7024.04
Total Irrigated Acres	475	28118.37	19613.47	316	92508

[a] n represents the number of observations in the 19 county region over 25 years. Fewer observations in some variables result due to lags used in generating the variables.

Empirical Model

The theoretical model is developed based on a representative farm. Typically farm level data are not available to study an individual farm's irrigation acreage response when faced with risk. Instead, the empirical model of acreage response is based on some reasonable level of aggregation. Each level of aggregation has an implied assumption regarding the homogeneity of the producers of a given commodity. Not only can this be a strong assumption regarding land characteristics, it is particularly over-simplifying while examining irrigation responsiveness. Furthermore, aggregation may also limit the degrees of freedom available for hypothesis testing. The extent of aggregation problems may be somewhat alleviated in using a more disaggregated level of data. The current analysis uses county level data for irrigated acreage and yield to reduce the afore-mentioned negative effects of aggregation.

Given the hypothesis of expected utility maximization and the functional relationship between the optimal irrigated acreage and components of expected utility in equation (3.9), the empirical model for optimal irrigated acreage equations may be derived. The irrigated acreage, $IA^*_{iyt} = f(\pi_{jyt}, \sigma_{jyt}, Cov\pi_{ijy}, TIA_{yt})$ can be estimated with the following empirical model,

$$IA^*_{iyt} = \alpha_0 + \sum_{j=1}^{4} \beta_j \pi_{jyt} + \sum_{j=1}^{4} \delta_j \sigma_{jyt} + \sum_{\substack{j=1 \\ j \neq i}}^{4} \gamma_{ij} Cov\pi_{ijy} + \sum_{\substack{j=1 \\ j \neq i,k}}^{4} \sum_{\substack{k=1 \\ k \neq i,j}}^{4} \phi_{jk} Cov\pi_{jkyt} + \theta_i TIA_{yt} + \sum_{y=1}^{18} \eta_y D_y + \varepsilon_{iyt} \qquad (4.12)$$

for i = 1, . . ., 4

where IA^*_{iyt} is the number of irrigated acres planted to the ith crop in the yth county at time t, π_{iyt} is the expected profit per acre of the ith crop in the yth county at time t. The expected per acre profits are included to capture the substitutability in the crops. σ_{jyt} is the variance of the profits for the jth crop in the yth county at time t included to account for producer's risk responsiveness. $Cov\pi_{ijy}$ is the covariance of the profits of the ith and the jth crop at time t are included to capture the portfolio effect relation between the crops. The total irrigated acres in the yth county at time t (TIA_{yt}) are included in estimation to capture the expansion effect in irrigated acreage responsiveness as explained in chapter three. D_y is the county specific dummy variable to account for cross sectional heterogeneity in the data. A county specific intercept shifting dummy allows differences in mean irrigated acreage of the four crops across the counties. ε_{iyt} is an error term associated with the i^{th} crop in the y^{th} county at time t. α_0, β_j, γ_j, δ_{ij}, ζ_{jk}, η_i and θ_y are all parameters to be estimated with the data. The equations for each of the crops in (4.12) may be appropriately estimated equation by equation using ordinary least squares (OLS).

Hypothesized Signs

Hypothesized relationships between irrigated acreage of a crop and each of the parameters in equation 4.12 are based on economic theory of expected value - variance (EV) and the agronomic relationships, such as rotational consideration, between the crops as described in chapter three. The expected signs on estimated regression coefficients are summarized in Table 4.3.

The expected utility function of a risk averse producer in a competitive setting is concave. In the model context, concavity of the expected utility function suggests that it is a monotonically increasing function of own profits. Hence a positive sign is expected on the coefficient associated with profits for the i^{th} crop. Risk aversion suggests that expected utility will be a decreasing function of variance in the profits of the i^{th} crop. Therefore, an inverse relationship is hypothesized between irrigated acres committed to the i^{th} crop and variance in own profits.

In an allocation model, crops may have a substitute, complementary or no relationship at all. If two crops are substitutes to each other then they are expected to be negatively related to each other in the producers acreage allocation decision. Increasing profitability in a competing enterprise, say the j^{th} crop, is expected to lower acreage commitments for crop i.

On the contrary, rising profits in the i^{th} crop may result in rising levels of acreage committed to the k^{th} crop that serves as a rotation crop. Hypothesized

Table 4.3. Expected Impact under Irrigated Acreage

Variable [a]	**Expected Impact under Irrigated Acreage**	
	EV	**Agronomic**
Profit		
Expected, i^{th} crop (π_{iyt})	+	
Expected, j^{th} crop (π_{jyt})	-	-, if substitute crop
		+, if rotation crop
Variance, i^{th} crop (σ_{iyt})	-	
Variance, j^{th} crop (σ_{jyt})	+	+, if substitute crop
		-, if rotation crop
Covariance, i^{th} and j^{th} crop	-	
Covariance, j^{th} and k^{th} crop	+	
Total Irrigated Acres (TIA_{yt})	+	

[a] i^{th} crop refers to the crop associated with the dependent variable and j^{th} and k^{th} crops refer to the remaining three crops.

sign assignment on variance-covariance is also based on agronomic considerations of the crop.

With regards to the coefficient of variation in the profits of an alternative enterprise, say j, it is expected that rising variability in their profits will influence irrigated acreage in the i^{th} crop in a manner similar to profitability of the competing crop. Here the expected relationship reverses; i.e., rising variability of a substitute crop will likely increase acreage committed to the i^{th} crop and rising variability of a complementary crop will tend to decrease the irrigated acres in the i^{th} crop.

In order to capture the differences among counties in the Flint River Basin, intercept shifting dummy variables for the 18 Lower Flint counties, (Baker, Calhoun, Crisp, Decatur, Dooly, Dougherty, Early, Grady, Lee, Macon, Miller, Mitchell, Randolph, Seminole, Sumter, Terrell, Webster and Worth) are compared against the aggregate county called Other. The category Other consists of Clayton, Coweta, Crawford, Fayette, Lamar, Marion, Meriwether, Pike, Schley, Spalding, Talbot, Taylor and Upson counties. The category Other was generated using those counties in the Flint River Basin with very small irrigated acres of each crop. The county category Other is comprises of 13 geographically contiguous upper Flint basin counties as seen in Figure 4.1. There is no *a priori* sign assignment on these indicator variables.

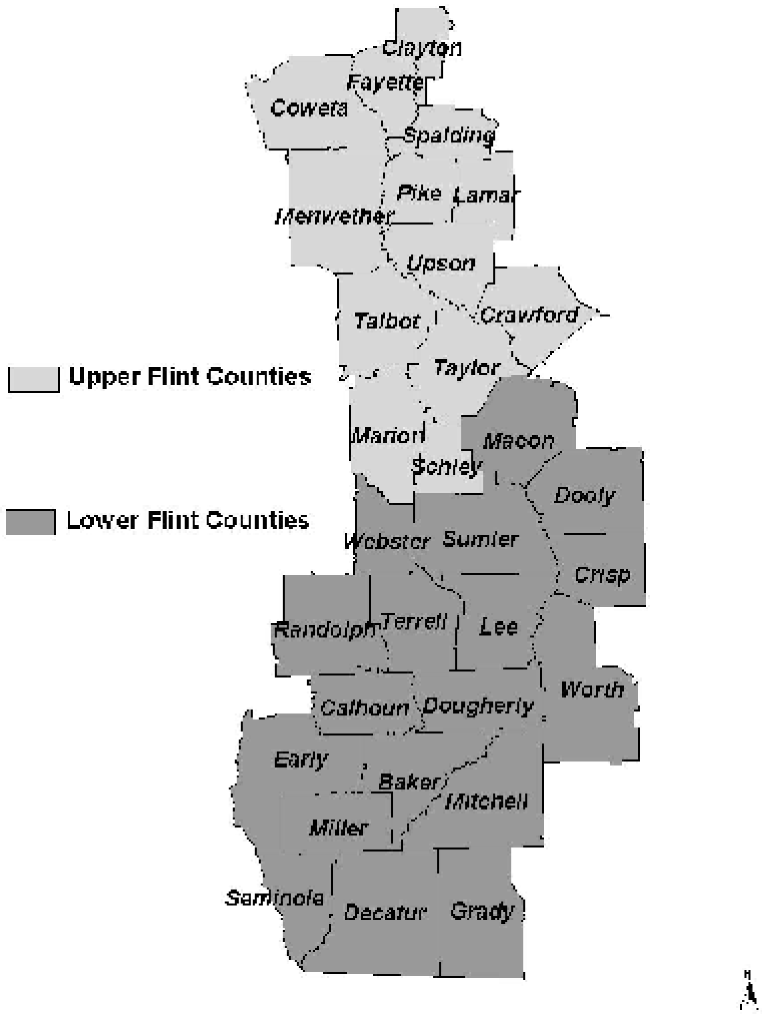


Figure 4.1. Upper and Lower Flint River Georgia Counties.

CHAPTER 5

ECONOMETRIC MODEL AND ESTIMATION RESULTS

The econometric model used in estimating acreage response for corn, cotton, peanuts and soybeans in the 19 county region of southwest Georgia for the years 1978-98 is presented in this chapter. Model goodness-of-fit statistics and parameter estimate results are presented and discussed.

Econometric Model

$$IA^{*}_{iyt} = \alpha_0 + \sum_{j=1}^{4} \beta_j \pi_{jyt} + \sum_{j=1}^{4} \gamma_j \sigma_{jyt} + \sum_{\substack{j=1 \\ j \neq i}}^{4} \delta_{ij} Cov\pi_{ijy} + \sum_{\substack{j=1 \\ j \neq i,k}}^{4} \sum_{\substack{k=1 \\ k \neq i,j}}^{4} \zeta_{jk} Cov\pi_{jkyt} + \eta_i TIA_{yt} + \sum_{y=1}^{18} \theta_y D_y + \varepsilon_{iyt} \qquad (5.1)$$

for i = 1, . . ., 4

where

IA^{*}_{iyt} = irrigated acreage of the i^th crop in the y^th county at time t,

π_{iyt} = mean expected net return per acre of the i^th crop in the y^th county at time t,

σ_{ijt} = coefficient of variation of profits of the i^th crop in the y^th county at time t,

σ_{ijt} = standardized covariance of profits between the i^th and j^th crop in the y^th county at time t,

TIA_{yt} = total irrigated acres in the y^th county at time t,

D_y = county specific indicator variable,

u_{iyt} = stochastic error term.

Assuming the error terms to be independent and identically distributed allows estimating equations (5.1) using ordinary least squares (OLS). All four equations (cotton, peanuts, corn and soybean) are specified as functions of an intercept term, profits, variance and covariance of each of the crops, the total irrigated acreage in a county and county-specific intercept-shifting dummy variables. Parameter estimates for each crop are presented in table 5.1. through 5.4.

Estimation Results

The F-test statistic in all acreage equations is statistically significant at the 1% level. This suggests a strong rejection of the null hypothesis that all parameters except the intercept are zero. The coefficients of determination, R^2, for the cotton, peanuts, corn and soybeans equation are 0.68, 0.95, 0.81 and 0.64, respectively.

Profits of cotton are positively related to the irrigated acres of cotton (Table 5.1). This relationship is statistically significant at 1% level. Cotton responsiveness to its profitability, as measured through elasticity at means, is 0.617. The measure of elasticity suggests that for every one percent increase in the expected profits, irrigated cotton acreage will increase by over 0.60 %. Cotton profits show the hypothesized inverse relationship in the corn and soybean equations. Cotton has higher cross profit elasticity in the soybean equation (-0.987) relative to the corn equation (-0.258). Both corn and soybeans are rotation crops for cotton, however, a higher elasticity vis-a-vis soybean may be explained by the marginal nature of soybean in Georgia agriculture.

As listed in table 5.2, the peanut model is strongly driven by profit potential in the peanut market. The coefficient associated with own profits in peanuts is significantly different from zero at the 1% level. A lower elasticity figure of 0.324 is indicative of the constraining role of government poundage quota on peanuts. Producers of quota peanuts do not have the flexibility to adjust their acreage in response to the changes in profitability. This study considers the quota prices and, therefore, total acreage adjustment in peanuts is not readily expected. The producers with quota provisions would commit acreage to ascertain meeting the quota poundage and would entertain other crops only for their rotation considerations. This is evident by the positive and significant coefficient associated with cross profitability of corn and soybeans, both are rotation crops vis-a-vis peanuts. Cross profit of peanut in relation to corn, cotton and soybeans are significantly different from zero at the 5%, 1% and 1% level, respectively. They demonstrate the hypothesized relationship in all instances except in the soybean equation. This may possibly be indicative of the complementary relationship between peanuts and soybeans. An increase in the profits of peanuts is complemented by a greater irrigated acreage commitment to soybeans in terms of rotation.

The coefficient for profits of corn has the counter-hypothesized sign in table 5.3 and it is statistically significant at the 5% level. This coefficient suggests that there is an inverse relationship between profits of corn and irrigated acres of corn in a county. This relationship is not strong as evidenced by low estimate of elasticity -0.1878. A possible explanation for this unanticipated sign is that corn is a minor crop in Georgia and it is grown primarily for its rotational considerations. Corn is rotated with cotton and peanuts due to its nematode resistant properties. The decision to commit irrigated acres of land into corn may be driven less by profit consideration and more due to rotational consideration. Also, corn has been the least loss yielding crop among perceived alternatives for rotation. This counter-hypothesized sign for the profits of corn repeats itself in the models for cotton and peanuts with statistical significance in both cases. However, in the soybean equation, another rotational crop in Georgia, profits of corn appear with the hypothesized sign, suggesting a competitive relationship with soybean for irrigated acres of a rotational crop.

Soybean profits have the hypothesized sign and are significant at the 1% level in table 5.4. The elasticity estimate for soybean profits is approximately 1.3, suggesting that soybean acreage is very responsive to changes in profits of soybeans. These strong values suggest that the choice of corn-soybean rotation may partly be driven by profits in soybean in addition to the agronomic rotational considerations. Cross revenue effects of soybean profits are significant, at the 1% level, in all three equations. A cross-revenue

Table 5.1. Estimated Cotton Irrigated Acreage and Elasticities at Mean: 1978 - 1998

Variable	Parameter Estimate	Standard Error	Elasticity
Intercept	8433.479*	1934.579	
Cotton			
Profits			
Mean	13.393*	5.055	0.6171
Variance[a]	0.010	0.058	0.00052
Corn			
Profits			
Mean	23.711*	8.069	0.7807
Variance	11.925	10.377	0.0647
Peanut			
Profits			
Mean	-9.012*	3.424	-1.0431
Variance	-10.238	9.992	-0.0605
Soybean			
Profits			
Mean	-172.652*	16.635	-2.9087
Variance	-6.988	9.747	-0.0259
Covariance[b]			
Corn-Cotton	-0.097	0.152	-0.01632
Corn-Peanut	-0.104*	0.149	-0.0252
Corn-Soybean	1.380	0.437	0.1306
Cotton-Peanut	-0.026	0.036	-0.0207
Cotton-Soybean	0.751*	0.223	0.0630
Peanut-Soybean	-0.735*	0.223	-0.1602
Total Irrigated Acres	0.325*	0.042	2.2801

Table 5.1. Continued

Variable	Parameter Estimate	Standard Error
County Dummies		
Baker	-5817.035*	1735.057
Calhoun	-2380.462***	1391.488
Crisp	-393.306	1270.179
Decatur	-10742*	2783.193
Dooly	-2285.452***	1363.412
Dougherty	765.271	1394.688
Early	-4749.727*	1648.892
Grady	302.127	1351.962
Lee	-6270.135*	1556.998
Macon	-1586.256	1343.008
Miller	-9224.589*	2142.552
Mitchell	-7146.759*	2357.419
Randolph	2959.494*	1388.789
Seminole	-7249.699*	1959.810
Sumter	-5470.557*	1603.949
Terrell	-1241.816	1344.895
Webster	654.665	1364.152
Worth	-1289.831	1320.450
Number of observations	398	
F-value	23.14*	
Mean square error	3990.1507	
R^2	0.68	

*** significantly different from zero at the 10% level.

** significantly different from zero at the 5% level.

* significantly different from zero at the 1% level.

[a,b] Measured as coefficient of variation

Table 5.2. Estimated Peanut Irrigated Acreage and Elasticities at Mean: 1978 - 1998

Variable	Parameter Estimate	Standard Error	Elasticity
Intercept	-5151.945*	602.136	
Peanut			
Profits			
Mean	5.109*	1.065	0.3240
Variance[a]	2.536	3.109	0.0082
Corn			
Profits			
Mean	6.644*	2.511	0.1199
Variance	-1.835	3.229	-0.0055
Cotton			
Profits			
Mean	0.6889	1.573	0.0174
Variance	-0.009	0.018	-0.00029
Soybean			
Profits			
Mean	36.416*	5.178	0.3361
Variance	2.018	3.034	0.0041
Covariance[b]			
Corn-Cotton	-0.024	0.047	-0.0022
Corn-Peanut	0.018	0.046	0.00242
Corn-Soybean	-0.135	0.136	-0.007
Cotton-Peanut	0.025**	0.011	0.0108
Cotton-Soybean	-0.246*	0.070	-0.0113
Peanut-Soybean	0.253*	0.069	0.0302
Total Irrigated Acres	0.244*	0.013	0.9384

Table 5.2. Continued

Variable	Parameter Estimate	Standard Error
County Dummies		
Baker	-671.615	540.035
Calhoun	-701.101	433.099
Crisp	116.438	395.343
Decatur	-3.811	866.267
Dooly	158.175	424.361
Dougherty	-1142.425*	434.096
Early	-497.516	513.217
Grady	-729.706***	420.797
Lee	498.614	484.615
Macon	-198.151	418.010
Miller	-186.932	666.868
Mitchell	-173.839	733.745
Randolph	657.915	432.260
Seminole	-292.731	609.990
Sumter	131.273	499.228
Terrell	-486.746	418.598
Webster	-439.403	424.591
Worth	-697.139***	410.989
Number of observations	398	
F-value	211.76*	
Mean square error	1241.932	
R^2	0.95	

*** significantly different from zero at the 10% level.

** significantly different from zero at the 5% level.

* significantly different from zero at the 1% level.

[a,b] Measured as coefficient of variation

Table 5.3. Estimated Corn Irrigated Acreage Equation and Elasticities at Mean: 1978 - 1998

Variable	Parameter Estimate	Standard Error	Elasticity
Intercept	1236.323	1127.551	
Corn			
Profits			
Mean	-9.531**	4.703	-0.1878
Variance[a]	2.523	6.048	0.0082
Cotton			
Profits			
Mean	-9.356*	2.946	-0.258
Variance	0.001	0.034	0.00004
Peanut			
Profits			
Mean	-4.868**	1.995	-0.3373
Variance	-2.481	5.824	-0.0088
Soybean			
Profits			
Mean	87.880*	9.696	0.8861
Variance	0.699	5.681	0.0015
Covariance[b]			
Corn-Cotton	0.068	0.088	0.00684
Corn-Peanut	-0.013	0.087	-0.00188
Corn-Soybean	-0.472***	0.255	-0.02672
Cotton-Peanut	0.027	0.021	0.01298
Cotton-Soybean	-0.361*	0.130	-0.0181
Peanut-Soybean	0.211	0.130	0.0275
Total Irrigated Acres	0.077*	0.025	0.3244

Table 5.3. Continued

Variable	Parameter Estimate	Standard Error
County Dummies		
Baker	5923.664*	1011.262
Calhoun	2653.353*	811.016
Crisp	-59.011	740.312
Decatur	9172.674*	1622.158
Dooly	-631.210	794.652
Dougherty	131.490	812.881
Early	5323.728*	961.041
Grady	186.869	787.978
Lee	4652.880*	907.482
Macon	587.872	782.760
Miller	6787.184*	1248.767
Mitchell	7639.525*	1374.001
Randolph	2779.345*	809.443
Seminole	6675.922*	1142.257
Sumter	4888.504*	934.847
Terrell	1211.406	783.860
Webster	-930.907	795.083
Worth	2109.221**	769.612
Number of observations	398	
F-value	47.21*	
Mean square error	2325.623	
R^2	0.81	

*** significantly different from zero at the 10% level.

** significantly different from zero at the 5% level.

* significantly different from zero at the 1% level.

[a,b] Measured as coefficient of variation

Table 5.4. Estimated Soybean Irrigated Acreage Equation and Elasticities at Mean: 1978 - 1998

Variable	Parameter Estimate	Standard Error	Elasticity
Intercept	-1246.262***	699.675	
Soybean			
Profits			
Mean	40.502*	6.016	1.2798
Variance[a]	-3.550	3.525	-0.0246
Corn			
Profits			
Mean	-9.442*	2.918	-0.5831
Variance	-8.373*	3.753	-0.0852
Cotton			
Profits			
Mean	-11.419*	1.828	-0.9868
Variance	-0.0002	0.021	-0.00002
Peanut			
Profits			
Mean	4.468*	1.238	0.9699
Variance	10.410*	3.613	0.1153
Covariance[b]			
Corn-Cotton	0.022	0.055	0.00693
Corn-Peanut	-0.074	0.054	-0.0336
Corn-Soybean	0.174	0.158	0.0309
Cotton-Peanut	0.011	0.013	0.0167
Cotton-Soybean	-0.141***	0.081	-0.0222
Peanut-Soybean	0.140***	0.080	0.0573
Total Irrigated Acres	0.037**	0.015	0.4887

Table 5.4. Continued

Variable	Parameter Estimate	Standard Error
County Dummies		
Baker	1913.216*	627.515
Calhoun	1010.842**	503.257
Crisp	-5.298	459.383
Decatur	2765.216*	1006.592
Dooly	747.295	493.103
Dougherty	-118.068	504.414
Early	1725.844*	596.352
Grady	282.824	488.961
Lee	1743.223*	563.117
Macon	545.325	485.723
Miller	2315.843*	774.893
Mitchell	2138.403**	852.603
Randolph	1141.140**	502.281
Seminole	1894.012*	708.801
Sumter	1509.253*	580.097
Terrell	524.601	486.406
Webster	501.732	493.370
Worth	541.528	477.564
Number of observations	398	
F-value	20.02*	
Mean square error	1443.1103	
R^2	0.64	

*** significantly different from zero at the 10% level.

** significantly different from zero at the 5% level.

* significantly different from zero at the 1% level.

[a,b] Measured as coefficient of variation

elasticity of soybean estimated at almost -3.00 in the cotton equation suggests a that there is a reduction of 3% irrigates acres in cotton for a 1% increase in the profits of soybeans.

Estimated coefficients of the variation of profits is not significantly different from zero at even a 10% level of significance for any crops with the exception of corn and peanuts in the soybean equation (Table 5.4). Lack of statistical significance on the estimated coefficients of the variation may be explained in two ways. Data suggests that Georgia producers are not risk averse with respect to profits and government price support enable these producers to consider only the expected mean profits in making acreage allocation decisions.

Covariance between crops, a parameter hypothesized to capture the risk-spreading behavior of the farmers, is significantly different from zero in half the instances. The covariance between corn and soybean is significant at the 10% level in the corn equation. The inverse relationship suggests the portfolio effect between the two crops. The covariance between cotton and soybean is significantly different from zero at 10% level in the soybean equation also suggesting the hypothesized portfolio effect.

The parameter estimate associated with the total irrigated acreage in a county, TIA_{yt}, has the expected positive sign and is significantly different from zero at the 1% level in the cotton, peanut and corn equation and at the 5% level in the soybean equation. In terms of elasticity the cotton irrigated acreage is highly responsive to changes in the total irrigated acreage in a county. A coefficient estimate of 0.325 in the cotton equation suggests that a one acre increase in the total irrigated acreage in a county results in approximately one-third acre increase in cotton, *ceteris paribus*. Peanut acres are estimated to increase about one quarter of an acre for a one acre increase in toal irrigated acres in a county. Corn and soybean equations 0.07 and 0.04 acres, respectively. The other equations have relatively inelastic measures of responsiveness with respect to TIA_{yt}.

The estimated coefficients on the dummy variables for the counties are included to account for any county effects, including differences in size, soil, climate and economic conditions. Each indicator variable is contrasted against the county group categorized as Other. Relative to county group Other, peanuts producers show the least amount of heterogeneity in production. In the peanut equation only three of the 18 indicator variables are significantly different from zero. A homogenous peanut production may be explained by the restrictive nature of peanut production. Relative to the county group Other, the equations for corn, cotton and soybeans show greater differences. Of the indicator variable associated with the county dummy in the corn, cotton and soybeans equations over 60%, 60% and 55% of the county dummies significantly different from zero, respectively.

CHAPTER 6

WATER DEMAND: ESTIMATION AND SENSITIVITY ANALYSIS

This chapter utilizes the results from estimating irrigated acreage in Chapter 5 and the Blaney-Criddle (BC) water application coefficients for modeling water demand. The econometric methodology of water demand is applied in two ways. First, the physical measure of water use is compared against econometric measure of water demand. Difference between these two measures of water demand is used to estimate slippage. Second, water demand is forecasted based on estimates of irrigated acreage for the four crops.

Water Demand Estimation

Consumptive and irrigated crop acreage trends of water by crops is estimated by irrigation specialists using climatological data. Blaney and Criddle found the amount of water consumptively used by crops during their normal growing season was closely correlated with mean monthly temperatures and daylight hours. Blaney and Criddle developed coefficients that can be used to transpose the consumptive use data for a given area to other areas for which only climatological data are available. The net amount of irrigation water necessary to satisfy consumptive use is found by subtracting the effective precipitation from the consumptive water requirement during the growing or irrigation season.

The net irrigation requirements for corn, cotton, peanuts and soybeans in normal and dry years are listed in Table 6.1. A normal year is defined as a growing season with average rainfall of 49, 44 and 55 inches of rain in Lower, Middle and Upper Flint River

Table 6.1. Net Irrigation Requirement (acre-inch) in Normal and Dry Years by Crop and Region

Crop	Lower Flint Basin[a]	Middle Flint Basin[b]	Upper Flint Basin[c]
Corn			
Normal Year[d]	11.14	12.15	12.32
Dry Year[e]	12.71	13.65	13.69
Cotton			
Normal Year	11.74	13.22	11.85
Dry Year	13.68	15.04	13.38
Peanut			
Normal Year	6.58	7.69	n/a
Dry Year	7.97	9.01	n/a
Soybean			
Normal Year	7.58	8.38	7.65
Dry Year	9.04	9.75	8.79

Source: Georgia Irrigation Guide, USDA Soil Conservation Service.

[a] Lower Flint consists of Baker, Calhoun, Decatur, Dougherty, Early, Grady, Lee, Miller, Mitchell, Seminole and Worth counties.

[b]Middle Flint consists of Crawford, Crisp, Dooly, Macon, Marion, Randolph, Schley, Sumter, Taylor, Terrell and Webster counties.

[c] Upper Flint consists of Clayton, Coweta, Fayette, Lamar, Meriwether, Pike, Spalding, Talbot, and Upson counties.

[d] A normal year is defined as a growing season with average rainfall of 49, 44 and 55 inches of rain in Lower, Middle and Upper Flint River Basin regions, respectively.

[e] Dry year is defined as a drought on the magnitude of 20% or an average of the two driest years in a ten year period over the last 30 years of weather data.

Basin regions, respectively. A dry year is defined as a drought on the magnitude of 20% or an average of the two driest years in a ten year period over the last 30 years. The net irrigation requirement data are based on 30 year averages of climatological data. As listed in table 6.1, the differences in water usage by crop are larger than the differences among the regions.

Tables 6.2 through 6.6 list the estimates of irrigated acres and the corresponding water demand in normal and dry years. Water demand for a crop in a county is calculated by multiplying the irrigated acres in a county by the crop and region specific BC coefficient of net irrigation requirement. For example, water demand for corn in Baker county is calculated by multiplying the 7,000 irrigated acres in the county by the BC coefficients of 11.14 and 12.71 for the normal and dry years, respectively. These numbers are then divided by 12 to get the measure in terms of acre-feet. This calculation gives the 6,498 and 7,414 ac-ft for the normal and dry years listed in table 6.2.

Tables 6.2 through 6.6 list both the estimated and predicted water demand for 1998. The estimated values are generated using equation 4.4 and the predicted values are prediction of the dependent variable in equation 5.1 with the predicted acreage modeled as a function of profits and total irrigated acreage. As listed in the tables, the Theil's U statistic suggests that the model tracks the data well, particularly in counties with higher levels of crop irrigated acreage. Theil's inequality coefficient (U) is an index of relative forecast accuracy based on ratio of the mean square error of the forecast (MSE_F) and the mean square error of a benchmark (typically no change) forecast ($MSE_{A,\ t-1}$). This measure of relative MSE assumes a quadratic loss function and is defined in a condensed form as

$U = MSE_F \ / \ MSE_{A,\ t-1}$.

where the denominator represents an implicit no-change forecast. A perfect forecast has U equal to zero while U equal to one suggests a forecast the same as the no-change forecast. If U is greater than one, the model has lesser predictive power than the no-

Table 6.2. Cotton Water Demand (acre-ft) in Normal and Dry Years by County

	Water Demand (ac-ft)*					
	1998 Estimated			1998 Predicted		
County	Acres	Normal[a]	Dry[b]	Acres	Normal	Dry
Baker	18500	18099	21090	16481	16124	18788
Calhoun	12381	12113	14114	14153	13846	16134
Crisp	8282	8103	9441	10670	10439	12164
Decatur	36000	35220	41040	24484	23954	27912
Dooly	16095	15746	18348	15360	15027	17510
Dougherty	8972	8778	10228	13029	12747	14853
Early	18722	18316	21343	16899	16533	19265
Grady	5428	5310	6188	9216	9016	10506
Lee	17905	17517	20412	14929	14606	17019
Macon	10916	10679	12444	14386	14074	16400
Miller	21000	20545	23940	16474	16117	18780
Mitchell	32736	32027	37319	25421	24870	28980
Randolph	8500	8316	9690	10612	10382	12098
Seminole	17000	16632	19380	18933	18523	21584
Sumter	17634	17252	20103	16440	16084	18742
Terrell	11347	11101	12936	15067	14741	17176
Webster	3348	3275	3817	8633	8446	9842
Worth	16694	16332	19031	14322	14012	16327
Other[c]	8676	8865	10034	11828	12085	13679
Theil's U				0.1284		
Total	290136	284226	330898	287337	281625	327759

[a] A normal year is defined as a growing season with average rainfall in a region

[b] Dry year is defined as a drought on the magnitude of 20%, or an average of the two driest years in a ten year period over the last 30 years of weather data.

[c] Other county is based on the 13 county upper Flint River basin region.

Table 6.3. Peanut Water Demand (acre-ft) in Normal and Dry Years by County

	Water Demand (ac-ft)*					
	1998 Estimated			1998 Predicted		
County	Acres	Normal[a]	Dry[b]	Acres	Normal	Dry
Baker	10552	5786	7008	11339	6218	7531
Calhoun	6802	3730	4518	6941	3806	4610
Crisp	4550	2495	3022	4285	2350	2846
Decatur	20542	11264	13643	22845	12527	15173
Dooly	8843	4849	5873	8918	4890	5923
Dougherty	4930	2703	3274	4343	2381	2884
Early	10287	5641	6832	10797	5920	7171
Grady	2982	1635	1981	2479	1359	1646
Lee	9838	5395	6534	10661	5846	7081
Macon	4600	2522	3055	5066	2778	3365
Miller	11614	6368	7714	12165	6670	8080
Mitchell	17986	9862	11946	19902	10913	13218
Randolph	5115	2805	3397	4920	2698	3268
Seminole	12770	7002	8481	13461	7381	8940
Sumter	9689	5313	6435	9795	5371	6506
Terrell	6234	3418	4140	5640	3093	3746
Webster	1840	1009	1222	844	463	561
Worth	9172	5029	6092	9383	5145	6232
Other[c]	4767	3055	3579	4149	2659	3115
Theil's U				0.0425		
Total	163113	89881	108747	167933	92467	111895

* 1 ac-ft = 325,800 gallons/day

[a] A normal year is defined as a growing season with average rainfall in a region

[b] Dry year is defined as a drought on the magnitude of 20%, or an average of the two driest years in a ten year period over the last 30 years of weather data.

[c] Other county is based on the 13 county upper Flint River basin region.

Table 6.4. Corn Water Demand (acre-ft) in Normal and Dry Years by County

	Water Demand (ac-ft)*					
	1998 Estimated			1998 Predicted		
County	Acres	Normal[a]	Dry[b]	Acres	Normal	Dry
Baker	7000	6498	7414	7280	6758	7711
Calhoun	4707	4370	4985	3089	2868	3272
Crisp	1700	1578	1801	1591	1477	1685
Decatur	7500	6963	7944	14339	13311	15187
Dooly	500	464	530	2159	2004	2287
Dougherty	1800	1671	1907	176	163	186
Early	7117	6607	7538	7057	6551	7475
Grady	2063	1915	2185	409	380	433
Lee	4000	3713	4237	6514	6047	6899
Macon	3600	3342	3813	1546	1435	1637
Miller	8035	7459	8510	7810	7250	8272
Mitchell	5500	5106	5825	12000	11140	12710
Randolph	3539	3285	3748	2832	2629	3000
Seminole	8836	8203	9359	8661	8040	9173
Sumter	6703	6223	7100	6297	5846	6670
Terrell	4314	4005	4569	1757	1631	1861
Webster	1000	928	1059	-725	-673	-768
Worth	4500	4178	4766	5624	5221	5957
Other[c]	3298	3372	3759	1443	1475	1645
Theil's U				0.2264		
Total	85712	79880	91049	89859	83555	95292

* 1 ac-ft = 325,800 gallons/day

[a] A normal year is defined as a growing season with average rainfall in a region

[b] Dry year is defined as a drought on the magnitude of 20%, or an average of the two driest years in a ten year period over the last 30 years of weather data.

[c] Other county is based on the 13 county upper Flint River basin region.

Table 6.5. Soybean Water Demand (acre-ft) in Normal and Dry Years by County

	Water Demand (acre-ft)[*]					
	1998 Estimated			1998 Predicted		
County	Acres	Normal[a]	Dry[b]	Acres	Normal	Dry
Baker	898	567	676	1402	886	1056
Calhoun	579	366	436	-170	-107	-128
Crisp	387	244	292	-673	-425	-507
Decatur	1747	1104	1316	3876	2448	2920
Dooly	752	475	567	636	402	479
Dougherty	400	253	301	-2118	-1338	-1596
Early	875	553	659	1196	755	901
Grady	254	160	191	-1270	-802	-957
Lee	837	529	631	726	459	547
Macon	510	322	384	-362	-229	-273
Miller	988	624	744	2149	1357	1619
Mitchell	1530	966	1153	3095	1955	2332
Randolph	435	275	328	103	65	78
Seminole	1086	686	818	1593	1006	1200
Sumter	824	520	621	736	465	554
Terrell	530	335	399	-727	-459	-548
Webster	157	99	118	-2100	-1327	-1582
Worth	780	493	588	983	621	741
Other[c]	406	266	307	-559	-367	-423
Theil's U				0.4937		
Total	13975	8837	10529	8516	5366	6414

[*] 1 ac-ft = 325,800 gallons/day

[a] A normal year is defined as a growing season with average rainfall in a region

[b] Dry year is defined as a drought on the magnitude of 20%, or an average of the two driest years in a ten year period over the last 30 years of weather data.

[c]Other county is based on the 13 county upper River basin region.

change forecast (Griffith and Vere, 2000). The model for soybean consistently predicts low acreage counties as having negative acres of irrigated land. This flawed result is due to the ordinary least squares assumption of a linear relationship between the dependent variable and the explanatory variables.

Slippage

Changes in water demand are driven by changes in the distribution of crops farmers choose to irrigate from year to year. These changes in distribution of crops are in turn affected by their expected profitability and total available irrigated acreage. The conventional physical models do not consider the substitution and expansion effects in determining agricultural water demand. In contrast, the econometric model considers these effects. The difference in the estimates of water demand is called slippage. This adjustment may result in a higher or lower than expected water use depending on the effect of relative profitability.

Examining slippage in water use estimation, reduction in total irrigated acreage available in counties will be considered. Slippage is estimated by comparing the econometric forecast of reduction in water demand in 2001 with a physical model following the passage of Flint River Drought Protection Act (FRDPA). The FRDPA was passed by the Georgia Legislature in March of 2000 and signed into law by the Governor in April. Beginning in June 2000, EPD initiated a series of open public meetings seeking extensive farmer, farm organization and other interested individuals comments about the proposed rules. In these public meetings, EPD received many recommendations from agricultural interests, and modifications were made to the original proposal to reflect these concerns. Most significant was the change in the rule limiting participation to surface water users in the entire Flint River basin, instead of the original proposal which included both surface water and groundwater users in the lower Flint River Basin. The impact on Flint River flows caused by groundwater use was considered uncertain after the drought in 1999, while the impact on flows caused by direct surface water withdrawals from perennial streams was considered much clearer by the EPD. The recommended final rules to implement the Flint River Drought Protection Act were adopted by the Board of Natural Resources in December 2000.

Auction registration was held at eight sites throughout southwest Georgia, and 194 farmers holding 347 surface water permits, out of the potential 575 eligible permits registered to participate in the auction. On the designated auction date of March 17, 2001, bids to suspend irrigation were submitted on these 347 permits. After five rounds of auction, EPD declared the auction closed with the following final results.

- EPD accepted offers on 209 permits of the 347 permits registered.
- The average offer price for this entire accepted acreage was $135.70 per acre, leading to a cumulative expense of $ 4.5 million.
- The highest offer price accepted by EPD was for $200 per acre.

According to initial estimates, the auction withdrew more than 33,000 acres of farmland from irrigation using perennial surface water sources in 2001. The breakdown of the 33,006 acres by county is listed in Table 6.6. The counties with reduction in total irrigated acreage does not correspond to the county grouping used in the analysis. Of the 18 counties classified individually, five did not face a reduction in total irrigated acreage (Decatur, Dougherty, Grady, Miller and Mitchell). These counties are assumed to maintain the same total irrigated acreage in 2001 as in 2000. Six out of 19 counties listed in Table 6.6 are those that have been classified into the category Other. A total of 5,070 acres from these counties has been reduced from the category Other between the years 2000 and 2001. Using physical models, EPD estimates that this removal of 33,000 acres from direct surface water irrigation will mean approximately 130 million gallons per day of water that would otherwise have been consumed in irrigation will now remain flowing in the Flint River and its tributaries (Georgia Environmental Protection Division, 2001).

Slippage is measured by comparing the reduction in estimates of water demand, resulting from restrictions on total irrigated acreage available in a county, based on a physical model versus the econometric estimates of equation 5.1. The physical model estimates of change in water demand are calculated on a county basis in the following manner. First, the crop distribution is calculated by dividing irrigated acreage of each of the four crops in a county by the total irrigated acreage in the county. Second, the calculated weights are multiplied by the reduction in total irrigated acreage in a county in 2001. Third, the weighted reduction in acreage is multiplied by the region-specific B-C coefficient. Finally, the estimated change in water demand in the four crops are summed up over counties to give the total estimated decrease in water demand in 2001. The physical estimates of crop distribution are summarized in Table 6.7.

The expected profits and expected yields are calculated by applying the coefficients from OLS regression of equations 4.7 and 4.8 to the data for 2000 and 2001. The econometric estimates of reduction in water demand between the years 2000 and 2001 are conducted using the profits data sources listed in Table 4.1. While data on market and government price were available from the sources listed in Table 4.1, cost and yield used in forecasting maintain the same assumptions as in the estimation of equation 6.1. Yield data for 2000 and 2001 are assumed to remain constant at the average level of 1994 through 1998. Variable cost data are extrapolated using the 1999 level of variable cost. The cost series is adjusted for inflation by the average cost index for the years 1994-98 using data listed in Table 4.1.

Econometric forecasts, considering changes in prices, of irrigated acreage in 2000 and 2001 of corn, cotton, peanuts and soybeans irrigated acreage combined are 690,120 acres in the study area (Table 6.8). Under the econometric scheme, a change in price results in altering

Table 6.6. Reduction in Total Irrigated Acres in the Flint River Basin by County 2000 - 2001

County	Acres Reduced
Baker	1288
Calhoun	2400
Crisp	1524
Dooly	377
Early	2884
Lamar*	90
Lee	1010
Macon	1402
Marion*	3004
Pike*	167
Randolph	681
Schley*	1297
Seminole	91
Sumter	4595
Taylor*	275
Terrell	5109
Upson*	237
Webster	4833
Worth	1742
Total	33006

Source: Georgia Department of Natural Resources.

* Counties specified as Other in the analysis.

the distribution of the crop mix. Change in total irrigated acres and the crop distribution are listed in Table 6.8. The estimate of net change in irrigated acreage listed in table 6.8 is predicted by the econometric model. The model estimate of 33,775 acres is only 2.3% higher than the actual reduction in acreage. The change in irrigated acreage and crop distributions estimates are used in conjunction with the B-C coefficient to estimate slippage. The slippage estimate assumes a normal year and the results are listed in Table 6.9.

In disregarding price effects, the physical model implicitly assumes the irrigated crop distribution remains constant between 2000 and 2001. On the other hand, the econometric model allows an adjustment in acreage distribution to reflect the role of expected profits, risk aversion and total irrigated acreage in a farmer's irrigated acreage allocation decision. The differences in estimation techniques results in a slippage amount of approximately 13%. The amount of slippage means that a physical model over-predicts water savings by approximately 16.9 million gallons per day.

The amount of slippage is an important measure in determining the effectiveness of water conserving initiatives such as the Flint River Drought Protection Act. In considering the dynamic price effects in acreage allocation, policy makers may be better equipped to assess the net change in water demand. Greater precision in information is beneficial because a smaller than expected reduction in water demand implies increased government expenditures on payments to farmers to not irrigate in auctions such the one used in the FRDPA. Thus not only will the government expenditure increase, but also the intended reduction in water demand will not be met.

Forecasting Irrigated Acreage

A major contribution of the present analysis is the inclusion of price effects which affect the distribution of irrigated crops in a county. In this section, predicted commodity prices and

Table 6.7. Physical Estimates of Crop Distribution and Change in Total Irrigated Acres 2000 - 2001

	Total Irrigated Acreage		Net Change in	
Crop	2000	2001[a]	Irrigated Acreage[a]	Crop Distribution[b]
Corn	216,851	210,376	-6,475	0.299
Cotton	227,952	214,653	-13,299	0.314
Peanuts	175,383	165,704	-9,679	0.242
Soybeans	93,015	88,604	-4,411	0.128
Total	724,781	679,337	-33,864	

[a]Physical forecast.

[b] Crop Distribution = Irrigated $Acres_{i,\ y,\ 2000}$ / Total Irrigated $Acres_{i,\ y,\ 2000}$. i = corn, cotton, peanut and soybeans; y = counties in study area.

Table 6.8. Econometric Estimates of Crop Distribution and Change in Total Irrigated Acres 2000 - 2001

	Total Irrigated Acreage		Net Change in	
Crop	2000	2001[a]	Irrigated Acreage[a]	Crop Distribution[b]
Corn	216,851	216,070	-781	0.313
Cotton	227,952	218,073	-9,879	0.316
Peanuts	175,383	159,973	-15,410	0.232
Soybeans	93,015	85,310	-7,705	0.124
Total	724,781	690,120	-33,775	

[a]Econometric forecast.

[b] Crop Distribution = Irrigated $\text{Acres}_{i,\ y,\ 2001}$ / Total Irrigated $\text{Acres}_{i,\ y,\ 2001}$. i = corn, cotton, peanut and soybeans; y = counties in study area.

Table 6.9. Slippage in Measuring Change in Water Demand 2000 - 2001[a]

Crop	Net Change in Acres	B.C. Coeff.	Decrease in Water Demand (ac-ft)[b*] Physical	Econometric	Slippage[c]
Corn	-781	11.20	-72,515	-8,744	
Cotton	-9,879	11.77	-156,524	-116,242	
Peanuts	-15,410	6.37	-61,655	-98,103	
Soybean	-7,705	7.59	-33,478	-58,518	
Total	-33,775		-324,172	-281,607	0.131

[a] Slippage measure assumes normal year.

[b] Physical = $\dfrac{\text{Irrigated Acres}_{i,\,y,\,2000}}{\sum_{i=1}^{4} \text{Total Irrigated Acres}_{i,\,y,\,2000}} * \text{Change in Total Acres}_{y,2001} * \text{B.C. Coefficient}_i$

Econometric = Change in Acres$_i$ * B.C. Coefficient$_i$

i = corn, cotton, peanuts and soybeans; y = 19 counties in the analysis.

[c] Slippage = $1 - \dfrac{\text{Econometric Decrease in Total Water Demand}}{\text{Physical Decrease in Total Water Demand}}$

[*] 1 ac-ft = 325,800 gallons/day

variations on the total irrigated acreage available in a county are used to forecast irrigated acreage and water demand by crop and county to the year 2010.

The predicted price series is from the Food and Agricultural Policy Research Institute (FAPRI) at Iowa State University's Center for Agricultural and Rural Development (CARD). These data were downloaded from the FAPRI website at: http://www.fapri.org/Outlook2001/Tables/CPrices.xls. The FAPRI projections are generated from a multi-market commodity model. The exact econometric specification differs from country to country, but most crop projections are generated using a linear area and yield equation with adaptive expectations. Demand for a crop is separated into food, feed, and industrial components. Food demand is estimated with a linear or log-linear demand equation with the prices of appropriate substitute products included. Feed demand is estimated in a variety of ways, but the general specification includes calculating the number of animal units based on country-specific feed coefficients and projected livestock inventories or meat production. Then the grain use per animal unit is estimated as a function of competing feed prices. Livestock production is generated using an inventory-based modeling structure for cattle, sheep and goats, and swine. The supply functions for livestock products include both output and feed input prices. Demand for livestock products is typically estimated with a log-linear demand system. Homogeneity is imposed on all demand equations, but symmetry and adding-up conditions are frequently violated because of the log-linear specification. The FAPRI baseline projections are generated over several months during the winter. In November, the commodity models are simulated together to establish a global equilibrium that becomes the preliminary baseline. In December, comments are solicited on the baseline from industry specialists and commodity analysts at United States Department of Agriculture (USDA), Food and Agriculture Organization (FAO), Organisation for Economic Cooperation and Development (OECD) and Agriculture Canada. In January FAPRI adjusts the models to the January crop report that is released by USDA in early January, and makes their adjustments based on the comments received in December. In late January, the models are simulated again to reach a new equilibrium that becomes the final baseline, which is released in late February or early March (Fuller, 2001).

FAPRI price projections for corn, cotton and soybeans are listed in Table 6.10. As listed in the table, the raw prices refer to the nominal price series generated by FAPRI. The prices are adjusted to convert the nominal price series into real 1991 dollars and to obtain a smoother fit for the forecasted data relative to the observed price data. The scaling factors (1.047, 1.01 and 0.95 for corn, cotton and soybeans, respectively) estimated by the average ratio of expected prices, as estimated by equation 4.7, to the FAPRI raw price series between 1980 - 98. The adjusted prices are the product of raw prices multiplied by this scaling factor. The expected prices used in generating the scaling factor are in real 1991 dollar terms and, therefore, the adjusted FAPRI prices are also in real terms.

Peanut price projections are not reported by FAPRI. The peanut price forecast was generated by using a stepwise autoregressive (STEPAR) method in the forecast procedure in SAS®. The peanut price data used for the estimation were the expected peanut prices from 1980 - 98. The STEPAR method first detrends the data and then fits an autoregressive model to the detrended series. The method fits the autoregressive process to the residuals of the trend model using a backward-stepping method to select parameters. Specifically, the STEPAR method fits a time trend model to the data series using ordinary least squares, the residuals from the first step are used in computing the autocovariances. The current values are then regressed against the autocovariances from previous step in a Yule-Walker framework considering only autoregressive parameters

which are significant at the 0.20 level for the entry criteria. In the last step, the algorithm searches for the least significant autoregressive parameter and removes those parameters from the model whose value exceeds the threshold value of 0.05. This process is iterated over the parameters until only significant autoregressive parameters remain in the model.

Table 6.10. Modified FAPRI Projected Prices: 1999 - 2010

	Corn		Cotton		Soybean	
Year	Raw	Adjusted[a]	Raw	Adjusted[b]	Raw	Adjusted[c]
1999	2.20	2.30	0.53	0.54	4.94	4.68
2000	2.25	2.36	0.65	0.66	4.97	4.71
2001	2.45	2.56	0.69	0.70	4.79	4.54
2002	2.50	2.62	0.70	0.71	4.82	4.57
2003	2.55	2.67	0.70	0.71	4.94	4.68
2004	2.60	2.72	0.71	0.72	5.13	4.86
2005	2.66	2.79	0.72	0.73	5.28	5.00
2006	2.73	2.86	0.73	0.74	5.42	5.14
2007	2.79	2.92	0.74	0.75	5.58	5.29
2008	2.84	2.97	0.75	0.76	5.74	5.44
2009	2.91	3.05	0.76	0.77	5.85	5.54
2010	2.99	3.13	0.77	0.78	5.94	5.63

Source: FAPRI

[a] Price are adjusted from the raw FAPRI series to the adjusted prices by multiplying the raw prices with a scaling factor. The scaling factor for corn, cotton and soybeans are 1.05, 1.01 and 0.95, respectively. They were calculated as follows:

Corn: (Expected Price $Corn_{1980}$ / FAPRI Corn $Price_{1980}$ + . . . + Expected Price $Corn_{1998}$ / FAPRI Corn $Price_{1998}$) / 19

Cotton: (Expected Price $Cotton_{1980}$ / FAPRI Cotton $Price_{1980}$ + . . . + Expected Price $Cotton_{1998}$ / FAPRI Cotton $Price_{1998}$) / 19

Peanuts: (Expected Price $Peanuts_{1980}$ / FAPRI Peanuts $Price_{1980}$ + . . . + Expected Price $Peanuts_{1998}$ / FAPRI Peanuts $Price_{1998}$) / 19

Soybeans: (Expected Price $Soybeans_{1980}$ / FAPRI Soybeans $Price_{1980}$ + . . . + Expected Price $Soybeans_{1998}$ / FAPRI Soybeans $Price_{1998}$) / 19

This method results in the following per pound peanut price series from 1999 - 2010: 0.27, 0.29, 0.3, 0.31, 0.32, 0.33, 0.34, 0.35, 0.36, 0.36, 0.37 and 0.38, respectively.

Yield data forecasts assume yield remains constant at the average level of 1994 through 1998. This assumption implies the production technology from the five recent years will remain unchanged through year 2010. Variable cost data are extrapolated using the 1999 level of variable cost. The cost series is adjusted for inflation by the average cost index for the years 1994-98 using data listed in Table 4.1.

Forecasts of profit for the four crops are generated using the following equation:

$$\hat{\pi}_{iyt} = \hat{p}_{it} * \hat{Y}_{iyt} - \hat{c}_{it}, \tag{6.1}$$

where

$\hat{\pi}_{iyt}$ = forecast of profits for the i^{th} crop, in the y^{th} county at time t,

$\hat{p}_{it}$ = FAPRI price forecast or for peanuts the autoregessive model of the i^{th} crop at time t,

$\hat{Y}_{iy}$ = forecast of yield for the i^{th} crop in the y^{th} county,

$\hat{c}_{it}$ = forecast of variable costs of the i^{th} crop at time t.

The higher moments of expected profits are estimated similar to equation 4.10. for the forecasted value of profits.

$$Var(\hat{\pi}_{iyt}) = \hat{\sigma}_{\pi_{iyt}} = \sum_{j=1}^{3} \lambda_j [\hat{\pi}_{i,t-j} - E_t(\hat{\pi}_{it})]^2, \tag{6.2}$$

where

$$E_t(\hat{\pi}_{it}) = (\hat{\pi}_{i,t-1} + \hat{\pi}_{i,t-2} + \hat{\pi}_{i,t-3})/3.$$

$E_t(\pi_{it})$ is a three year moving average of predicted profits and the λ_1, λ_2 and λ_3 represents the weights from an adaptive expectations model similar to the one used in equation 4.10. An equally weighted scheme assumption is maintained for the data as earlier, with the three time periods weighted at 0.34, 0.33 and 0.33 for the first, second and third year, respectively. The covariance for the forecasted profits is calculated using:

$$Cov(\check{\pi}_{it,jt}) = \sigma_{\pi_{it,jt}} = \sum_{k=1}^{3} \lambda_k [[\check{\pi}_{i,t-k} - E_t(\check{\pi}_{it})]\,[\check{\pi}_{j,t-k} - E_t(\check{\pi}_{jt})]], \tag{6.3}$$

where

$$E_t(\check{\pi}_{it}) = (\check{\pi}_{i,t-1} + \check{\pi}_{i,t-2} + \check{\pi}_{i,t-3})/3,$$

$$E_t(\check{\pi}_{jt}) = (\check{\pi}_{j,t-1} + \check{\pi}_{j,t-2} + \check{\pi}_{j,t-3})/3,$$

and $i \neq j$.

The change in total irrigated acreage during the forecast period (1999 - 2010) is projected by regressing total irrigated acreage on time. The slope coefficient on time in this regression suggests a 10% increase in the total irrigated acreage in a county. Thus, the acreage is assumed to increase annually by 0.83% for a total increase in the 12 year period of 10%. The predicted variables are then given by:

$$IA^{*}_{iyt} = \alpha_0 + \sum_{j=1}^{4} \beta_j \hat{\pi}_{jyt} + \sum_{\substack{j=1 \\ j \neq i}}^{4} \gamma_j \hat{\sigma}_{jyt} + \sum_{\substack{j=1 \\ j \neq i}}^{4} \delta_{ij} Cov\hat{\pi}_{ijy} + \sum_{\substack{j=1 \\ j \neq i,k}}^{4} \sum_{\substack{k=1 \\ k \neq i,j}}^{4} \zeta_{jk} Cov\hat{\pi}_{jkyt} + \eta_i TIA_{yt} + \sum_{y=1}^{18} \theta_y D_y + \varepsilon_{iyt} \tag{6.4}$$

for i = 1, . . ., 4

Forecasted irrigated acres of corn, cotton, peanuts and soybeans are presented for years 2000, 2005 and 2010 in Tables 6.11 through 6.14.

The forecasted acreage of each of the four crops is the predicted value of the dependent variable in equation 6.4. It is forecasted that there is greater than 18% reduction in the corn acreage between year 2000 and 2005. There is also a 16% and 7% increase in cotton and peanut irrigated acreage, respectively, for the same time period.

Caveat, the increase in peanut acreage assumes a continued peanut price support program. The increase in acreage is not likely given a phasing out of the peanut program. Soybean are forecasted to decrease by over 58%. Some of this trend reverses between 2005 and 2010. Soybean acreage regains irrigated acreage and there is a 31% increase in soybean acreage relative to 2005. Corn and cotton trend continues, albeit dampened. There is a

Table 6.11. Corn Irrigated Acres Forecast by Georgia County for Years 2000, 2005 and 2010

County	2000	2005	2010
Baker	6084	4214	3870
Calhoun	2813	944	599
Crisp	101	0	0
Decatur	9333	7463	7119
Dooly	0	0	0
Dougherty	291	0	0
Early	5484	3614	3270
Grady	347	0	0
Lee	4813	2943	2599
Macon	748	0	0
Miller	6947	5078	4733
Mitchell	77099	75230	74886
Randolph	2939	1070	725
Seminole	6836	4966	4622
Sumter	5048	3179	2835
Terrell	1371	0	0
Webster	0	0	0
Worth	2269	400	55
Other[b]	160	0	0
Total	132684	109100	105313

[a] Acreages predicted as negative have been set to zero.

[b] County category Other consists of 13 Upper Flint River counties.

Table 6.12. Cotton Irrigated Acres Forecast by Georgia County for Years 2000, 2005 and 2010

County	2000	2005	2010
Baker	17875	21083	21761
Calhoun	21312	24519	25198
Crisp	23299	26506	27185
Decatur	12950	16158	16837
Dooly	21407	24614	25293
Dougherty	24458	27665	28344
Early	18943	22150	22829
Grady	23994	27202	27881
Lee	17422	20630	21308
Macon	22106	25314	25992
Miller	14468	17675	18354
Mitchell	16545	19753	20432
Randolph	20733	23940	24619
Seminole	16443	19650	20329
Sumter	18222	21429	22108
Terrell	22450	25658	26337
Webster	24347	27554	28233
Worth	22402	25610	26289
Other[a]	23692	26900	27579
Total	383068	444010	456907

[a] County category Other consists of 13 Upper Flint River counties.

Table 6.13. Peanut Irrigated Acres Forecast by Georgia County for Years 2000, 2005 and 2010

County	2000	2005	2010
Baker	12133	12954	14159
Calhoun	12104	12924	14130
Crisp	12921	13742	14947
Decatur	12801	13622	14827
Dooly	12963	13784	14989
Dougherty	11662	12483	13689
Early	12307	13128	14334
Grady	12075	12896	14101
Lee	13304	14124	15330
Macon	12607	13427	14633
Miller	12618	13439	14644
Mitchell	12631	13452	14657
Randolph	12147	12968	14173
Seminole	12512	13333	14538
Sumter	12936	13757	14962
Terrell	12318	13139	14344
Webster	12365	13186	14392
Worth	12108	12928	14134
Other[a]	12805	13626	14831
Total	237319	252911	275816

[a] County category Other consists of 13 Upper Flint River counties.

Table 6.14. Soybean Irrigated Acres Forecast by Georgia County for Years 2000, 2005 and 2010

County	2000	2005	2010
Baker	992	378	528
Calhoun	90	0	0
Crisp	0	0	0
Decatur	1844	1230	1380
Dooly	0	0	0
Dougherty	0	0	0
Early	805	190	341
Grady	0	0	0
Lee	822	208	358
Macon	0	0	0
Miller	1395	780	931
Mitchell	1217	603	753
Randolph	220	0	0
Seminole	973	359	509
Sumter	588	0	124
Terrell	0	0	0
Webster	0	0	0
Worth	0	0	0
Other[b]	0	0	0
Total	8947	3747	4925

[a] Acreages predicted as negative have been set to zero.

[b] County category Other consists of 13 Upper Flint River counties.

further 3% decline in the corn acreage, while cotton gains an additional 3% irrigated acreage between 2005 and 2010. Peanut acreage registers a 9% increase.

The changes in acreage between 2000 and 2010 are a consequence of the price effects as well as allowing an increase in the total irrigated acreage. Considering only the price effects, with the total irrigated acreage in a county held constant at the 1998 (last year of observed data) level, irrigated acreage adjustments may be investigated solely due to price effects. These results are listed in Tables 6.15 through 6.18.

The constant total irrigated acreage model highlights the role of price effects, with highly-valued crops gaining acreage at the cost of their less profitable counterparts. Corn irrigated acreage adjusts downwards by 19% between 2000 and 2005. The change in corn acreage is approximately the same as it was when total irrigated acreage were allowed to vary. Cotton irrigated acreage increases by 13% with restricted irrigated acreage; this is also proportional to the adjustment relative to the variable total irrigated acreage model. A 3% increase in the peanut acreage is slightly less than its variable total irrigated acreage counterpart of 7%. Adjustment in the soybean acreage is a little more dramatic, with irrigated acres dropping by 65% relative to the 58% drop in the unconstrained total irrigated acreage model. The changes between 2005 and 2010 generally replicate the comparison between constrained and unconstrained model results of 2000 - 2005. The exceptions are adjustments in irrigated acres of cotton and soybean. Between 2005 - 2010 there is virtually no adjustment in the cotton irrigated acreage, and the upward adjustment in soybean acreage is dampened to 17% compared with 31% in the unconstrained total irrigated acreage model.

Table 6.15. Corn Irrigated Acre Forecast with Total Irrigated Acres Fixed at 1998 Levels

County	2000	2005	2010
Baker	6022	3996	3487
Calhoun	2752	725	217
Crisp	40	0	0
Decatur	9271	7245	6736
Dooly	0[a]	0	0
Dougherty	230	0	0
Early	5423	3396	2887
Grady	286	0	0
Lee	4752	2725	2216
Macon	687	0	0
Miller	6886	4859	4351
Mitchell	77038	75011	74503
Randolph	2878	851	343
Seminole	6775	4748	4239
Sumter	4987	2960	2452
Terrell	1310	0	0
Webster	0	0	0
Worth	2208	181	0
Other[b]	99	0	0
Total	131644	106696	101432

[a] Acreages predicted as negative have been set to zero.

[b] County category Other consists of 13 Upper Flint River counties.

Table 6.16. Cotton Irrigated Acre Forecast with Total Irrigated Acres Fixed at 1998 Levels

County	2000	2005	2010
Baker	17618	20163	20152
Calhoun	21055	23600	23589
Crisp	23042	25587	25576
Decatur	12693	15238	15227
Dooly	21150	23695	23684
Dougherty	24200	26746	26734
Early	18685	21231	21219
Grady	23737	26283	26271
Lee	17165	19710	19699
Macon	21849	24394	24383
Miller	14210	16756	16745
Mitchell	16288	18834	18822
Randolph	20475	23021	23010
Seminole	16185	18731	18719
Sumter	17964	20510	20499
Terrell	22193	24739	24727
Webster	24090	26635	26624
Worth	22145	24691	24679
Other[a]	23435	25980	25969
Total	378179	426542	426328

[a] County category Other consists of 13 Upper Flint River counties.

Table 6.17. Peanut Irrigated Acre Forecast with Total Irrigated Acres Fixed at 1998 Levels

County	2000	2005	2010
Baker	11940	12263	12950
Calhoun	11911	12234	12921
Crisp	12728	13051	13738
Decatur	12608	12931	13618
Dooly	12770	13093	13780
Dougherty	11469	11792	12480
Early	12114	12437	13124
Grady	11882	12205	12892
Lee	13110	13433	14121
Macon	12413	12737	13424
Miller	12425	12748	13435
Mitchell	12438	12761	13448
Randolph	11954	12277	12964
Seminole	12319	12642	13329
Sumter	12743	13066	13753
Terrell	12125	12448	13135
Webster	12172	12495	13183
Worth	11914	12238	12925
Other[a]	12612	12935	13622
Total	233646	239787	252843

[a] County category Other consists of 13 Upper Flint River counties.

Table 6.18. Soybean Irrigated Acre Forecast with Total Irrigated Acres Fixed at 1998 Levels

County	2000	2005	2010
Baker	963	273	344
Calhoun	60	0	0
Crisp	0[a]	0	0
Decatur	1815	1125	1196
Dooly	0	0	0
Dougherty	0	0	0
Early	775	85	157
Grady	0	0	0
Lee	793	103	174
Macon	0	0	0
Miller	1365	675	747
Mitchell	1188	498	569
Randolph	191	0	0
Seminole	944	253	325
Sumter	559	0	0
Terrell	0	0	0
Webster	0	0	0
Worth	0	0	0
Other[b]	0	0	0
Total	8653	3012	3513

[a] Acreages predicted as negative have been set to zero.

[b] County category Other consists of 13 Upper Flint River counties.

Forecasting Water Demand

Forecasted water demand is an application of the crop and region specific BC coefficient as listed in table 6.1. To illustrate water demand, the baseline assumption of total irrigated acreage increasing by 10% over the 1999 - 2010 period is maintained. Water demand is calculated by multiplying the irrigated acreage by the crop and region specific BC coefficient, therefore, trends that emerge in water demand are a replicate of the variable total irrigated model case. Water demand for 2000, 2005 and 2010 normal and dry years are listed in tables 6.19 through 6.22.

Table 6.19. Corn Irrigation Water Demand Forecast by County for Years 2000, 2005 and 2010

	Water Demand (ac-ft)*					
	2000		2005		2010	
County	Normal[a]	Dry[a]	Normal[a]	Dry[a]	Normal[a]	Dry[a]
Baker	5648	6444	3912	4463	3592	4099
Calhoun	2612	2980	876	1000	557	635
Crisp	94	107	0	0	0	0
Decatur	8664	9885	6928	7905	6609	7540
Dooly	0	0	0	0	0	0
Dougherty	271	309	0	0	0	0
Early	5091	5808	3355	3828	3035	3463
Grady	322	367	0	0	0	0
Lee	4468	5098	2732	3117	2413	2753
Macon	694	792	0	0	0	0
Miller	6449	7358	4714	5378	4394	5013
Mitchell	71574	81661	69838	79681	69519	79316
Randolph	2729	3113	993	1133	673	768
Seminole	6346	7240	4610	5260	4291	4896
Sumter	4687	5347	2951	3367	2631	3002
Terrell	1273	1452	0	0	0	0
Webster	0	0	0	0	0	0
Worth	2107	2403	371	423	51	59
Other[b]	164	182	0	0	0	0
Total	123190	140547	101281	115555	97766	111544

* 1 ac-ft = 325,800 gallons/day
[a] Water demand predicted as negative values have been set to zero.
[b] Other counties consists of 13 Upper Flint River counties.

Table 6.20. Cotton Irrigation Water Demand Forecast by County for Years 2000, 2005 and 2010

	Water Demand (ac-ft)*					
	2000		2005		2010	
County	Normal[a]	Dry[a]	Normal[a]	Dry[a]	Normal[a]	Dry[a]
Baker	17488	20378	20626	24034	21290	24808
Calhoun	20850	24295	23988	27952	24652	28726
Crisp	22794	26561	25932	30217	26596	30991
Decatur	12670	14763	15808	18420	16472	19194
Dooly	20943	24404	24081	28060	24745	28834
Dougherty	23928	27882	27066	31538	27730	32312
Early	18532	21594	21670	25251	22334	26025
Grady	23474	27354	26613	31010	27277	31784
Lee	17045	19861	20183	23518	20847	24292
Macon	21627	25201	24765	28857	25429	29631
Miller	14154	16493	17292	20150	17956	20923
Mitchell	16187	18862	19325	22518	19989	23292
Randolph	20284	23635	23422	27292	24086	28066
Seminole	16086	18745	19224	22401	19888	23175
Sumter	17827	20773	20965	24429	21629	25203
Terrell	21964	25593	25102	29250	25766	30024
Webster	23819	27755	26957	31412	27621	32186
Worth	21917	25539	25055	29195	25719	29969
Other[a]	24208	27400	27485	31110	26981	31440
Total	375796	437088	435558	506616	447007	520874

* 1 ac-ft = 325,800 gallons/day
[a] Other counties consists of 13 Upper Flint River counties.

Table 6.21. Peanut Irrigation Water Demand Forecast by County for Years 2000, 2005 and 2010

	Water Demand (ac-ft)*					
	2000		2005		2010	
County	Normal[a]	Dry[a]	Normal[a]	Dry[a]	Normal[a]	Dry[a]
Baker	6653	8059	7103	8604	7764	9404
Calhoun	6637	8039	7087	8584	7748	9385
Crisp	7085	8582	7535	9127	8196	9928
Decatur	7019	8502	7469	9047	8130	9848
Dooly	7108	8610	7558	9155	8219	9955
Dougherty	6395	7746	6845	8291	7506	9092
Early	6749	8174	7199	8719	7860	9520
Grady	6621	8020	7071	8565	7732	9366
Lee	7295	8836	7745	9381	8406	10181
Macon	6913	8373	7363	8918	8024	9719
Miller	6919	8380	7369	8925	8030	9726
Mitchell	6926	8389	7376	8934	8037	9735
Randolph	6661	8068	7111	8613	7772	9413
Seminole	6861	8310	7311	8855	7972	9656
Sumter	7093	8592	7543	9137	8204	9937
Terrell	6754	8181	7204	8726	7865	9527
Webster	6780	8213	7230	8758	7891	9558
Worth	6639	8042	7089	8587	7750	9387
Other[a]	8206	9614	8732	10231	8132	9850
Total	131314	158729	139940	169156	151239	183188

*1 ac-ft = 325,800 gallons/day
[a] Other counties of 13 Upper Flint River counties.

Table 6.22. Soybean Irrigation Water Demand Forecast by County for Years 2000, 2005 and 2010

	Water Demand (ac-ft)*					
	2000		2005		2010	
County	Normal[a]	Dry[a]	Normal[a]	Dry[a]	Normal[a]	Dry[a]
Baker	627	747	239	285	334	398
Calhoun	57	68	0	0	0	0
Crisp	0	0	0	0	0	0
Decatur	1165	1389	777	926	872	1040
Dooly	0	0	0	0	0	0
Dougherty	0	0	0	0	0	0
Early	508	606	120	143	215	257
Grady	0	0	0	0	0	0
Lee	519	619	131	157	226	270
Macon	0	0	0	0	0	0
Miller	881	1051	493	588	588	701
Mitchell	769	917	381	454	476	568
Randolph	139	166	0	0	0	0
Seminole	615	733	226	270	322	383
Sumter	372	443	0	0	78	94
Terrell	0	0	0	0	0	0
Webster	0	0	0	0	0	0
Worth	0	0	0	0	0	0
Other[b]	0	0	0	0	0	0
Total	5652	6740	2367	2823	3111	3711

* 1 ac-ft = 325,800 gallons/day

[a] Water demand predicted as negative values have been set to zero.

[b] Other counties consists of 13 Upper Flint River counties.

CHAPTER 7

SUMMARY, CONCLUSIONS AND IMPLICATIONS

Summary

Georgia agriculture, with its 1.4 million irrigated acres of farmland, is the major consumptive water user in the state (Proceedings Georgia Water Resources Conference, 2001). Despite this large consumption, the precise agricultural water uses on a county by commodity basis are generally unknown. In the absence of this information, policy proposals and decisions regarding irrigation management are made under incomplete, and potentially inaccurate, information. This dissertation addresses four main problems associated with providing information for water allocation decisions: limited data sources, absence of a model for determining agricultural water demand, lack of linkages between water demand and physical models of agricultural water use and the slippage due to differences in the physical and agricultural demand measurements of water use.

Specifically, the present analysis develops a method for forecasting Georgia agricultural water demand for corn, cotton, peanuts and soybeans on county basis. First, the available irrigation data is disaggregated to a county by crop level. Second, the disaggregated data is used to estimate the irrigated acreage responsiveness for corn, cotton, peanuts and soybean as a function of profits, variance-covariance of profits and the total irrigated acreage available to producers in a county. Third, the estimated measures of irrigated acres are used in conjunction with the crop- and region-specific Blaney-Criddle coefficients of net irrigation requirements to forecast water demand. Finally, sensitivity analysis is conducted on the parameters of the acreage response model to trace the effects of alternative prices and institutional arrangements which result in slippage.

The theoretical underpinnings of the analysis are based in expected utility maximization. The producer is assumed to be a risk averting expected utility maximizer operating in a competitive market facing uncertain output prices and yield. The producer maximizes expected utility by allocating the total amount of irrigated acreage available among competing enterprises. Given the assumption of risk aversion and an acreage constraint, the resulting empirical model of irrigated acreage is a function of profits, variance-covariance of profits and the total irrigated acreage. Data for estimating the empirical model are not available for an individual producer and the highest degree of disaggregation is on a county level. Data on irrigated acreage are also not available on a county by crop level. The state level crop irrigation data were disaggregated on a county level by assuming the county total irrigated acreage of the i^{th} crop is proportional to the state irrigated acres of the i^{th} crop. A problem with this method is that it is not linked with the crop mix in a county. Thus, present analysis adopts this method with a modification to account for the crop mix in a county.

Data imputation is a two-stage process. The first stage assumes that the proportion of irrigated acreage devoted to a given commodity in each county is identical to the proportion of irrigated acreage devoted to that commodity at the state level.
The second stage uses the rule that the irrigated acres estimate of the i^{th} crop in the y^{th} county at time period t is less than or equal to the harvested acres of the i^{th} crop in the y^{th} county. Through the two stages all available information employed for measuring and is the chosen measure of irrigated acres by crop and county for the analysis.

Assuming the error terms to be independent and identically distributed allows estimating the equation for crop acreage using ordinary least squares (OLS). All four crop equations are specified as functions of an intercept term, profits, variance and covariance of each of the crops, the total irrigated acreage in a county and county-specific intercept shifting dummy variables. The overall goodness-of-fit was considered by examining the F-test statistic and the coefficient of determination, R^2, and a linear fit was imposed.

The signs on the parameters associated with the mean net returns are as expected, except for mean net returns associated with corn. Corn profitability registers the hypothesized sign in the soybean equation as an evidence of the rotation relationship between corn and soybeans.

The estimated coefficients of the variation of profits, designed to capture the risk aversion of producers, is generally not significant even at 10% level. The only exception are the estimated coefficients of variation of profits of corn and peanuts in the soybean equation. Lack of statistical significance on the estimated coefficients of variation may be explained in two ways. One, producers may not be risk averse in their irrigated acreage allocation decision. Two, government price support may enable farmers to consider only the first moment of their expected utility in making acreage allocation decisions.

Covariance between crops, a parameter hypothesized to capture the risk-spreading behavior of the farmers, is significantly different from zero in half of the instances. The covariance between corn and soybean is significant at the 10% level in the corn equation. The inverse relationship suggests the portfolio effect between the two crops. The covariance between cotton and soybean is significantly different from zero at 10% level in the soybean equation also suggesting the hypothesized portfolio effect.

The parameter estimate associated with the constraint, TIA_{yt}, has the expected positive sign and is significantly different from zero at the 1% level in the corn, cotton and peanut equations and at the 5% level in the soybean equation. In terms of elasticity, the cotton irrigated acreage is highly responsive to changes in the total irrigated acreage in a county. In terms of elasticity the cotton irrigated acreage is highly responsive to changes in the total irrigated acreage in a county. A coefficient estimate of 0.325 in the cotton equation suggests that a one acre increase in the total irrigated acreage in a county results in approximately one-third acre increase in cotton, *ceteris paribus*. Peanut acres are estimated to increase about one quarter of an acre for a one acre increase in toal irrigated acres in a county. Corn and soybean equations 0.07 and 0.04 acres, respectively. The other equations have relatively inelastic measures of responsiveness with respect to TIA_{yt}.

The results from estimating irrigated acreage are used in conjunction with the Blaney-Criddle (BC) water application coefficients for modeling water demand. The parameter estimates are then used to forecast irrigated acreage and water demand. Forecasting is based on prices from the Food and Agricultural Policy Research Institute (FAPRI) at Iowa State University's Center for Agricultural and Rural Development (CARD).

Yield data forecasts assume yield remains constant at the average level of 1994 through 1998. This assumption implies the production technology from the five recent years will remain unchanged through year 2010. Variable cost data are extrapolated using the 1999 level of variable cost. The cost series is adjusted for inflation by the average cost index for the years 1994-98 using data listed in Table 4.1.

It is forecasted there is over a 21% reduction in the corn acreage between year 2000 and 2010 and increases of 19% and 16% in cotton and peanut irrigated acreage, respectively, for the same time period. Soybean acreage is forecasted to decrease by over 45%. The changes in acreage between 2000 and 2010 are a consequence of both the price effects as well as allowing an increase in the total irrigated acreage. Considering only the price effects, with the total irrigated acreage in a county held constant at the 1998 (last year of observed data) level, irrigated acreage adjustments maybe investigated solely due to price effects.

The constant total irrigated acreage model highlights the role of price effects with highly-valued crops gaining acreage at the cost of their less profitable counterparts. Corn irrigated acreage adjusts downwards by 23% between 2000 and 2010. Cotton irrigated acreage increases by 13% with restricted irrigated acreage; this is also proportional to the adjustment relative to the variable total irrigated acreage model. An 8% increase in the peanut acreage is half that of its variable total irrigated acreage counterpart. Adjustment in the soybean acreage is a little more dramatic, with irrigated acres dropping by 65% relative to the 45% drop in the unconstrained total irrigated acreage model.

Changes in water demand as a result of reduced total irrigated acreage are measured using both physical and demand models. The two estimates differ in their assumptions about the crop distribution. The physical model assumes a constant crop distribution from year to year. The demand model allows for variation in the crop distribution due to price and total acreage effects. The difference in water use between the two models is a measure of slippage. Slippage, in the context of water demand, is a reduction in total irrigated acreage for which there is partial corresponding adjustment in water use. Slippage occurs when, based on price effects, producers switch to crops with higher or lower supplemental water requirements. In the present analysis, this switch is towards cotton, which is the highest water user of the four crops under consideration. This results in a slippage value of 13% which suggests an overestimation in water savings following a reduction in irrigated acreage using physical parameters.

Conclusion, Implications and Further Research

A major contribution of this research is incorporating price effects in a producer's acreage allocation decision. Data suggest producers' decision-making process is primarily based on the expected net returns from the competing enterprises. Focus on first moments of an expected utility function with minimal regard for the riskiness of competing crops may be attributed to a lack of evidence in favor of risk aversion and also price supports afforded by the government.

Until recently, policy changes generally occurred in relatively small increments. According to Knutson, *et al.*, the 1996 Farm Bill reverses this trend through a directional change in policy that had previously not occurred since 1973 when the target price program was established. The 1996 Farm Bill made two key policy changes:

- Eliminated the target price and the set-aside program.
- Decoupled transition payments with virtual flexibility.

The target price had the effect of increasing supplies, which, in order for the market to clear, results in lower market price. Eliminating the target price has the effect of raising the market price to the free market equilibrium price. Typically, if the equilibrium price is below the target price, the quantity supplied falls. With the higher market price, the quantity exported declines more than domestic demand. This is consistent with the notion that deficiency payments have been an implicit export subsidy and a domestic consumer subsidy.

Decoupling is aimed at reducing price distortionary effect of policy. It involves the separation of income payments from market prices and from production decisions. The 1996 Farm Bill decouples by providing farmers with fixed transition payments over the period 1996 - 2002 with no ties to either production (acreage or yield) or prices. The magnitude of the annual transition payments over the period is known. These payments are divided among farmers on the basis of historical program base and yield but are independent of the level of planting. Each individual participating producer knows the approximate amount of fixed payments that will be received each year through 2002. These payments are authorized by law, but each year Congress will decide whether to appropriate the funds.

Virtual flexibility is provided in commodities produced regardless of a farmer's acreage base. However, the land cannot be commercially developed for nonagricultural uses. The only restriction on planting is that fruits and vegetables cannot be planted unless the farmer has a history of planting them. This restriction was to protect traditional fruit and vegetable farmers from a potential influx due to flexibility and lower market prices. It is important to note that since land allocation decisions are made based on marginal revenue and cost, the fixed transition payments do not have a role in acreage allocation decision.

The direction of recent policy initiatives is opening up domestic agricultural producers to world market prices. Operating in a relatively open economy will necessitate consideration of multiple sources of risk in farmer's decision making. While crop insurance is designed to mitigate risks associated with yield, revenue insurance considers both the risk associated with yield and prices guaranteeing farmers certain level of gross revenue from a crop. In addition to considering revenue insurance, farmers are likely to employ irrigation to a larger proportion of their land. Specifically, highly valued crops will tend to have a larger share in irrigated acreage allocation.

Incorporating price effects in the acreage allocation decision leads to slippage in the measurement of water demand. This study has attempted to identify the presence of slippage and the pitfalls associated with disregarding it in measuring changes in water demand. Considering slippage is a first attempt in determining the effectiveness of water conserving initiatives such as the Flint River Drought Protection Act. Currently, policy makers are assuming a certain level of decrease in irrigation water demand as a result of reducing the total irrigated acreage. The decrease in water demand is then in turn assumed to benefit both the interstate and intrastate allocation of water from the Flint River. The policy makers contend increase water flows for Alabama and Florida as well more water for the competing users within the state. In considering the dynamic price effects in acreage allocation, policy makers may be better equipped to assess the net change in water demand. Greater precision in information is beneficial because a smaller than expected reduction in water demand implies increased government expenditures on payments to farmers to not irrigate in auctions such the one used in the FRDPA. Thus not only will the government expenditure increase, but also the intended reduction in water demand will not be met. Failure to make adjustment as suggested in this dissertation would lead to erroneous policy analysis.

As with any empirical research, data are a limitation to the present study. Research points to benefits of improved irrigation data collection on a county by crop basis. These data are required for accurate policy analysis. Developing such data set would provide an opportunity to further exploit the panel relationships in the irrigation data.

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