

DISSERTATION

OF GOLF AND GRAINS: THREE ESSAYS ON RESOURCE USE IN THE NEW
AMERICAN WEST

Submitted by

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In partial fulfillment of the requirements

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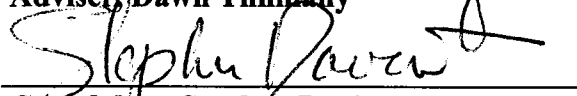
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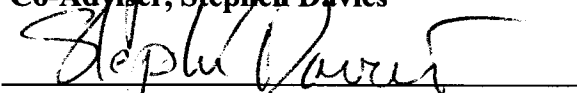
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ABSTRACT OF DISSERTATION

OF GOLF AND GRAINS: THREE ESSAYS ON RESOURCE USE IN THE NEW AMERICAN WEST

The state of Colorado, and indeed much of the Western United States, has experienced rapid population growth and economic development over the past 50 years, transforming this once largely rural region dominated by agriculture and mining into an increasingly urban and suburban population with a diverse economy. The implications of this transformation on the region's natural resource base are numerous and complex. Industries associated with population growth such as golf and house remodeling now have similar gross sales to grain farming and cattle production respectively.

This dissertation examines forces that drive land and water allocations in Colorado and the West. It is found that while limited amounts of land and water are expected to transfer out of agriculture and into industries such as golf over the coming decades, agricultural production will persist and evolve in the West.

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INTRODUCTION

According to the U.S. Census Bureau, the five states with the highest percent gain in population from 1990 to 2000 are all located in the Intermountain West. These states, Nevada, Arizona, Colorado, Utah, and Idaho, share many attributes including low annual precipitation and areas with high natural amenities. They are also characterized by economies that have historically been based on agriculture and mining. As populations in the West have grown and diversified, so too has the region's economic base. In Colorado, for example, the 1860's through the 1960's were economically dominated by agriculture and mining while tourism, manufacturing, and technology have emerged as larger sectors since the 1960's (Kendall 2002).

Still, agriculture remains an important economic base in the region, especially in remote areas. As the West continues to develop, agriculture will remain an important industry both economically and culturally in many regions, yet the sector is expected to decline as a primary driver of economic activity in the West as a whole. Its competitiveness is, in part, affected by its ability to compete for factors of production, of which water and land are the most scarce and fixed in supply. Because of this, there is interest in exploring these place-specific factors in the context of their importance to economic performance from the micro-firm level to regional economy level. In this dissertation, these issues are explored at three levels, through a snapshot, intercounty analysis of financial performance in the West, then to a general equilibrium treatment of how changes in factor reallocation affect a specific (Colorado) economy, down to a narrow treatment of how a specific industry, golf, reacts to policies meant to manage

impacts from a drought that severely shrank access to water. Each of these is a unique approach and method to answer the same question: how will water and land dependent industries react to changing market forces, and what are the subsequent effects on the local economies in which they operate?

The first chapter of this study looks at the factors that are expected to contribute to financial performance and resilience of the agricultural sector in different regions of the West. Our hypotheses are that a variety of factors attract agricultural producers because of the heightened ability to generate agricultural revenues, or alternatively, keep input and capital costs (land) low. Using 2002 Census of Agriculture data, the factors that contribute to various measures of farm financial performance are estimated with a cross-sectional, county-based spatial econometric model. The results of this chapter are intended to inform the discussion of agriculture's role in the rural economy, what production strategies are most likely to lead to strong farm performance, how this might vary by place-specific factors, and subsequently, where agriculture is likely to persist versus where it is likely to decline.

In many areas of the Western United States, the decline of agriculture has been evident for decades. Natural resource based industries such as mining and agriculture, once the dominant economic base of Colorado and the West, are no longer the major drivers of the regional economy. While these sectors remain important in specific counties, broader economic and population growth have changed the character of the West. Despite its loss of economic dominance, agriculture controls a majority of the state's water, a resource that will allow it to remain an important industry if this resource is maintained in the future. According to the U.S. Geological Survey, agriculture

accounts for 60% of the total water usage and 94% of the consumptive water usage in Colorado. As the region continues to grow, water will be increasingly demanded by municipal and industrial users. Agriculture currently owns the water and therefore agriculture has a large stake in the future development of Colorado and the West. According to the Colorado Farm Bureau Water Development Study, municipal and industrial water demand is expected to grow by 120% over the next century, up from 1.0 million acre feet in 2000 to 2.2 million acre feet in 2100. Nearly all of that water will have to come from the agricultural sector.

It is assumed (and arguably desirable) for the most marginal agricultural producers to be the first to sell their water rights. These marginal producers have the most to gain by selling their water rights as they are most likely operating on marginal lands which do not have high expected net revenue while producers who are able to generate higher net returns are likely to stay in agriculture. Following this logic, the first chapter of this paper examines what factors are likely to contribute positively to financial performance in the agriculture sector throughout the West and where agriculture is likely to persist in the future even as water is diverted from agricultural production.

Still, this gradual diversion of water from agriculture to municipal and industrial uses will have a profound effect on the state's economy and demographics. From 1987 to 1997, the conversion of agricultural lands to development in the state averaged 141,000 acres per year. Many current agricultural producers stand to gain a great deal financially by selling off and leasing of water rights. It is uncertain, however, how the rural economies that depend on agricultural production for their economic base will be affected by these water transfers.

The second chapter of this study looks specifically at the effects of economic and population growth on land and water use in the Platte River Basin of Colorado. This basin consists, in part, of Colorado's Northern Front Range. The Front Range is a rapidly growing and economically diverse region of the state. As the region's population is expected to grow by between 1% and 1.5% annually over the next decade, land and water that are currently employed in agriculture will need to be transferred to non-agricultural sectors. To examine this issue a computable general equilibrium model was constructed that explicitly incorporates land and water as primary factors of production and a social accounting matrix for the counties comprising the South Platte River Basin in Colorado.

Finally, it is of interest to explore how water is used within a recipient sector, as a case study of how water allocations will affect various economic bases. The economic and natural resource interplay between agriculture and golf serve as an interesting proxy for the larger rural/urban issues currently arising due to increasing populations in Colorado and across the West. Golf represents one industry that stands to benefit from the projected population growth over the coming century is golf. Since 1898, the correlation coefficient between population growth and golf course development has been 0.99. Over this time period, on average, one golf course has been built for every 14,500 person increase in the state's population. Golf can be thought of as an urban counterpart to agriculture as it uses similar inputs of water, fertilizer, machinery, and labor to produce its output. Golf, however, is much more intensive in its use of all these inputs. This study also examines the larger implications of population growth and water policy on Colorado's state economy through analysis of effects on the contribution golf makes to the economy. This is accomplished through a partial equilibrium analysis that

specifically looks at water and land allocations and how they may impact golf's economic activity directly through water consumption and indirectly through investment in water saving technology and management approaches.

Because the golf industry is so strongly tied to population growth and because it tends to be a high profile user of municipal water, it is often targeted by those who feel water is misallocated or inefficiently managed by the golf sector. Given the drought, that reached its most critical stage in 2002, and high visibility policy actions, the responses of golf courses to public concern about water conservation is of interest. The second chapter examines how golf courses in Colorado use water and what policy instruments are likely to be most effective in giving golf courses incentives to conserve water while minimizing the economic impacts on their golf course operations. In short, since water is moving from agriculture to municipal and industrial uses, partly due to the reallocation and competition from sectors such as golf which are strongly associated with population growth, this is an interesting case study of water market forces at work.

The purpose, then, of this dissertation is to examine the current competitive state of agriculture in the West, the subsequent land and water allocations in the face of increasing population pressures in Colorado and the West, and emerging policy tools that may influence private firms' water usage in eras of water scarcity. In a broader perspective, the goal of this research is to explore the implications of land and water usage on the agriculture sector's performance as well as the region's economy.

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CHAPTER ONE

Where and Why Agriculture is Thriving: County Level Analysis of Western Agricultural Financial Performance

Introduction

In the recent debate as to the role that agriculture now plays and will continue to play in rural development, two issues remain largely unexplored. The first is what factors have been shown to be important to agricultural sector performance itself among counties in the US and the second is where conditions are expected to remain favorable for agricultural sector performance (or particular sectors of agriculture) in the future, given potential, alternative uses for scarce resources such as land and water. This paper examines how agriculture might be viewed in the context of rural development.

Prevailing thoughts on agriculture's role in rural development have changed throughout the past 50 years (Ellis and Biggs 2001), reflecting the changes in attitudes and opinions as to what factors contribute the most to economic and social well-being in rural areas (Ashley and Maxwell 2001). Research in rural development has highlighted the importance of the non-economic as well as the economic aspect in the overall well-being of rural communities (Deller et. al 2001, Blank 2002). Additionally, recent trends in rural development have also emphasized urban-rural linkages (CAST 2002, Weber 1998, Mishra and Sandretto 2002, Kimhi 2000) and socio-environmental sustainability factors in the overall well being of America's farming communities (Lyson and Welsh 1993). Although this research cannot address the full set of issues, integration of urban influence codes and climatic information into the model controls for some of the land

resource and valuation issues expected to arise from financial performance issues related to these factors.

People living in rural areas are not simply profit maximizing producers of agricultural commodities, they are utility maximizing households which make decisions that are financially, culturally, and lifestyle based (Brewster 1961, Blank 2005). According to Blank (2005), the goal of any business, including rural agricultural producers, is to increase the wealth of owners and wealth is accumulated not only as net revenues from farm operations, but also as off-farm income and capital gains on assets invested in the operation. It has long been realized that on-farm income is only a part of the picture of rural economic development and rural sociological decision making (Mishra et al. 2002, (Mishra and Sandretto 2002).

Rural agricultural producing households face dual objectives of wealth accumulation and utility maximization. The two are obviously correlated, but not perfectly. A household may face higher expected wealth by selling the farm and moving into town, however the disamenity associated with that move may negatively influence the utility function to a greater extent than the increased wealth contributes. In this case, the household may continue to persist in agriculture for sociological reasons, even if net returns to agricultural production are low. Similarly, an agricultural producing household may persist in agriculture despite low returns if the appreciation on their land or water assets are sufficiently high to compensate for low, short-term cash returns. For example, if a farming household owns land and a water right in Colorado with a value growing at a rate greater than that of other investment options, the water right becomes an investment that the household would be smart to hold on to. In this case the net returns to

agricultural production may be low, but wealth accumulation is sufficiently high to keep them on their land and in agriculture. In summary, net returns to production, asset appreciation, and off-farm income, as well as lifestyle preferences, all play a role in rural wellbeing and farm household decision making.

While sociological factors and non-production based income have been shown to be vitally important to rural well-being and may increase in importance in the future, the farm income from operations component has been largely ignored in recent literature. The revenue associated with the production of agricultural goods continues to be an economic base of many rural areas (Irz et. al 2001). It is estimated that one in five rural counties in the United States is dependent on agriculture for its economic base (Ghelfi and McGranahan 2004), and only real cash returns (not land appreciation) will benefit agriculturally enabled industries. In short, agriculture will face many challenges in coming decades (Blank 1999) and an understanding of the factors that contribute to financial performance of the agricultural sector will be crucial information to guide policy decisions and rural economic development strategies.

While previous studies have examined the importance of off-farm income and of capital gains on assets such as land (Blank et. al 2004, Mishra et. al 2002), this study focuses primarily on the factors that contribute to on-farm net revenues of operations. Still, production-based gross revenues, off-farm income, and land valuation are not completely independent concepts. Many factors that affect one of those three measures will likely affect another. For example, urban encroachment is likely to provide greater opportunity for off-farm employment and will also yield higher asset valuation growth, thus making production income a less vital component of household wealth (as well as

less competitive relative to other land and water uses). In examining the factors that contribute to on-farm financial performance, aspects of off-farm income decisions and land valuation will come into the story as they influence agricultural production decisions. For example, some regions may be closer to urban centers and therefore may have greater potential for off farm employment. Likewise, some areas may have specific natural characteristics that allow that region to pursue production and marketing strategies that will yield higher net returns than other areas. The expected returns in these respective regions will influence the value of the land to agricultural producers both through real net cash returns and returns to investments in assets (namely water and land). Moreover, some characteristics that make locations more desirable to agricultural producers may also make them more desirable to other industrial sector and households.

This study will conceptually look at what factors might be expected to draw producers to a given location and will attempt to quantify factors that contribute to financial performance, describing the role of these factors now and where they are likely to persist in the future. We then attempt to identify the strategies and characteristics of the agricultural sector in the 413 counties of the western United States and determine how these characteristics and strategies relate to financial performance of the agricultural sector. Given these findings, we then turn our attention to why these characteristics exist where they do and what factors might influence them using discussion of spatial patterns within maps illustrating differential financial performance. We attempt to model where these characteristics are likely to persist, indicating where agricultural sector performance is likely to continue to flourish despite the mounting threat of both international trade

competition among product markets, as well as competition for important resources (land, water, labor) to agriculture among input markets.

This study will conceptually look at what factors contribute to financial performance, and then look for geographically specific aspects that explain where these factors exist now and where they are likely to persist in the future. The primary research goal, then, is twofold; first to determine what factors contribute to agricultural sector financial performance in the 413 counties of the western United States, and secondly, to explore why some regions perform better than others and where agriculture is most likely to persist in the face of continued threats from falling commodity prices and increasing production costs (including opportunity costs for fixed resources such as land). Obviously there is more to this story than simply determining what counties have high net farm incomes per acre and describing their agricultural sector. This is a regional economic question that must also consider locational dynamics, locational dependence, climate, and heterogeneous land values.

Land Use Evolution

According to the USDA Census of Agriculture, total land in agriculture peaked in the United States in 1950 at around 1150 million acres, representing roughly 48% of the total land use in the United States. Since then total land in agriculture has decreased steadily, reaching 938 million acres in 2002, or 39% of total land use. This represents a 22% reduction in the amount of land in agriculture over fifty years.

Employment has seen an even greater reduction over the same time period. Labor is more mobile and adaptive than is land and can switch out of sector much faster than

can land. In 1950 7.9 million of the total 65.5 million jobs in the U.S. were in agriculture, representing 12% of the total labor force. In 2002 3.3 million of the total 166.7 million total jobs in the U.S. were in agricultural production, representing about 2% of the total labor force. It is undeniable that agriculture in the United States has changed greatly since the middle of the last century. This paper attempts to examine the forces that have created the changes seen over the past 50 years and model how these forces might play out in the future.

In order to discuss the factors that influence land use evolution we will first examine what features are likely to exert an attracting force on agricultural producers and other households. Imagine, if you will, that the world really were flat. Then imagine that it was a featureless plane with no climatic differences, no natural amenity differences, no cities, no differences in the land what so ever (figure 1). In this hypothetical world there would be no reason for an agricultural producer to prefer to live in any one location over another. No area would have any productive comparative advantage over any other area for high yields or the ability to produce high value crops. Because this world is one homogeneous plane and there are no features that would entice a producer to want any one parcel of land over another, it is expected that all this homogeneous land would have identical expected returns per acre and would therefore be equally valued.

Likewise, imagine the situation where a nonagricultural household were deciding where to live given this homogeneous plane of land. If the characteristics of the land and its location relative to desirable features were indistinguishable across all the parcels, then there would be reason for a household to value the land elsewhere over the land they

currently occupy. In short, we assume that if not acted upon by a force, an object at rest, an agricultural producer in this case, tends to stay at rest.

Now imagine that a single feature were added to this world (figure 2). Imagine that this feature would allow agricultural producers to grow higher value crops or obtain higher yields than in other locations. Their expected net revenues would be higher in this location and, all else equal, there would be a reason to want to be in this location relative to all the other locations. Producers would be drawn to this new location and should be willing to pay more for this land than the other homogeneous land that does not possess this net revenue boosting feature. The land value in this location would increase through arbitrage to the point where the expected gains that accrue to the producer from producing on this land relative to other land would be equal to the additional cost of owning this land over the other land. This is the familiar marginal benefit equals marginal cost outcome. Because of this process it would also be expected that the net returns per value of land would be equal across all land. Land values would be bid up to the point where all the additional net revenue for producing in this higher revenue per acre area over the other locations would be capitalized into the value of the land and, all else equal, the producers would not prefer the better location with the higher revenues and higher land cost to the other locations.

Now place a single factor that draws nonagricultural households to a given location. This factor makes living in this location more desirable than all the other locations. All else equal, every household will want to move to this location and should be willing to pay more for this land than the other homogeneous land. As in the case of the agricultural producers, this will drive up the cost of the land with the desirable

characteristics to the point where the benefit of living in this desirable location will equal the cost of living there over the other locations.

This is, of course, a reworking of the Von Thunen rent gradient model with a gravity model framework. In the next section we will turn our attention to formally describing the relationship between the attractiveness of a piece of land and entities who would be enticed by the properties of the location by incorporating a modified gravity model into the ideas that Von Thunen proposed back in the 19th Century.

Hypothesis

Based on the principles first introduced by von Thunen and incorporating the recent concepts of agricultural competitiveness presented by Blank (1998), a hypothesis is constructed that all potential uses for land will be bid into land costs. This includes both agricultural and nonagricultural uses, thus agricultural land uses will be jointly determined by all potential land uses. Certain land may have a comparative advantage for high value agricultural production, but it may also have a comparative advantage for even higher value residential development. This even holds true if we consider the option valuation perspective, since future returns are likely influenced by perceptions of farm and nonfarm comparative advantages. Blank (1998) predicted that as competition for land intensifies, low returning agricultural production per unit of land will need to evolve into higher returning production. As costs continue to rise, land will need to move out of agriculture completely to be profitable. The hypothesis raised in this paper is that, all else equal, land that has higher expected revenues per acre will be desirable to agricultural producers. This paper empirically tests what factors relate favorably to net

agricultural returns per acre in the western United States and thus predict what land should be highly desirable to producers. Von Thunen predicts that expected returns should be bid into land values thus equilibrating the expected net returns per value of land. Using the same 2002 Census of Agriculture data, this study also empirically examines if such an equilibrium more or less existed in 2002, albeit through aggregate, county-level measures that may mask some of the place-specific characteristics.

We will now present a more formal description of the forces that are hypothesized to influence whether land is attractive to either agricultural producers, households, or both. Controlling for these forces, we can then determine whether they impact the gross financial performance of the farm sector (revenues), and if so, whether factor prices have been bid up to control for such forces with respect to net returns.

Theoretical Gravity Model

A theoretical gravity model is proposed that characterizes the attractive forces of land characteristics that are expected to influence both agricultural producers and all households. This model serves to frame the issue of where agriculture is likely to generate high enough net returns per acre to represent a comparative advantage in competition for scarce resources or where it will need to evolve to better compete and/or be removed from the regional industry portfolio. The model then discusses the equilibrium that is expected to be achieved when the gravitational attraction of desirable land and the detracting force of increased land costs are matched.

The gravitational principal that was developed by Newton has been long been applied to economics (Carrothers 1956, Haynes and Fotheringham 1985, Reilly 1929).

The principal states that the attraction between two bodies is directly related to their mass, and inversely related to their distance. This concept could play a role in explaining the differential performance among counties if we consider land attributes, proximity to urban centers, and degree of natural amenities as factors that are important with respect to the desirability of land to both agricultural producer and to households, respectively.

Gravity models have been used to describe the spatial distributions of shopping centers (Huff 1963), health care facilities (Gesler 1986, McGlashan and Blunden 1983, and Guptill 1975), trade flows (Tinbergen 1962, Bergstrand 1989, Oguledo and Macphee 1994), and migration (Karemera, Oguledo, and Davis 2000, Borjas 1989, and Zipf 1946). Theoretical support for the use of gravity models has been increasingly strong (Anderson 1979, Helpman and Krugman 1985, Zipf 1946), and the gravity models enjoy both empirical and theoretical support.

As introduced earlier, it is assumed that given a homogeneous plane, agricultural and nonagricultural households would not prefer one location over another and land prices would be constant per unit. Returns per unit of land in agricultural and nonagricultural enterprises would depend only on management practices. But, homogeneous land and locations are obviously not realistic assumptions about the real world and, in fact, location does matter.

Growers, all else constant, prefer to operate in an area where they can generate higher net incomes. Likewise households generally prefer to live in areas with higher amenities than in areas with few amenities (Roback 1988, Deller et. al 2001, Deller et. al 2005). The attractiveness of a relative location for both production potential and natural desirability influences the price that producers and households are willing to pay for that

land, a fixed resource for any area. Land with a comparative advantage for agricultural production will be bid up by producers and land with high natural amenities will be bid up by existing or in-migrating households with increased buying capacity. Thus, land with a comparative advantage for agricultural production as well as perceived desirability for households will face a dual pressure and will be bid up by the activity with the relatively higher willingness to pay for the land as a function of derived demand for land as an input. So, if we still see agricultural production in these areas, it should result in relatively high gross and net returns, otherwise it would convert to a higher use (housing or commercial development) (Blank 1999).

From a theoretical perspective, this issue can be best thought of as a gravity model of natural and human-made centers of mass that draw people and production to them. In the physical sense, gravity is a force that draws two objects to each other based on their respective masses and whose effect decays with distance. In his Theory of General Relativity, Einstein modeled gravity as a distortion in the fabric of what would otherwise be homogeneous space-time. The distortions are generated by the mass of objects, with larger masses creating a greater distortion. The size of the distortion is related to the mass of the object and the effects of the distortion decay with distance from the massive object. The equation for gravitational attraction that Newton developed in the late 17th Century (and which Einstein's theory reduces to under "normal" conditions) is as follows:

$$F_{grav} = G \frac{m_1 \cdot m_2}{r^2} \quad (1.1)$$

where F_{grav} is the force of attraction between two bodies, G is the universal gravitational constant, m is the mass of the respective bodies, and r is the distance between the two bodies.

This model lends itself well to this economic model as we are investigating a phenomenon where attractive distortions draw producers and households to land with given attributes. Some important distinctions, however, need to be made. First, the economic model deals with only two dimensions. This allows for the simplification of viewing land as a homogenous plane rather than the multi-dimensional space-time continuum and, as Zipf (1949) suggested, leads to distance relating linearly to the gravity function, not squared. Secondly, gravity in the physical sense is a universal constant relative only to the mass of the two objects and their distance from one another, not to any other attribute of them. In economics, utility is only considered an ordinal, not cardinal measure of well-being. Therefore, there is no need for an analogous “universal utility constant”. Thirdly, gravity in a physical sense is a force that draws two bodies together based on their respective mass. Forces act in an equal and opposite manner and the force of gravity is acting equally on a person and on the earth at the same time, even though their respective masses are so different. This relationship is given by the general equation for forces:

$$F = ma \quad (1.2)$$

where F is the force, m is the mass of a body, and a is the acceleration of the body (acceleration is defined as the second derivative of a body’s location over time equation or $\frac{d^2x}{dt}$). A simple rearrangement of this equation and the incorporation of the gravity

equation gives the acceleration of one body (with mass m_1) to another body (with mass m_2):

$$a_{m_1} = \frac{d^2x}{dt} = \frac{Gm_2}{r^2} \quad (1.3)$$

This states that the rate to which a body is accelerated to another body is related to the force between them (gravity in our example) which is equally acting on both bodies, and the mass of the respective body. Therefore, when a person jumps, the earth's gravity accelerates the person back to the ground and, in some immeasurably small way, the person's mass accelerates the earth to them. Economically significant land features are fixed and are not drawn to producers or households even in a theoretical sense. Therefore we will model agricultural producers and households as test particles in the gravitational force field created by the mass of desirable land. The desirable land will accelerate the actors to it, but there will be no reciprocal relationship.

In previous gravity models of trade and migration the mass terms have been proxied with the population. It was theorized that due to the forces of agglomeration and cultural amenities, population itself created "mass" that drew more people and industries to the area. In this case, current population is not the most obvious choice for the attractive "mass" term. While population does create some cultural amenities that tend to draw households, we will be more interested in examining other type of amenities (such as natural amenities) more explicitly in this study because these types of amenities are more likely to directly interact with derived demand for agricultural land. In addition to the amenities that population centers create, it also leads to congestion and other disamenities. The extent to which higher population densities are an amenity or

disamenity varies from person to person and to the extent of population density. Natural amenities, to some extent, tend to be considered an amenity to all people. While some households may place a higher weight on living closer to natural amenities than others, all else equal, it is unlikely that a household would choose to live in a low natural amenity area over a high natural amenity area. So while urban proximity and the cultural amenities that it generates will be discussed here (and indirectly proxied through urban area proximity), natural amenities will be more closely examined. For the purposes of this study we will assume that households are drawn to all types of amenities in general and natural amenities specifically.

Agricultural producers are drawn to areas that might offer high returns on their investment in land and capital. In the initial “homogeneous plane” boundary condition, this would equate to net farm income per acre because all land would have the same attributes and therefore the same value. With the inclusion of differentially attractive forces, the net farm income per acre and the net farm income per value of land and capital would begin to diverge as land values in areas with greater potential for net farm income per acre, all else equal, were bid up. The land prices would be bid up to the point that all agricultural lands would generate equivalent net farm incomes relative to the value of land and capital invested. This result, however, assumes that only producers are bidding on the land. In actuality, households and other industries are also bidding on lands that are attractive to them, for similar or different reasons.

Amenity factors, including both natural amenities and cultural amenities, have been shown to draw households (Roback 1988, Power 1996, Deller et. al 2001). These households, in turn, draw other sectors through the economic activity generated by the

households and through sectors moving to the region to take advantage of the workforce willing to take a lower relative wage to live in this high amenity area (Power 1996).

Previous research has demonstrated that amenities in general (Rosen 1979, Diamond and Trolley 1983, Roback 1988) and natural amenities specifically (Cragg and Kahn 1997, Shumway and Otterstrom 2001, Hunter et al. 2004) attract households and, all else equal, people would rather live in higher natural amenity areas than lower amenity areas. This has been empirically demonstrated by studies that have found people are willing to endure higher housing costs and lower wages to live in relatively high amenity areas (Roback 1988). Likewise, firms are also drawn to areas with natural amenities for the same reasons as households. Firms may be drawn to an area based on agglomeration factors with other similar industries or allied industries or may be drawn to these regions to take advantage of the relatively lower cost and highly educated labor supply that have been shown to exist in high amenity areas (Power 1996).

All else equal, agricultural producers are expected to want to go to where they have the highest expected returns per acre. If there were no other factors and no land scarcity all producers would be expected to flock to the land that yielded the highest returns per acre. If, however, highly productive land is scarce and the increased demand for land with the highest expected returns per acre bid up the cost of the land, then the increased cost would act as a repelling force. Likewise, it is assumed that the attraction of moving to a new location diminishes the farther the producer currently is from the attractive force of higher expected returns. This decay in the attractive pull over distance can best be thought of as transactions costs of moving and learning to farm in a new area. Both physical and human capital fixity as well as moving costs factor into this parameter.

Zipf (1949) presents the rationale for why this parameter is likely to be 1 and not 2 as it is in Newton's gravity equation. The exact relationship depends on whether the attraction of more desirable land falls off linearly (as a coefficient of 1 would represent) or if distance is not at all important and more desirable land a great distance away has the same attraction as highly desirable land very close to your current location. In reality, the relationship is likely to be very complicated with institutional rigidities (such as country borders), transactions costs, and the degree of physical and human capital fixity influencing the degree to which distance will influence the attraction of desirable land. For the purposes of this study we will not concern ourselves with the exact nature of the distance decay of the attraction of higher returning land, beyond assuming that it is a negative relationship and the exponent is bounded by 0 and 1.

For simplification purposes we will assume that the attractiveness of land to an agricultural producer is a function of the expected returns that the land will generate while households, all else equal, are attracted to amenities. We will be making the rather large assumption that "amenities" are a universally accepted good. In later equations households will be allowed to put a higher or lower relative weight on amenities in their gravitational attraction equation, but an amenity is, to some extent, a good to all households. This is a particularly difficult assumption when it comes to cultural amenities. It is highly likely that there will be a high degree of heterogeneity among households for what they consider a cultural amenity. For example many households may consider cities and the theaters, museums, restaurants, and nightlife they afford as a cultural amenity while other households will consider the crowding, congestion and lack of open space a cultural disamenity. The reciprocal relationship is also likely where

certain households regard rural towns and the open space and rural lifestyle as a cultural amenity and others will view it as a cultural disamenity. This assumption becomes somewhat less problematic when natural amenities are considered. There seems to be much less variance for what is considered a natural amenity and what is not. Households may differ in the relative weight they put on natural amenities, but generally areas that afford more scenic vistas and recreational opportunities are desired by households. For this reason, the amenity term in this study will be empirically proxied with a natural amenity index. Because mass in this model is a function of expected returns for agricultural producers and amenities for households, the gravitational force field will similarly be a function of these mass terms and the distance from them.

$$F_{grav}^a = \frac{ER_1 \cdot ER_2}{r^{\rho_a}} \quad (1.4)$$

$$F_{grav}^h = \frac{AI_1 \cdot AI_2}{r^{\rho_h}} \quad (1.5)$$

Where F_{grav}^a is the gravitational force vector of region with a given expected returns per acre on a given agricultural producer, F_{grav}^h is the gravitational force vector of a given region with a given level of amenities on household, ER is the expected returns of agricultural productions in a given region and serves as the mass term for agricultural producers, AI is the degree of desirable amenities (amenity index) in a given region and serves as the mass term for households, and d is the distance between the producer (or household) and the locations with the respective masses. The exponents ρ_h , and ρ_a are distance between actor j and location i . As discussed above, ρ_h , and ρ_a are assumed to be bounded by 0 and 1.

These two equations will set up a force field where the attractive mass terms exert pull on the actors and accelerate the actors to them based on their distance to the actor and their relative mass. Actors will be acted upon by the attractive masses of all the expected to accelerate to the location with the attractive mass. For this discussion we are not particularly concerned with the actual force field itself, but rather the affect that this field has on the respective actors (test particles in physics terms). We want to model what comprises the mass terms which in turn create an attractive force on the respective actors.

We will examine how an actor (producers and households respectively) will be accelerated to an attractive mass. The actor will be modeled as a test particle in a gravitational field created by two attractive masses (higher expected returns for producers or higher amenities for households). For simplicity we will focus on agricultural producers but the discussion will hold true for households as well. The midpoint between the two masses will be called 0. The distance from 0 to ER_1 will be $+r$ and the distance between 0 and ER_2 will be called $-r$. Also for simplification purposes we will set $\rho=1$ for the time being. If the gravitational acceleration of a given actor is modeled as a function of the relative attractiveness of the regions to the actors, agricultural producers and households respectively, then the equations would be as follows:

$$\frac{d^2x}{dt} = \frac{ER_2}{(x+r)} + \frac{ER_1}{(x-r)} \quad (1.6)$$

This equation describes the acceleration of the agricultural producers to the respective locations based on their mass and the distance of the producer from the locations. If we, for simplification purposes, say that ER_2 has a “mass” twice that of ER_1 ,

then it can be determined that acceleration equals zero when $x = \frac{r}{2}$. At this point, when the location of the agricultural producer is $\frac{3}{4}$ of the way from ER_2 to ER_1 , the producer will not be move from their original location. This is due to the marginal, distance-based cost associated with moving. When the producer is at point $r/2$, the cost of moving to either location will be prohibitive and the expected future gains would be offset by the cost of moving. If, however, the producer was originally located to the left of $r/2$, the additional revenue associated with moving will more than compensate for the cost of moving and the producer will be drawn to m_2 . Likewise if the boundary condition finds the producer to the right of $r/2$, they will be inextricably drawn to m_1 .

The nature of ρ will have a profound impact on the gravitational field that the producer experiences. For example, if ρ is 0 then distance has no influence on the gravitational force and no matter where the producer is they will be drawn to ER_2 (the location with the higher mass term). The exact specification of ρ is likely to be complex, but distance from the areas with the higher expected returns per acre will certainly have an influence on their attractiveness due to distance based costs of moving, as well as physical and capital fixity.

In the case were the only difference between the two locations is the addition of the attractive characteristic, then equation 1.6 would describe how attractive the new location would be relative to original location. The expectation, however, is that through arbitrage the land values in this location with the desirable characteristic would be bid up. The increased cost of the land would act as a friction to the actors, diminishing the attractiveness of a desirable location. The attractive force of the higher expected returns and the repulsive force of the increased land costs will compete. It is also assumed that

there would be a fixed cost associated with moving above and beyond the marginal distance based cost of moving. If land costs are increasing as the producer moves towards areas of higher expected returns, this becomes a repulsive force on the continued attraction of the land to the producer.

$$\frac{d^2x}{dt} = \frac{ER_2}{(x+r^\rho)} + \frac{ER_1}{(x-r^\rho)} - m - \frac{\partial c}{\partial x} \quad (1.7)$$

$$\frac{d^2x}{dt} = \gamma \left(\frac{AI_2^\alpha}{(x+r^\rho)} + \frac{AI_1^\alpha}{(x-r^\rho)} \right) - m - \left(\frac{\partial c}{\partial x} \right)^\beta \quad (1.8)$$

Where c is the cost of land, m is the fixed cost of moving (both monetary and sociological costs), and the terms α_j , and β_j are relative utility weights to amenities and land costs for household j respectively. The weights α_j and β_j are functions of household preferences and of budgetary necessity. A household that encounters a severe budget constraint may have a higher relative weight on land costs and a lower relative weight on amenities than they would if that budget constraint were relaxed.

This specification allows not only for gravitational attraction, but also for a repulsive force of a given location to the respective actors. If the land cost term becomes sufficiently large relative to the attraction term (gain in relative expected returns or increase in relative amenities), then the land will actually repulse the respective actors and drive them away. It is easily conceivable that marginal growers or growers of low value crops will be the first to encounter the situation where $C_{i-j} > (ER_{i-j} \cdot d_{ij}^{-\delta_a})$, and the land cost differential is greater than the expected gain in returns of the land. This will drive producers of lower value crops out when land opportunity costs rise. This result is consistent with the von Thunen land rents model and with Blank (1996).

Households in this model are allowed to vary in the relative weights they put on amenities and land costs, α_j , and β_j , respectively. Some households may have a stronger weight for amenities than do others and they, presumably will be willing to pay a higher premium for the land with higher amenities than the households who put a higher relative weight on lower land costs. It is also an outcome of equation 1.7 that households with a lower relative α_h (either due to budget constraints or preferences) will be the first to be repulsed out of higher amenity areas and only people with higher relative α_h will compete for land in these higher amenity areas. This will occur for a given household when $\beta_j C_{i-j} > (\alpha_j A I_{i-j} \cdot d_{ij}^{-\delta_h})$. This has implications for the demographics and self selection characteristics that are likely to be present in high amenity areas.

In this model there are no exponents on ER_{i-j} or C_{i-j} in the agricultural producer's attraction force equation. It is initially assumed that agricultural producers only care about bottom line returns, therefore the $ER_{i-j} - C_{i-j}$ expression can simply be thought of as the discounted net present value of the expected returns in the new location over the old location minus the discounted net present value of the expected land costs in the new location over the old location. The assumptions that agricultural producers care only for bottom line financial performance is not in line with the most current literature on rural development and sociology, and this assumption can be relaxed.

The fact that agricultural producers can be both a way of life and a business (Blank 2002) means that both the F_{ij}^a and F_{ij}^h forces may be acting on them. This will somewhat complicate how these type of producers value land. This also serves to add to the explanation of how rural agricultural producers make decisions. Equation 1.6 specifies how attractive land will be to strictly an agricultural production business.

Agricultural producers who are also households will be subject to equation 1.7, and therefore, may make decisions that are inconsistent with equation 1.6 but are not inconsistent with a utility maximizing producing household that is subject to both equations 1.6 and 1.7.

If the attraction of land to producers were completely independent of the attraction of land to households then producers would bid up agricultural land values to the point where the total per acre revenue generated on the land would equal the total per acre cost of owning and cultivating the land. Likewise, households would bid up the value of high amenity land to the point where the total utility of living in that region relative to other regions would equal the total cost of living in that region relative to other regions (assuming no income effects). It is possible, however, that the factors that influence the attractiveness of land to an agricultural producer is not completely independent of the factors that influence the amenity value the land has to households. A conflict in land use planning exercises for economic development purposes arises when there is a correlation between the attraction of land for agricultural production and the attraction of land for households. In such cases, two different forces, guided by similar attractions, compete in the market for a resource (land), and this has driven much of the rural and exurban land planning and assessment debates and policy discussions over the past 20 years. This issue will be explored more fully later in this study.

As explained earlier, it is expected that producers will desire more productive land more than less productive land. Through arbitrage, the increased returns will be bid into land values. In equilibrium, then, it might be expected that all the possible combinations of $ER_{i-j} - C_{i-j}$ from equation 1.6 and $AI_{i-j}^{\alpha_h} - C_{i-j}^{\beta_h}$ from equation 1.7 will

be equal to zero. What this would mean for agriculture is that, although the expected returns in some locations might be greater in some locations, net present value of the increased returns over the returns in other locations is equal to the net present value of the land cost over the land cost in other locations, thereby connecting current land values to the real cash returns and returns on investment because of appreciation. One of the main focuses of this study is to examine whether there is any evidence of this in the data.

Is there a way to draw some generalizable conclusions from intercounty financial performance analysis that would lend insight into what factors influence $ER_{i,j}$? Can empirical evidence be garnered on how this one type of rural wealth generation, net production revenue, relates to the other components of rural household wealth and to characteristics of a given location? The authors will look at USDA Census of Agriculture data from 2002 to investigate what factor are contributing to financial returns in agriculture and whether the predictions of von Thunen, Blank, and the authors of this study are supported in the counties of the Western United States.

Data and Methods

To provide some insight into the factors that might be expected to contribute to the attractive mass term in the gravity model, the cropping portfolios, livestock production, marketing strategies, and regional characteristics that contribute to agricultural sector performance are examined in the counties of the western contiguous United States. It is assumed that every county has a portfolio of production strategies and natural characteristics which are employed to generate agricultural sector returns. Data on the total sales, net farm income of operations, total value of land and buildings in

agriculture, and total acres in agriculture for the 413 counties of the western United States were obtained from the 2002 United States Census of Agriculture administered by the United States Department of Agriculture.

The independent variables in this study fall into three main categories: 1) county agricultural sector production portfolios, 2) financial and marketing strategies employed in the county and 3) county characteristics. The production portfolios were constructed as shares of total crop acres in fruits, vegetables, corn, wheat, forage, and silage; the percent of total revenues from livestock sales, dairy sales, and horticultural crop sales. The financial and marketing strategies employed include revenues of goods marketed through cooperatives, revenues from custom agriculture, revenues from direct sales, average size of farm (to control for the magnitude of agricultural operations), and percent of principal operators who work more than 200 days off-farm (a factor that competes with human capital inputs but mitigates some financial risk and may relate to urban adjacency/agglomeration if we believe labor markets are stronger in those areas). Other county characteristics include degree of urban influence, average temperature in January (to control for climatic effects), and the natural amenity rank index.

All data for the counties' agricultural production portfolios and financial and marketing strategies were obtained from the USDA's 2002 Census of Agriculture. The degree of urban influence, average temperature in January, and the natural amenity rank index came from the USDA's Economic Research Service (ERS).

To look at returns to portfolios, sales and net farm income data were adjusted by three factors to account for specific aspects of financial performance. Total sales were adjusted by acres in production to yield the total sales per acre measure of agricultural

performance. For a more refined financial measure, net farm income data were adjusted by both total acres in agriculture and by total value of land and buildings in agriculture to obtain net farm income per acre and net farm income per value of land and buildings. Each of these three measures provides some insight into agricultural sector performance and may be useful in examining the market force and economic activity differences among Western counties. From a finance perspective, total sales per acre represents a gross sales turnover ratio or economic contribution to the economy, net farm income per acre represents net returns per unit of a fixed resource, and net farm income per value of land and buildings represents the closest available proxy for a rate of return on assets.

Census of Agriculture data is subject to non-disclosure issues when there are not sufficient numbers of operators of a given type in a county to keep from divulging financial information about specific operators. Missing data is a particular problem in spatial econometrics due to the fact that it makes contiguous counties neighbors in instances where there is no missing data, but not neighbors in other variables where data is missing. In order to account for this, missing data were imputed in STATA using a regression of all the other independent variables. This method ensures that these imputed values add no more or less information to the regression than the other explanatory variables would predict. The most missing observations were found in the corn variable where 35 of the 413 observations (8.47%) were subject to nondisclosure. A total of 3% of the observations of the independent variables needed to be imputed.

In order to further characterize the variables and their relationships a principal component analysis (PCA) was conducted. PCA was first described by Pearson (1901) and independently by Hotelling (1933) and has been a common tool for multivariate

analysis. The method is useful for describing the relationships between independent variables by assigning them to unique orthogonal eigenvectors with corresponding eigenvalues. The size of the eigenvalue relates to the percentage of the variation in the data that the respective eigenvector explains.

This type of analysis is often used to determine if the first couple of components account for a substantial portion of the variation in the model, and if they do, then to determine which variables relate to one another and are responsible for the variation associated with the corresponding eigenvectors. It may be helpful to think of these eigenvectors as predictive combinations of variables. If silage and dairy production are found to move together in an eigenvector, then it is helpful to think of the two variables in tandem as a broader market force characterization rather than looking at the individual effects separately. From the principal components analysis, component scores were estimated for all observations (Jackson 1991). The fitted values were incorporated into a rank restricted regression.

This study is limited to the 413 counties in the western contiguous United States. It was theorized that sufficient climatic, historical and demographic differences exist between the agricultural sectors in the eastern United States and western United States as to render a single relationship between explanatory variables and the measure of financial performance unrealistic. Following similar logic, it is unclear whether the counties in the western United States should even be considered together in a single regression. It is not a given that these counties represent one comparable region and one relationship may or may not exist between the variables across these counties. In order to explore whether structural differences exist between counties in the West Coast states and counties in the

Interior West states, the counties of California, Oregon, and Washington were coded and the regressions run separately, then together as a seemingly unrelated regression estimate. A Chow test was used to test if the underlying coefficients are the same between the two regions, and a short comparative analysis was performed.

Issues Surrounding Government Payments

Deciding whether or not to include government transfer payments to farmers in the measures of farm financial performance was somewhat difficult. On the one hand, government payments represent a distortion to the underlying economic market and therefore including them in the analysis does not give an accurate picture of the true profitability of agricultural operations in and of themselves. On the other hand, government transfer payments are the reality of agriculture and have a real effect on the bottom line of agricultural operators.

Because these payments are the current reality of agriculture, they expected returns to agricultural operations include government transfer payments. The value of the agricultural land, which is in large part a function of expected returns of the land, is higher than it would otherwise be for land suitable to program crops. To not include these transfer payments would then misrepresent the current agricultural market, especially concerning land values. Therefore, it was decided that government transfer payments would need to be included in this study to accurately reflect the state of agricultural operations.

Spatial Econometric Model

This is obviously a spatial question as each of these counties exists in a specific place and each county is not an independent observation from its neighbors. Spatial dependence negates the standard assumptions of ordinary least square regression analysis and can exhibit itself in two possible ways. The first, a spatial error model, arises when observations are related through common unmeasured variables that are correlated across space or through measurement errors that arise from the use of spatial units whose boundaries are not perfectly suited to the problem at hand. For example, county boundaries are somewhat arbitrary distinctions. Economic attributes, such as labor markets, and physical attributes, such as soil types, can cross over these boundaries. This introduces the possibility for correlation in the error between observations.

The second possible spatial dependence is seen in the spatial lag model. This occurs when a given attribute in one location has a direct effect on that attribute in another location. For example, if land prices increase in one county, land prices in nearby counties are likely to go up as well. In both of these cases the individual observations can not be considered independent of one another. Independence of observations is an assumption of the ordinary least squares model, therefore this type of regression analysis is no longer the best method for analyzing these relationships in the presence of spatial dependence and spatial statistics are needed. It is also the case that, as opposed to autocorrelation in time series data, spatial dependence is not unidirectional. In time series data, observations from period $t-1$ can affect period t , but period t can not affect period $t-1$. This relationship is not true in spatial data. Larimer County, Colorado can affect the adjacent Weld County, Colorado and likewise Weld County can affect

Larimer County. This makes the variance-covariance matrix full instead of upper triangular as it is in the case of time series. Because of this fact generalized least squares analysis is no longer the preferred solution to autocorrelation and different methods will need to be employed. The spatially dependent econometric model is generally estimated through maximum likelihood, although instrument variable and generalized methods of moments estimators may also be employed.

The first step in conducting a spatial econometric model is to specify a weighting matrix that relates the observations to each other. There are a variety of possible weighting matrices, with the majority falling into one of two main categories, distance based weights and contiguity based weights (Anselin 1990). The nature of the weighting matrix is generally specified a priori (Anselin and Berra 1998), meaning that the investigator generally appeals to theory to determine whether distance based or contiguity based methods are most appropriate and how far to extend the weights. Different weighting matrices are often generated and the results of models ran with each are then compared to see which performs best (i.e. maximizes the likelihood function).

In this study, a variety of different weighting matrices were constructed and incorporated into a maximum-likelihood regression. The first approach was to generate a spatial weights matrix using a first order Rook contiguity weighting matrix. This type of weighting matrix is constructed based on counties sharing a common border. Alternatively, a distance based weighting matrix based on centers of counties, a $k=4$ nearest neighbors weighting matrix based on the four nearest counties, and a second order contiguity weighting matrix that included terms for both the counties that shared a

common border and for the counties that were two counties away were all constructed and incorporated into the maximum likelihood regression.

The potential problem with distance based weighting matrices in a county level study is that, depending on the distance specified, smaller counties might have neighbors that are two counties away and sufficiently large counties may not have a neighbor at all. Contiguity matrices allow for large and small counties to have their weights determined by the counties that surround them. Regardless of whether distance based or contiguity based measures are used, the spatial weights matrix is subject to some degree of arbitrariness. The contiguity based spatial regression made more sense in this context and was found to maximize the likelihood function in all three regressions, thereby adding further credence to its selection as the appropriate spatial relationship. Thus, the results of the first order contiguity based method are discussed for this study.

To determine whether the spatial lag or the spatial error model is the most appropriate specification, Anselin et. al (1996) developed a series of diagnostic tests for spatial dependence which serve to determine which model is the appropriate choice. The tests use the residuals from a generalized least squares regression of the model with a spatially lagged dependent variable then conducting simple and robust LaGrange multiplier (LM) tests on this regression for both the spatial lag and spatial error models. If neither LM test is significant then the model does not display spatial dependence and ordinary least squares regression can be employed. If one or the other of the simple LM tests is significant then that model is the appropriate choice. If both simple LM tests are significant then the robust LM test must be employed. The robust test is a test of spatial error dependence in the presence of misspecification in the form of spatial lag

dependence or vice versa. Depending on which robust LM test is significant, that is the correct model specification.

The maximum likelihood function for both the spatial error and spatial lag model was first specified by Ord (1975) and it has yet to be improved upon (Anselin and Berra 1998). The likelihood function for the spatial lag model is as follows:

$$\ell(\beta, \rho, \sigma^2) = -\frac{N}{2} \ln 2\pi - \frac{N}{2} \ln \sigma^2 + \ln |I - \sigma W| - \frac{1}{2\sigma^2} \left[y'(I - \sigma W)'(I - X(X'X)^{-1}X')(I - \sigma W)y \right]$$

Results on the Structure of the Data

Principal Components Analysis

It is often the case in these types of cross section studies that the largest two or three eigenvectors explain 80% of the variation. In this case it took 9 vectors to account for 80%, suggesting that a fairly diverse set of components are needed to explain differences in performance, likely due to varying factors that have some place-specific characteristics. This would suggest that there is a very diverse set of market and place-based factors that influence farm financial performance. Five of our eigenvectors had values over one. The principal component analysis results are summarized in table 1.

The first vector, which accounted for just over 20% of the variation of the independent variables was primarily associated with the average temperature in January. This vector, which we call the temperature vector, was strongly associated with fruits, vegetables, horticultural sales, natural amenities, and ruralness. The natural amenity index, ruralness index, and average temperature in January are correlated with each other, indicating that larger cities in the western United States tend to be in warmer areas with

higher natural amenities. It is not surprising, then, that these would all be moving together in the same eigenvector. It is also not surprising that temperature, orchards, and vegetable production would be in the same eigenvector. Areas where fruits and vegetables can be successfully cultivated over a long growing season are associated with mild winters.

For this study, it is helpful to think of the results of fruits, vegetables, and temperature in January as moving together in a unique eigenvector. This vector is also, not surprisingly, negatively related to forage, livestock sales, and average size of farms. It can easily be hypothesized that intensive high value fruit and vegetable crop production is negatively associated with low value extensive agriculture often characterized by ranches and large-scale, field crop farms. The classification of vegetables in the Census of Agriculture, however, can be somewhat problematic. For example, potatoes are considered vegetables in the data and from a marketing standpoint this makes good sense. Potatoes take extra post harvest care and are marketed more like vegetables than field crops. From a production standpoint, however, potatoes are cultivated more like a field crop with extensive acreage, minimal cultural requirements during the growing season, and fully mechanized production. This dual nature of potatoes (as well as other crops like onions) is reflected in the principal component analysis where, in addition to eigenvector one, vegetables figure significantly into eigenvector five, which is primarily associated with field crops such as corn and wheat.

The second vector is strongly associated with livestock and forage. This vector, referred to as the livestock vector, is negatively related to wheat, corn, and custom agriculture. It can be postulated that livestock and forage are complementary activities

and that livestock and field crops are competitors for land, and therefore would be negatively related.

The third vector is most strongly associated with dairies, coops, and silage. This component, referred to as the dairy vector, is negatively associated with horticultural sales, direct sales and off farm income. It makes sense that dairies, coops, and silage would be associated with each other as dairies create a large derived demand for silage and close to 80% of the milk sold in the western United States is marketed through cooperatives.

The fourth vector, referred to as the average size vector, most clearly demonstrates the negative relationship between the proportion of days worked off farm and the average size of farm. There should be a negative relationship between the size of an agricultural operation and the time it takes to manage it, so a larger farm would leave less time for off-farm employment. Larger farms are also less likely to be hobby farms and are more likely to be the primary revenue source for the operator. The fifth vector is primarily associated with field crops such as corn, wheat, silage, and size of farm. This component is referred to as the corn vector and is negatively related to custom agriculture, cooperatives, and fruit sales.

Due to moderate levels of multicollinearity, it may be more appropriate to think of the explanatory variables in this model not simply as individual independent variables, but as contributing to unique orthogonal components. The results of the principal component analysis present a clear explanation for the five largest eigenvectors in the analysis. The results from the regressions on the five largest principal components tell a

similar story to the results of the larger model. As the results are presented it is advisable to keep in mind these five principal components and how they move together.

Chow Test for Structural Differences

From a simple examination of the location of the top net farm income per acre counties, (table 4) there seems to be some differences between West Coast counties and the Interior West. The results of the Chow test for structural differences found that the underlying relationships between these variables were statistically different from one another between the Pacific and non-Pacific state counties for total sales per acre and net farm income per acre, but not for net farm income per value of land and buildings: an interesting finding since controlling for differing land values should, and does appear to, “level the playing field” across counties. The test results provide some insight into differences between the two regions which will be discussed further in subsequent development of the theoretical model. The bulk of the results and discussion, however, will focus on the West as a whole as there is some interest, from a geo-political standpoint, in looking at the entire West together. Yet, the results suggest that further research should be conducted as to the nature of the structural differences that exist between the West Coast and the Interior West, and more broadly, that small regions of the US must be considered independently if different place-based and market factors affect them uniquely.

Results of Agricultural Sector Performance

One of the main goals of this study was to describe the components of agricultural sector performance and to determine what factors contribute to farm income. The question of farm profitability is a complicated one, and depends on what measure is being used to determine performance. The factors that contribute to counties performing well in each of these three metrics varied somewhat among the three models, although total sales per acre and net farm income per acre were quite similar. The full model results for all three regressions are presented in table 2. Results for the spatial econometric maximum likelihood regressions of the three measure of financial performance on the fitted values from the five principal components with Eigenvalues over one are presented in table 3.

We will now take a closer look at the results of the regressions on each of the three measures of farm financial performance.

Total Sales per Acre

The most simplistic way to look at this question of farm performance is to focus on total sales per acre. This is a measure of a gross sales turnover ratio and gross contribution to the county's economic base. The total sales per acre variable was derived by dividing total market value of goods sold by total land in farms. This measure does not get at any measure of profitability because different cropping regimes will have different cost structures, even when on the same amount of acreage. However, it is important from a regional development standpoint and points at areas where agriculture is generating a great deal of economic activity per unit of land (considered one of the truly

fixed resources for any geo-political area). This measure proved to be the most variable of the all the measures of agricultural sector performance with a range of \$2 per acre to over \$30,000 per acre. The county with the total highest total sales per acre (\$32,000) was Denver County, Colorado, a densely populated county with greenhouses but little farmland, and was shown to be an outlier. Still, after removing the outlier, the range was still quite large.

Figure 1 presents the quantile map of the counties with the highest total sales per acre. There is a large concentration of high performing counties on the West coast, as well as in the Southwest and in Central Idaho.

Turning to econometric results, it is not surprising that fruits, vegetables and horticultural sales shares contribute positively to gross sales per acre. Fruits, vegetables and horticultural specialties are high value, high input crops which generate a great deal of gross revenue per acre. The main areas of production for these crops tend to be in the Southwest and West Coast, where climate allows, and is likely the primary driver of higher value sales per acre in those areas. After controlling for climate, the natural amenity index was found to be negatively related to total sales per acre.

In looking at the regression on the fitted values of the principal components, it can also easily be seen that the climate/fruit/vegetable component has a strongly positive influence on this measure of financial performance. This would be expected as warm weather fruit and vegetable crops tend to be high revenue operations. The dairy component is also significant and positive indicating that dairies contribute favorably to total sales per acre in counties. The extensive agricultural operations component was found to relate negatively to total sales per acre. This, again, is consistent with the idea

that lower value crops are grown extensively with relatively high land usage. The first principal component is also strongly associated with urban influence indicating that vegetable orchard, and horticultural crops tend to be associated with urban proximity. These findings are consistent with Blank (2001) where agriculture is expected to evolve from low returning extensive operations to high value intensive operations as opportunity costs rise and it becomes necessary to generate greater revenue per acre to stay in agriculture. Or alternatively, reinforces the idea that households are drawn to the same climatic amenities needed to produce many high value crops.

Although it may provide insight into where agriculture might generate a great deal of economic activity in a local economy, total sales per acre does not account for production costs and therefore does not provide insight into overall financial viability of a given county's agricultural sector. Thus, the fact that far greater sales per acre are generated in areas where high value production like horticultural and vegetable crops are grown is not terribly enlightening. This begs the question, then, can other measures of agricultural performance provide more insight into what factors are likely to contribute positively to agricultural sector profitability? Or if controlling for costs will "level the playing field" across Western counties as the gravitational model would suggest?

Net Farm Income per Acre

Net farm income per acre is a very common (although still overly simplistic) measure of agricultural performance that is used to describe the net returns per unit of the primary input used for production. Net farm income per acre was constructed by taking the net farm income of operations and dividing by total land in farms. This metric is

designed to get at the net returns per unit of the most important and fixed asset used in production. It is superior to the original metric, sales per acre, because it nets out the direct costs of producing crops, but still may be biased towards high-value, intensive agriculture since it does not account for the land investment needed to create the income.

Table 4 lists the top performing counties in the West in net farm income per acre. Even netting out costs, there was still a wide range of returns per acre across the west, from negative \$134 to over \$1600 per acre with a mean of \$78 and a median of \$11. Figure 2 shows similar geographical patterns as those seen with total sales per acre. There is, however, a subtle shift toward the interior West relative to the total sales per acre graphic. Still, the highest performing counties are concentrated among the Southwest and West Coast counties.

The results of the net farm income per acre regression are also similar to the total sales per acre regression but fewer variables were statistically significant, as would be expected because net income partially controls for the differences in productive returns. Again, positive effects were found for fruits, vegetables, and dairies. The natural amenity index was negatively related to net farm income per acre and again was the opposite sign as average temperature in January (you say again, but this was not mentioned above). The spatially lagged dependent variable was positive and significant, suggesting some place-specific factor unrelated to climate or urban influence is influencing net income per acre, and influences multicounty regions rather than specific local places. The share of marketing receipts from direct sales continues to show up as a negative influence on profits. (again you say continue, but I don't think this was mentioned above)

Net Farm Income per Value of Land and Buildings

The last, and maybe most interesting, metric of agricultural sector performance was net farm income per value of land and buildings. This is similar to a return on fixed assets or return on assets measure and was generated by taking net farm income of operations and dividing by estimated market value of land and buildings. It was expected that the distribution would be tighter for this metric than for the previous metrics, as it puts county agricultural portfolios over a more common denominator, the value of land they are being produced on, and one would assume that any agriculture that remains or is developed in a region takes the opportunity costs of land into consideration. So, for counties with more potential uses for land (housing development, industrial or commercial production), land values should be bid up, so the only agriculture would be higher value goods, and vice versa for more remote, rural areas. To show the differences, Figure 3 shows where land values are high in the West. In short, it is hypothesized that, following the gravitational model, potential profitability and alternative uses for land are built into land prices and that any anticipated rents will be bid away and capitalized into land prices.

The range for net farm income per value of land and buildings was between -.046 and .319 with a mean of .028 and a standard deviation of .039. These can be loosely interpreted as percentage returns to investment, so the range goes from losses to a fairly healthy return of 31.9%. Not surprisingly, land values are generally higher in urban areas and in high amenity areas. The correlation coefficient between ruralness and average value of land and buildings is -0.49, 0.39 between share of sales from horticultural crops, and 0.37 between the natural amenity index and average value of land and buildings.

These are the highest correlation coefficients seen between the average value of land and buildings and any of the independent variables in this study.

By accounting for value of land and buildings, the distribution of high performing counties continues to move east and north from the original map of gross sales per acre (figure 4). High returns are seen in areas where land values are low but returns to agricultural production are still substantial, such as in northwest Montana, southeast Idaho, southeast New Mexico, the San Luis Valley of Colorado, southwest Arizona and eastern Washington.

The regression for net farm income per value of land and buildings shows in some significant variables that were not seen in the previous regressions. Vegetables are still a significant factor which might be due to the influence strong performance in the potato sector in 2002 since counties with a concentration of potato production are strong performers in this map. Dairy continues to have a strong, positive influence on agricultural returns, indicating that agricultural products that have some locational dependence, a high degree of perishability, or import non-substitutability may compete well even in the face of increased land costs. The share of sales in horticultural enterprises now has a negative impact, probably due to the high cost of production assets (land and greenhouses), and, as in the case of Denver County, CO, the potential alternative uses for such land.

Interestingly, the fitted value, principal component corn vector shows up as contributing positively to this measure of performance, probably due to the low land costs associated with many major corn production regions. After controlling for land prices, counties that grow extensive field crops such as corn compete relatively well.

Government transfer payments are included in net farm income measures so program crops such as wheat and corn do enjoy that advantage and their profitability is arguably artificially high. However, this is the reality of agricultural policy in the US, and in areas with little competition for land, program field crops do seem to contribute to financial performance in the agricultural sector.

Economic Implications of the Spatial Autocorrelation

The spatially lagged dependent variable in this study was consistently found to be positive and significant. Additionally the spatial Lagrange multiplier tests were also found to be significant for spatial lag dependence. This means that observations in this study (i.e. the counties) are not independent of each other and exhibit spatial dependence. In other words, the dependent variables of counties in this study could not be considered as independent of neighboring counties.

The likelihood dominance of the first order Rook contiguity matrix indicates that the structure of the spatial dependence is best represented by the lagged dependent variable of the average of the surrounding counties that share a border. This means that the substance of the spatial dependence can be captured with just the first ring of surrounding counties, indicating a fairly simple spatial relationship.

Economically, the spatial dependence can occur due to factors such as spillover effects, agglomeration effects, spatial diffusion, and geopolitical effects. The type of analysis performed in this study does not determine why the dependence exists; only that it does. An appeal to economic theory is invoked to provide insights into the reason for the spatial dependence. In this case it is theorized that counties will not be independent

of one another due to a variety of factors including agglomeration effects and spillover effects. Climate is already accounted for in the independent variables, however, factors such as transportation distance to processors and capital fixity are not. An area may have the right climate to grow vegetables but for whatever reason the infrastructure to process and transport the crops are not present. It does not make economic sense for a single grower to invest in all the processing and transportation infrastructure on their own, but when enough growers come together, the cost of the infrastructure is sufficiently spread out to make the investment feasible. Likewise, once the infrastructure is in place, the area will be increasingly attractive to new growers coming in and will grow due to these agglomeration effects. Likewise, the benefits of these investments will likely not stop at an arbitrary political border such as a county; they will spill over into neighboring counties and create spatial dependence. Other theoretically likely causes of spatial dependence in this study include unmodeled agronomic characteristics such as common soil types among neighboring counties, similar water delivery infrastructure and availability among neighboring counties, and geopolitical spillover effects that occur between neighboring counties in the same state.

While it is beyond the scope of this study to determine the precise mechanism for the economic spatial dependence exhibited between counties in this dataset, the dependence was exhibited as statistically significant. Appeals to economic theory can provide plausible and likely scenarios for why the spatial dependence is likely to exist and the specific causality presents a potential further avenue for future research.

What Type of Counties Performed Best?

The empirical portion of this paper sought to examine two important empirical questions crucial to both the farm sector structure and performance and rural development fields. First, what are the “models” of agriculture that show the best financial performance as defined by enterprise mix, business strategies and locational aspects? Then, subsequently, if locational factors are important (either in absolute terms, or indirectly, through their influence on relative land values), what might this suggest about the need for more place-based agricultural and rural development policies and strategies?

With respect to successful models of agriculture, counties which had a larger share of their portfolio in higher valued crops actually did generate more revenue and net returns per acre. This result may not be terribly surprising, but it does imply that in areas where it is necessary to generate more revenue to account for rising land and input costs, remaining producers have switched to higher input, higher value crops. This follows a business evolutionary process as Blank suggested, and may mean that agriculture will likely be transformed in areas that feel increasing urban and development pressure.

Dairy, silage, and shares of sales in cooperatives all consistently contributed positively to agricultural performance. Dairies figured positively into all three measures of farm financial performance, including net farm income per value of land and buildings. This indicates that even after accounting for the high production costs and relatively high land and building costs associated with dairy production, this vector associated with dairy, silage and coops demonstrates strong financial performance. A likely explanation is that the dairy industry enjoys a relatively high degree of “locality”,

so the global competitive pressure may be lower with respect to dairy prices than with other industries. In short, dairy, silage, and coops have some import non-substitutability and potential for value added spillovers to them which may translate to a relatively higher multiplier for communities. This is important to combat the pressure of increasing local costs coupled with the global price pressure that Blank outlined. So getting people to drink more milk might not only be good for our health, it also appears to be good for rural economic health, even though there continue to be environmental challenges to address as the West sees the development of more, larger dairies.

One of the predictions that Blank (1999) posits is that locally determined agricultural production costs, including land costs, are going to continue to increase over the coming decades in the face of competition for land, labor, capital, and inputs from other sectors. This coupled with decreasing prices that are increasingly determined on the world market may lead to the decline and eventual end of the agricultural sector in America. In keeping with Blank's conclusions, we found that high value crops generally do generate more revenue and when rising land and production costs necessitate higher returns per acre, production of fruits, vegetables, and horticultural crops is adopted as a means to generate more revenue if land does stay in production (although we cannot talk about how this coincides with actual losses in farmland given the static nature of this analysis). When opportunity costs increase, agriculture is forced to switch to higher value production or move, a dynamic that could be explored with a longitudinal study of the same counties. It seems that non-agricultural related factors are driving the agricultural sector to generate higher returns, or leading to longer-term shifts in agricultural production, an important focus for future research. Conversely, if you are in

a low land value area with low opportunity costs, low value and low input crops are a rational investment and do generate high enough returns to the relatively modest investment in land, so the future of agriculture is not as bleak as Blank might suggest.

To a regional economist, this is not necessarily a bad thing for agriculture or for rural economies. Higher input, higher revenue crops have the potential for higher multipliers that will spur more economic activity. As Blank's predictions play out, it would be expected that areas facing population pressures and increased costs, specifically opportunity costs associated with escalating land values, would switch to higher revenue crops or enterprises to add value to lower value crops such as the emerging bioenergy initiatives. Agriculture would remain until land prices got so high as to make any type of agricultural production infeasible. Presumably, increased population in areas would lead to increased demand and greater access to markets in the region.

The problem that Blank and others have identified is if the areas of population pressure and land suitable for high value production are the same or if the availability of cheap imports (increased supply) negates the effect of the increased local demand, thus making the cultivation of the new hinterland and exurban area unprofitable, then there is a real threat to agriculture in these regions. If the land that is taken out of agriculture for development is significantly better than the lands remaining for production, and if U.S. producers continue to see rising cost of land and production coupled with lower prices on the world market, then we are in danger of entirely losing agriculture in the American economic portfolio. This has been the impetus for the emergence of numerous land trusts that seek to not only preserve farmland, but also target areas with greater urban influence, seeking to maintain some open spaces and agricultural presence even when land in

production cannot compete in the market with commercial development. In short, they think farmland offers public goods that are underinvested in, and threaten agriculture's survival since many land allocation decisions are based on current cash returns.

There were some interesting findings for counties that consistently performed well in this study. First of all, potato counties did well, which may be a function of 2002 being a good year in terms of potato yields and prices. For example, the San Luis Valley of Colorado is a persistent poverty region which grows a lot of potatoes, but it performed well in all the financial measures, which is not always the case.

After controlling for land values, it was again found that low value crops such as corn are significant contributors to returns per value of land. This is an interesting finding, indicating that field crops are likely to be important generators of income in remote rural areas that do not face the land cost pressures seen in areas where vegetables and fruit crops tend to be grown. Moreover, the alternatives for other economic development enterprises may also be low, so agriculture will persist. New efforts to explore conservation and biofuel generation goals of the US may play a role in increasing returns and to address broader rural development goals.

In keeping with this finding, some markedly different responses were found between the Interior west and the Pacific west in our study. Low value agriculture still contributed positively for all three measures of performance in the interior west. There is little population pressure in much of the Interior west and Central U.S. so land costs remain fairly low. A simple consideration of opportunity costs, as expected given the lower attracting masses conceptualized in the gravitational model, would suggest agriculture can be sustained in these areas. In short, Blank's conclusions seem to be

playing out in the Pacific west, but not as of yet in the Interior west. More importantly, policies framed and implemented at the federal level may not be effective given these findings, as seemingly different market forces are affecting the viability of agriculture when comparing regions, states and counties, thereby suggesting a need for more localized policy actions to support competitive agricultural sectors.

Evolution of the Agricultural Sector in the Context of the Gravity Model

So do the results of our empirical analysis provide any support for what would be predicted by the gravity model presented earlier? The gravity model predicted that attractive forces would draw agricultural producers to where they would have the greatest expected returns. A finding of this study was that of all the characteristics of the counties, mean temperature in January was found to be most closely tied to expected returns. The regressions consistently found that mean temperature in January related positively to all the measures of farm performance and natural amenities, after controlling for temperature, related negatively to farm financial performance. This gives further support to the idea that locations with favorable climates for high value agriculture, but that do not face the higher population pressure that comes from natural amenities, will enjoy strong financial performance in their agricultural sector. It is proposed that mean temperature in January might be the best proxy for the attractive mass term that creates an attractive force on agricultural producers. Mean temperature in January is highly correlated not only with total sales per acre and net farm income per acre, but also with the ability to grow high value vegetable and orchard crops.

The gravity model also predicted that areas with the highest expected returns would draw producers to that land. This would subsequently raise demand for land with these desirable attributes and the value of this land would be bid up. It was found that total sales per acre and net farm income per acre were positively correlated with average value of land and buildings, with a correlation coefficient of 0.53 and 0.44, respectively. It was also predicted that, in equilibrium, net farm income per value of land and buildings would be equal across all types of land. In looking at net farm income per value of land and buildings, it might be expected that returns to a portfolio would be a random walk and that all counties would have similar returns to land. In short, holding all other derived demand for land constant, it is assumed that expected returns to land would be bid into land values leading to a homogeneous plane of returns per value of land.

Although we did see a much more even distribution of returns across the counties using this measure, it was far from a homogeneous plane and there were areas that performed statistically better in the specified model than others. This was not found, indicating either that we are not yet at equilibrium and, therefore, economic rents are still able to be obtained by locating in areas with higher returns on investment than in others, or that agriculture is not the only commercial and industrial demand determinant for agricultural land, thereby putting dual pressure on agricultural land prices and driving prices for agricultural land higher than would otherwise be expected.

It is very conceivable that some of the mass factors that contribute favorably to increased agricultural production returns may also contribute to increased amenity values. For example expected returns of agricultural production is a function of the climate of the location, the cost of land at a given location is a function of expected returns and natural

amenities, and the natural amenity index is a function of (among other things) climate. One interesting result of the regressions was that mean temperature in January was a strongly positive factor in farm financial performance and that the natural amenity index was a strongly negative factor. In looking at the correlations, temperature was positively correlated with all three measures of financial performance (although less so with net farm income per value of land and buildings) and natural amenities, although positively correlated with temperature, actually became negatively correlated with net farm income per value of land and buildings, suggesting competition with housing development.

The land that has a high mean temperature in January is well suited to high value agriculture and therefore is being bid on by agricultural producers. If these were the only demand agents for this land, we would expect to see the West Coast dominated by high value agriculture and the land prices bid up to where the expected marginal returns over other land is bid to zero. We do, in fact, see a great deal of high value agriculture along the West Coast and, in fact, we see a disproportionately high concentration of counties with high net farm income per value of land and buildings in the Southwest and in the Northwest, indicating that there is not yet an equilibrium in expected returns on investment across the United States.

However, counties that were in the top tier of net farm income per acre counties and have very favorable climates for agricultural production such as Ventura County, California and Santa Barbara County, California are no longer in the top tier for net farm income when deflated by the value of land and buildings. This is likely due to the fact that land in these counties is valued for their natural amenities and housing values as well as their productive potential. Because households can generally outbid agricultural

producers for desirable land, agriculture is expected to be driven out of these counties despite the high expected returns. Likewise, Sutter County, California is expected to perform very well in our model, yet it does not show up in the top echelon of farm financial performing counties. Sutter County, home to Sacramento, the California state capital, has a favorable climate for high value agriculture, but a relatively low natural amenity index. We would predict, then, that this county would attract producers but not households and agriculture would enjoy a comparative advantage. The fact that it does not perform as well as counties like Yuma County, Arizona is hypothesized to be due to the fact that Sutter County, California is home to a state capital which artificially puts an increased household demand for land as people move to this region because of economic activity generated by the state capital. Therefore, this county which is predicted to be well suited to high value agriculture is less so due to artificially high land costs.

Overall, counties with the right climate for high value agricultural production but with little population pressure also performed well. Yuma County, Arizona for example was in the top 20 for all three metrics and was number one in returns per value of land. In short, those counties who can grow high value crops (especially off season) but are not attractive to in-migrants do well with respect to agricultural returns. Not surprisingly, these counties may face other challenges including absent landowners and more migrant labor, both of which contribute to leakages of economic activity out of the county.

In fact, it was found that the residuals from the regression of natural amenities on mean temperature in January was a very strong predictor of high net farm income per value of land and buildings, the most standardized measure of financial performance. The top performing counties are clustered in the bottom right of figure 7, representing

counties with relatively high January temperatures and relatively low natural amenities. Conversely, counties that are clustered in the upper left of figure 7 are counties with relatively high natural amenities and low temperatures in January.

Finally, we should mention some other issues surrounding this study. This study is based on 2002 data which may not be representative of all years. First of all it was a strong year with respect to potato yields and prices and counties that grow a large amount of potatoes tended to perform well in this analysis. Secondly, 2002 was a drought year across much of the West which may have made it an unrepresentative year in terms of several agricultural enterprises. A panel data model examining performance (as well as absolute volume of agricultural production and sales activity) may be useful to extend this study in the future. Finally, an analysis that controlled for other demand determinants with respect to land and water, and possibly labor, may also allow for better predictions. Yet overall, this model did predict financial performance across counties well, and illustrated the potential for further geographic diversity among Western US agricultural sectors in the future as fixed factor prices diverge.

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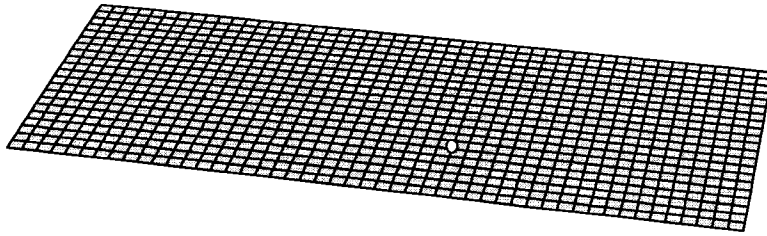


Figure 1 - Homogenous land

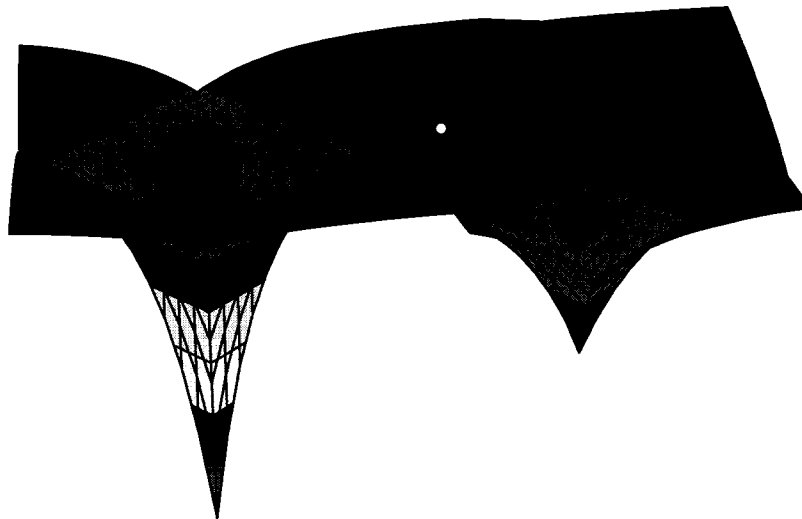


Figure 2 - Land with attractive features

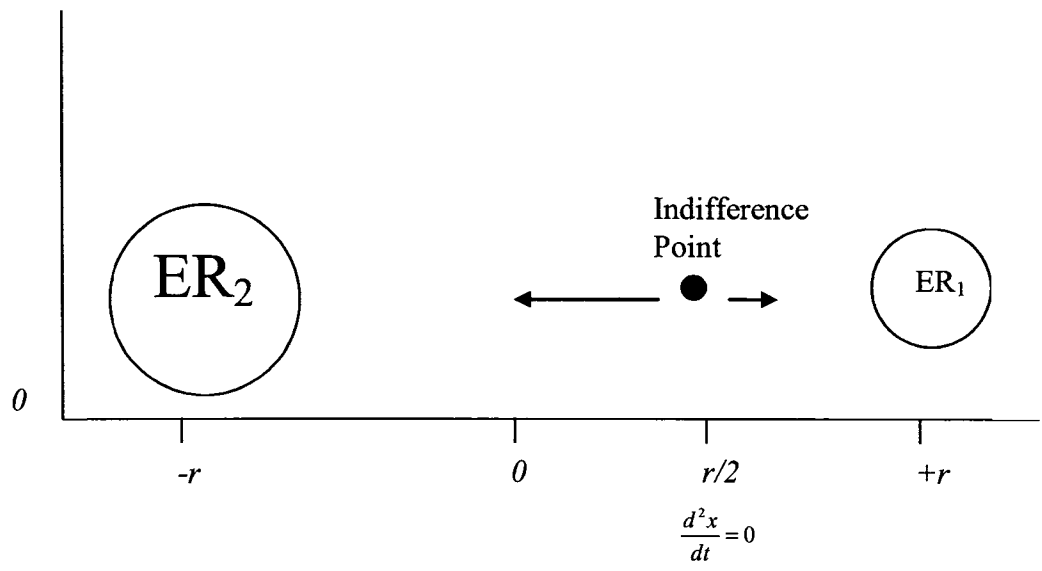


Figure 3 - Attraction between two areas with higher expected returns

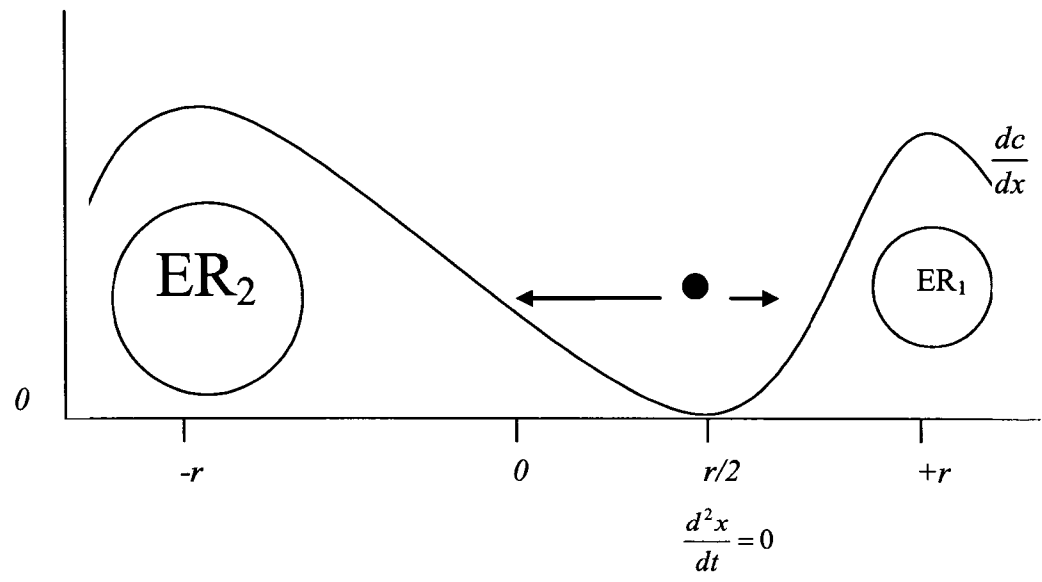


Figure 4 - Attraction with the addition of higher land costs closer to the attractive areas

Table 1 - Principal Component Analysis

| Variable | Temperature | Livestock | Dairy | Farm Size | Corn | Component | Eigenvalue | Difference | Proportion | Cumulative |
|--------------|-------------|-----------|---------|-----------|---------|-------------|------------|------------|------------|------------|
| orchards | 0.3244 | -0.2154 | 0.1044 | -0.2467 | -0.1717 | Temperature | 3.44428 | 1.12046 | 0.2026 | 0.2026 |
| vegetables | 0.2895 | -0.0601 | -0.1075 | -0.2484 | 0.122 | Livestock | 2.32382 | 0.517694 | 0.1367 | 0.3393 |
| corn | -0.0085 | -0.128 | 0.1662 | 0.087 | 0.5666 | Dairy | 1.80613 | 0.47467 | 0.1062 | 0.4455 |
| wheat | -0.1771 | -0.4849 | 0.0207 | 0.2588 | 0.1179 | Farm Size | 1.33146 | 0.172847 | 0.0783 | 0.5239 |
| forage | -0.0909 | 0.4743 | 0.0785 | 0.0784 | -0.2833 | Corn | 1.15861 | 0.199415 | 0.0682 | 0.592 |
| silage | 0.126 | 0.1229 | 0.5426 | 0.1303 | 0.2862 | Comp6 | 0.959197 | 0.0463909 | 0.0564 | 0.6484 |
| hort | 0.276 | 0.0897 | -0.2481 | 0.3249 | 0.1391 | Comp7 | 0.912806 | 0.08615 | 0.0537 | 0.7021 |
| direct sales | 0.1529 | 0.1782 | -0.2069 | 0.2424 | -0.0523 | Comp8 | 0.826656 | 0.0958336 | 0.0486 | 0.7508 |
| livestock | -0.2424 | 0.3987 | 0.2063 | -0.1624 | 0.0224 | Comp9 | 0.730823 | 0.0190871 | 0.043 | 0.7938 |
| off-farm Y | 0.0497 | 0.2373 | 0.0356 | 0.4488 | -0.0277 | Comp10 | 0.711736 | 0.0644205 | 0.0419 | 0.8356 |
| Jan. temp | 0.4279 | -0.0035 | 0.0309 | -0.1073 | 0.102 | Comp11 | 0.647315 | 0.13485 | 0.0381 | 0.8737 |
| rural | -0.4251 | 0.0381 | 0.0093 | -0.1383 | -0.1119 | Comp12 | 0.512465 | 0.0428762 | 0.0301 | 0.9038 |
| ave. size | -0.2461 | -0.0241 | -0.0202 | -0.4439 | 0.2396 | Comp13 | 0.469589 | 0.106848 | 0.0276 | 0.9315 |
| coop | 0.1281 | -0.226 | 0.3454 | -0.1302 | -0.4242 | Comp14 | 0.362741 | 0.024057 | 0.0213 | 0.9528 |
| custom | -0.0163 | -0.2974 | 0.1682 | 0.2497 | -0.4069 | Comp15 | 0.338684 | 0.0904917 | 0.0199 | 0.9727 |
| dairy | 0.1888 | 0.1456 | 0.5557 | -0.017 | 0.0369 | Comp16 | 0.248192 | 0.0326967 | 0.0146 | 0.9873 |
| nat. amen. | 0.3434 | 0.2016 | -0.2072 | -0.2836 | -0.0898 | Comp17 | 0.215495 | | 0.0127 | 1 |

| | tsa | nfia | nfiass | orch | veg | corn | wheat | forage | silage | hort | direct | livestock | off-farm | temp | rural | ave size | coop | custom | dairy | nat amen | land value | |
|------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|-----------|----------|---------|---------|----------|---------|---------|--------|----------|------------|--|
| tsa | 1 | | | | | | | | | | | | | | | | | | | | | |
| nfia | 0.9023 | 1 | | | | | | | | | | | | | | | | | | | | |
| nfiass | 0.6073 | 0.7272 | 1 | | | | | | | | | | | | | | | | | | | |
| orch | 0.4292 | 0.3732 | 0.2232 | 1 | | | | | | | | | | | | | | | | | | |
| veg | 0.5236 | 0.5365 | 0.3805 | 0.2453 | 1 | | | | | | | | | | | | | | | | | |
| corn | 0.0248 | -0.0205 | 0.0933 | 0.0209 | -0.0016 | 1 | | | | | | | | | | | | | | | | |
| wheat | -0.1185 | -0.0753 | 0.1433 | -0.1378 | -0.11 | 0.1009 | 1 | | | | | | | | | | | | | | | |
| forage | -0.0984 | -0.1215 | -0.0758 | -0.2795 | -0.0957 | -0.1673 | -0.4516 | 1 | | | | | | | | | | | | | | |
| silage | 0.2526 | 0.1275 | 0.2269 | 0.1043 | 0.0382 | 0.1375 | -0.0993 | 0.0865 | 1 | | | | | | | | | | | | | |
| hort | 0.3542 | 0.2243 | -0.0184 | 0.0323 | 0.1407 | -0.0577 | -0.157 | -0.0188 | -0.0065 | 1 | | | | | | | | | | | | |
| direct | -0.0176 | -0.0603 | -0.1897 | -0.0053 | 0.0308 | -0.0636 | -0.1986 | 0.0579 | -0.0598 | 0.2356 | 1 | | | | | | | | | | | |
| livestock | -0.3091 | -0.2711 | -0.2471 | -0.3824 | -0.2862 | 0.0213 | -0.3496 | 0.3747 | 0.0926 | -0.2896 | -0.0115 | 1 | | | | | | | | | | |
| off-farm | -0.0303 | -0.0387 | -0.0421 | -0.0567 | -0.0722 | -0.0259 | -0.1694 | 0.2018 | 0.1239 | 0.1114 | 0.0992 | 0.0776 | 1 | | | | | | | | | |
| temp | 0.5169 | 0.433 | 0.2918 | 0.4541 | 0.4181 | 0.076 | -0.2692 | -0.1764 | 0.1422 | 0.3343 | 0.1835 | -0.2966 | 0.0546 | 1 | | | | | | | | |
| rural | -0.4785 | -0.3913 | -0.17 | -0.4119 | -0.3569 | -0.0086 | 0.154 | 0.2114 | -0.2201 | -0.4258 | -0.2501 | 0.3373 | -0.1156 | -0.5559 | 1 | | | | | | | |
| ave size | -0.2962 | -0.2207 | -0.1701 | -0.1433 | -0.1321 | -0.0104 | 0.0431 | -0.0862 | -0.1008 | -0.2655 | -0.1631 | 0.2613 | -0.1706 | -0.2019 | 0.3152 | 1 | | | | | | |
| coop | 0.2357 | 0.1836 | 0.1663 | 0.3378 | 0.0674 | -0.0012 | 0.0934 | -0.1577 | 0.0501 | -0.0799 | -0.0594 | -0.1144 | -0.1092 | 0.1588 | -0.1098 | -0.1163 | 1 | | | | | |
| custom | -0.0549 | -0.0579 | 0.011 | 0.1305 | -0.0805 | 0.0462 | 0.2479 | -0.1036 | 0.0073 | -0.1174 | -0.0892 | -0.1824 | -0.0428 | -0.0039 | -0.0279 | -0.1049 | 0.2235 | 1 | | | | |
| dairy | 0.3731 | 0.2283 | 0.2916 | 0.1286 | 0.0383 | -0.0046 | -0.1468 | 0.1239 | 0.597 | 0.0467 | -0.0107 | 0.1225 | 0.0241 | 0.3011 | -0.2303 | -0.1494 | 0.3191 | -0.0588 | 1 | | | |
| nat amen | 0.2714 | 0.2221 | -0.0735 | 0.2897 | 0.326 | -0.1405 | -0.5134 | 0.0357 | -0.0497 | 0.284 | 0.1696 | -0.1359 | -0.0045 | 0.4781 | -0.3831 | -0.2293 | -0.0253 | -0.2154 | 0.0976 | 1 | | |
| land value | 0.53 | 0.435 | 0.1265 | 0.3479 | 0.2143 | -0.0236 | -0.1587 | -0.0845 | 0.0886 | 0.3885 | 0.1197 | -0.3292 | -0.1187 | 0.2781 | -0.4896 | -0.3334 | 0.0969 | -0.0357 | 0.1732 | 0.372 | 1 | |

Table 2 – Maximum Likelihood Regression Results

| Dependent Variable: | Total Sales per Acre <i>Pseudo-R² = 0.643</i> | | Net Farm Income per Acre <i>Pseudo-R² = 0.468</i> | | Net Farm Income per Value of Land and Buildings <i>Pseudo-R² = 0.452</i> | |
|------------------------------|--|----------------|--|----------------|---|----------------|
| Independent Variables | Coefficient | P-value | Coefficient | P-value | Coefficient | P-value |
| lagged dependent variable | 0.500 | 0.000 | 0.381 | 0.000 | 0.549 | 0.000 |
| constant | -272.628 | 0.099 | -16.081 | 0.787 | 0.001 | 0.926 |
| orchards | 1,411.147 | 0.000 | 347.494 | 0.000 | 0.033 | 0.076 |
| vegetables | 2,358.155 | 0.000 | 886.607 | 0.000 | 0.132 | 0.000 |
| corn | 380.415 | 0.570 | -184.601 | 0.447 | 0.083 | 0.100 |
| wheat | 343.098 | 0.189 | 63.607 | 0.501 | 0.034 | 0.089 |
| forage | 66.942 | 0.641 | -15.517 | 0.765 | 0.015 | 0.160 |
| silage | 456.984 | 0.592 | -194.504 | 0.528 | 0.011 | 0.868 |
| hort | 620.509 | 0.000 | 62.595 | 0.137 | -0.020 | 0.024 |
| direct sales | -2,734.940 | 0.064 | -1,350.980 | 0.012 | -0.270 | 0.016 |
| livestock | 95.007 | 0.266 | 24.838 | 0.421 | -0.010 | 0.126 |
| off-farm Y | 172.248 | 0.480 | 39.235 | 0.656 | 0.006 | 0.741 |
| Jan. temp | 4.623 | 0.087 | 1.619 | 0.094 | 0.000 | 0.017 |
| rural | 11.250 | 0.241 | -0.014 | 0.997 | 0.001 | 0.225 |
| ave. size | -0.016 | 0.098 | -0.006 | 0.071 | 0.000 | 0.077 |
| coop | 4,103.252 | 0.619 | 81.039 | 0.978 | -0.648 | 0.297 |
| custom | -2,446.270 | 0.411 | -1,402.760 | 0.191 | -0.318 | 0.156 |
| dairy | 912.040 | 0.000 | 165.452 | 0.021 | 0.057 | 0.000 |
| nat. amen. | -22.884 | 0.036 | -7.977 | 0.043 | -0.003 | 0.000 |

Table 3 - ML spatial regressions on principal components

| Dependent Variable: | Total Sales per Acre <i>Pseudo-R² = 0.612</i> | | Net Farm Income per Acre <i>Pseudo-R² = 0.561</i> | | Net Farm Income per Value of Land and Buildings <i>Pseudo-R² = 0.383</i> | |
|------------------------------|--|----------------|--|----------------|---|----------------|
| Independent Variables | Coefficient | P-value | Coefficient | P-value | Coefficient | P-value |
| lagged dependent variable | 0.556 | 0.000 | 0.479 | 0.000 | 0.797 | 0.000 |
| constant | 152.575 | 0.000 | 38.534 | 0.000 | 0.005 | 0.003 |
| temperature vector | 143.458 | 0.000 | 36.594 | 0.000 | 0.003 | 0.003 |
| livestock vector | 14.228 | 0.296 | -4.159 | 0.391 | -0.001 | 0.197 |
| dairy vector | 57.673 | 0.000 | 9.408 | 0.088 | 0.006 | 0.000 |
| average size vector | -43.412 | 0.022 | -24.217 | 0.000 | -0.002 | 0.192 |
| corn vector | 12.531 | 0.511 | -2.983 | 0.660 | 0.003 | 0.038 |

Table 4 - Top Counties by Net Farm Income per Acre

| Rank | County | Net Farm Income per Acre |
|-------------|------------------------|---------------------------------|
| 1 | California\Santa Cruz | 1,649 |
| 2 | Arizona\Yuma | 1,463 |
| 3 | Washington\Mason | 1,399 |
| 4 | Washington\Skamania | 1,183 |
| 5 | California\Orange | 1,076 |
| 6 | California\San Mateo | 911 |
| 7 | California\Napa | 737 |
| 8 | California\Ventura | 722 |
| 9 | Washington\King | 701 |
| 10 | California\Los Angeles | 691 |
| 11 | Oregon\Multnomah | 647 |
| 12 | California\Monterey | 640 |
| 13 | California\San Diego | 633 |
| 14 | Oregon\Tillamook | 632 |
| 15 | Washington\Whatcom | 558 |
| 16 | Washington\Skagit | 524 |
| 17 | California\Imperial | 403 |
| 18 | Washington\Pierce | 383 |
| 19 | Oregon\Washington | 379 |
| 20 | California\Riverside | 367 |
| | Average | 785 |
| | Median | 669 |
| | STD | 378 |
| | Pop Mean | 78 |
| | Pop Median | 11 |
| | Pop STD | 199 |

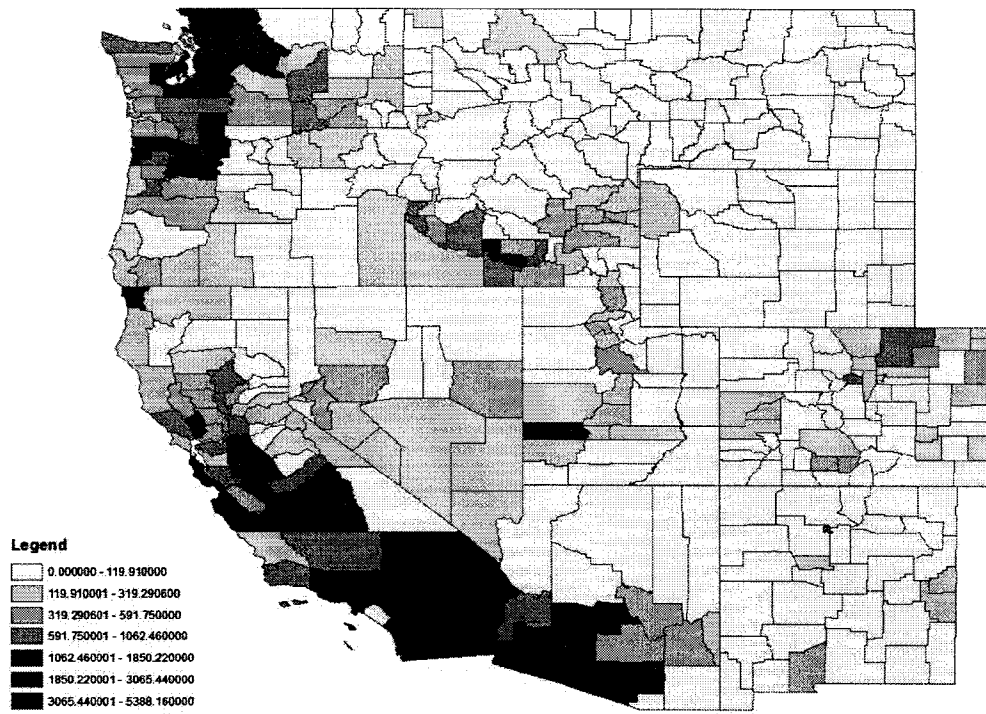


Figure 5 - Total Sales per Acre

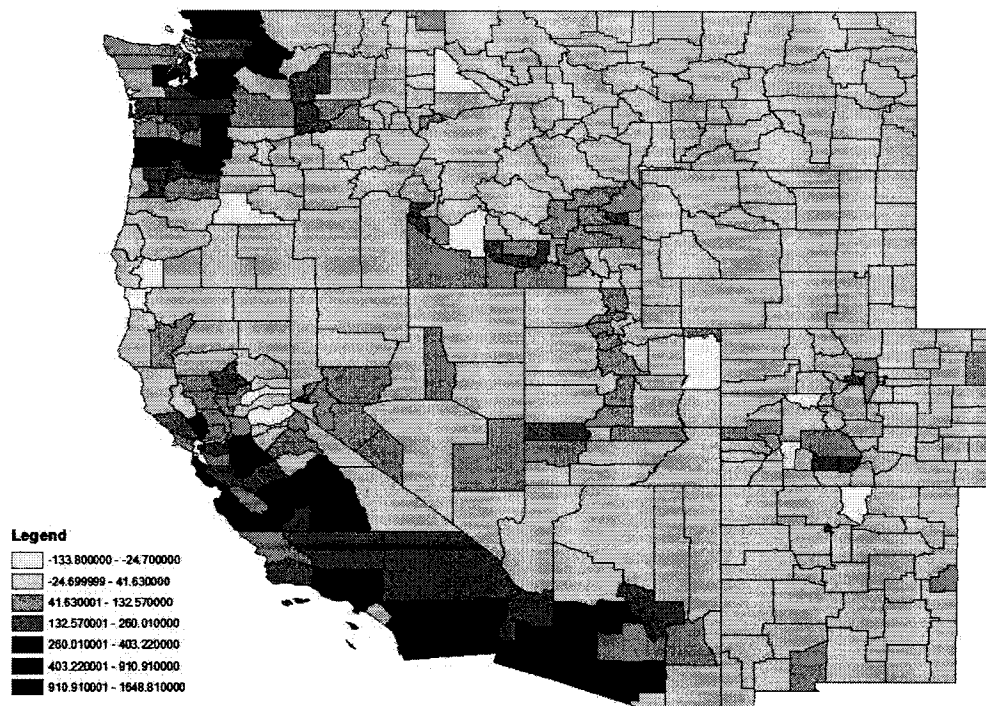


Figure 6 - Net Farm Income per Acre

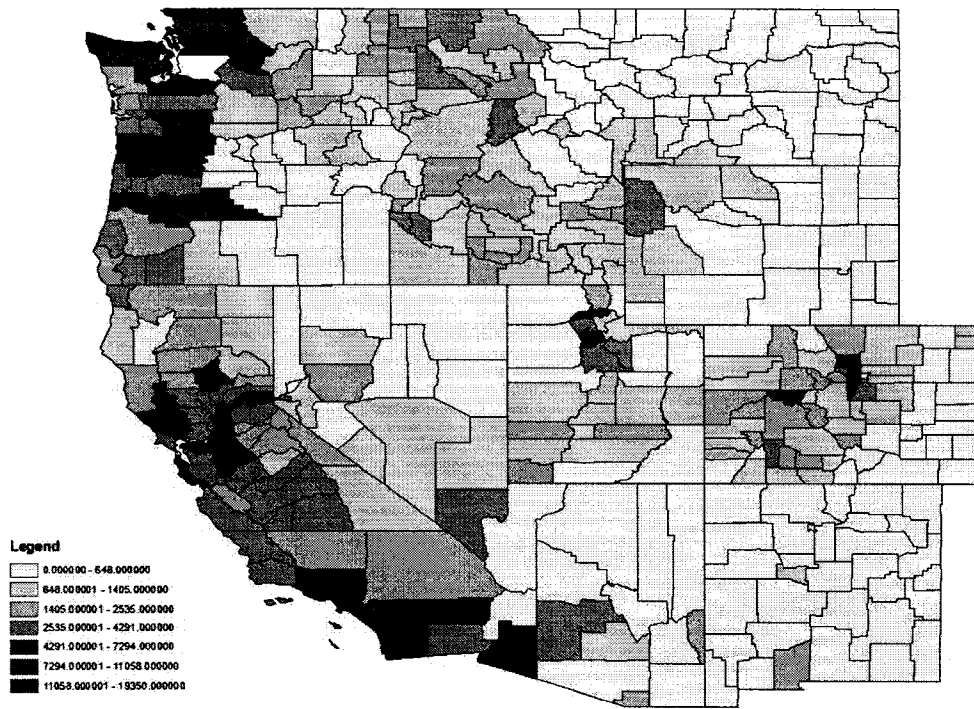


Figure 7 - Average Value of Land and Buildings in Agriculture

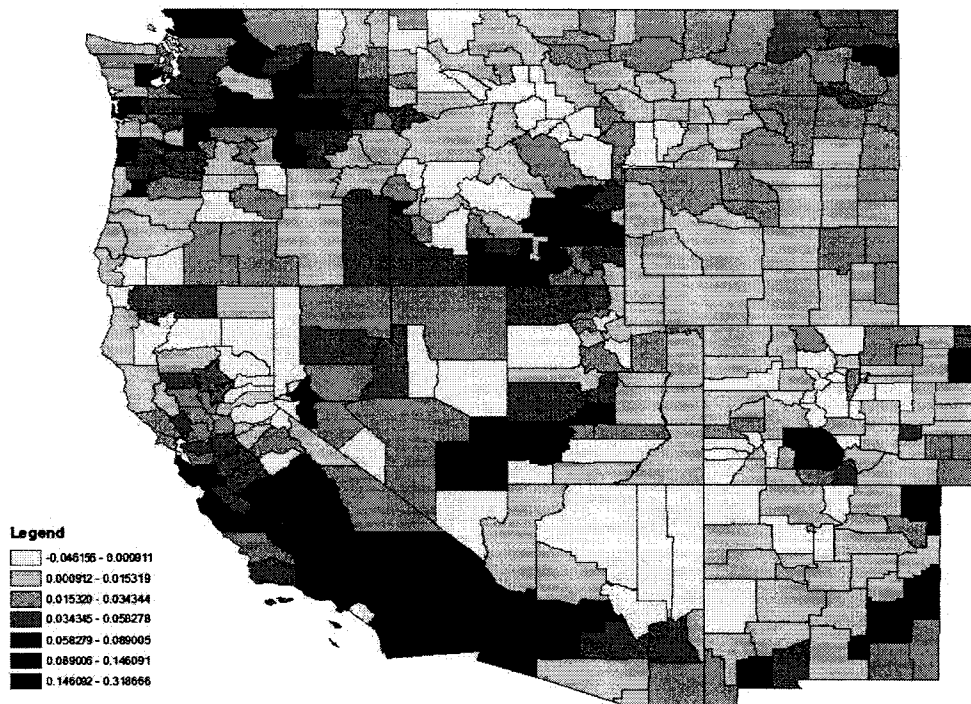


Figure 8 - Net Farm Income per Value of Land and Buildings

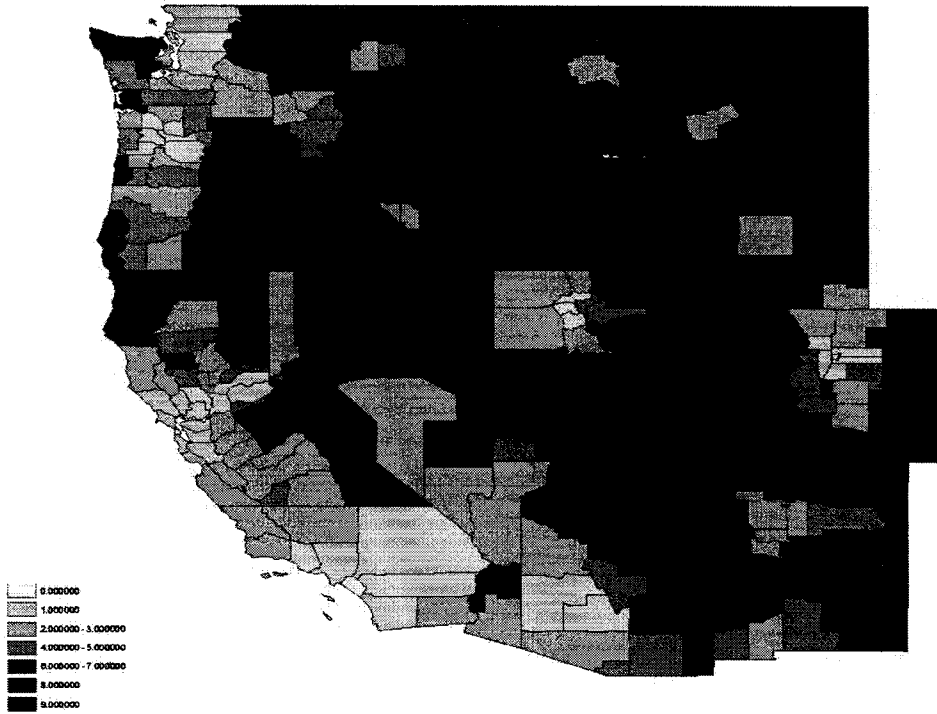


Figure 9 - Rural - Urban Continuum Index (lower numbers mean more urban influence)

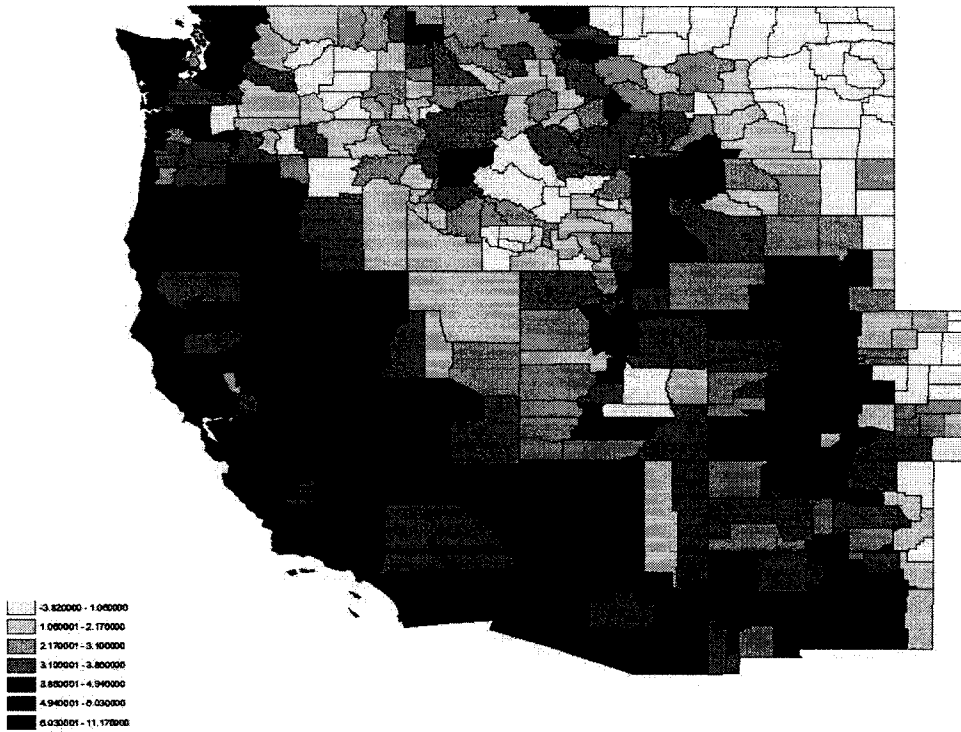


Figure 10 - Natural Amenity Index

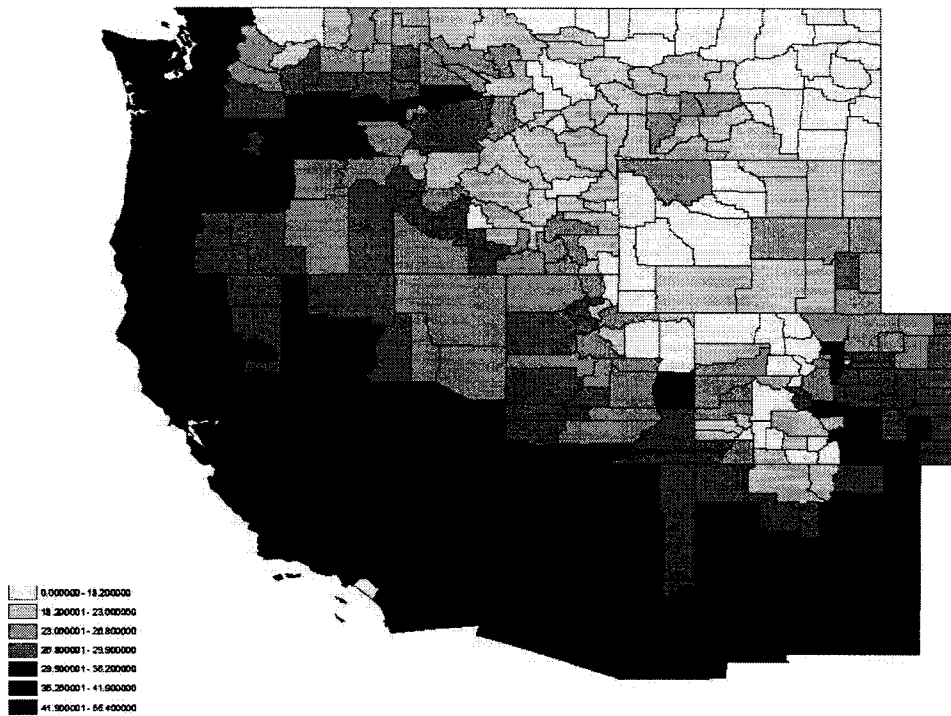


Figure 11 - Average Temperature in January

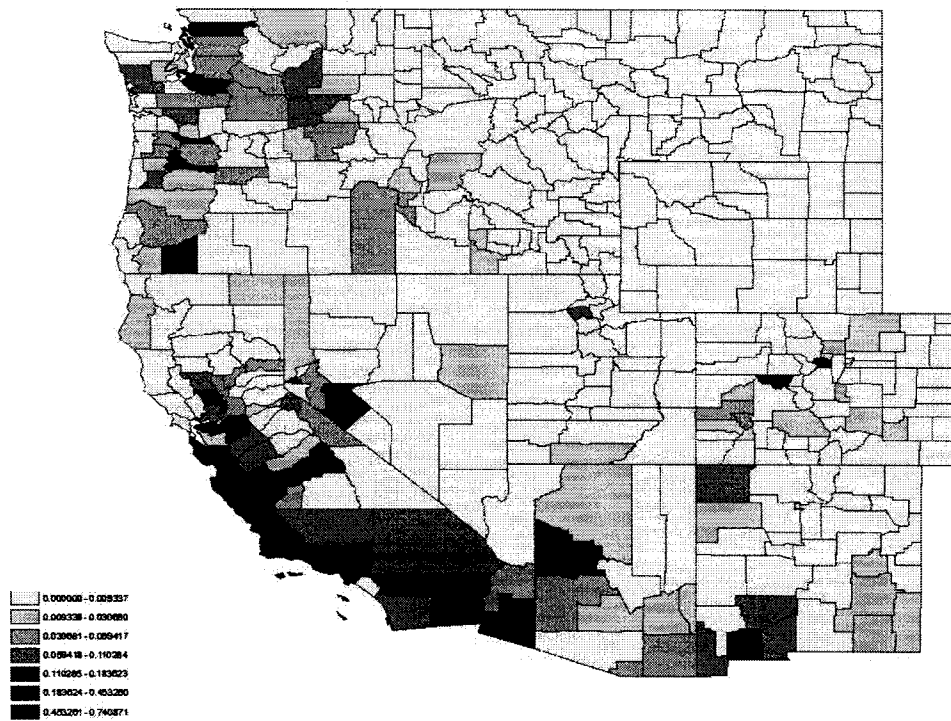
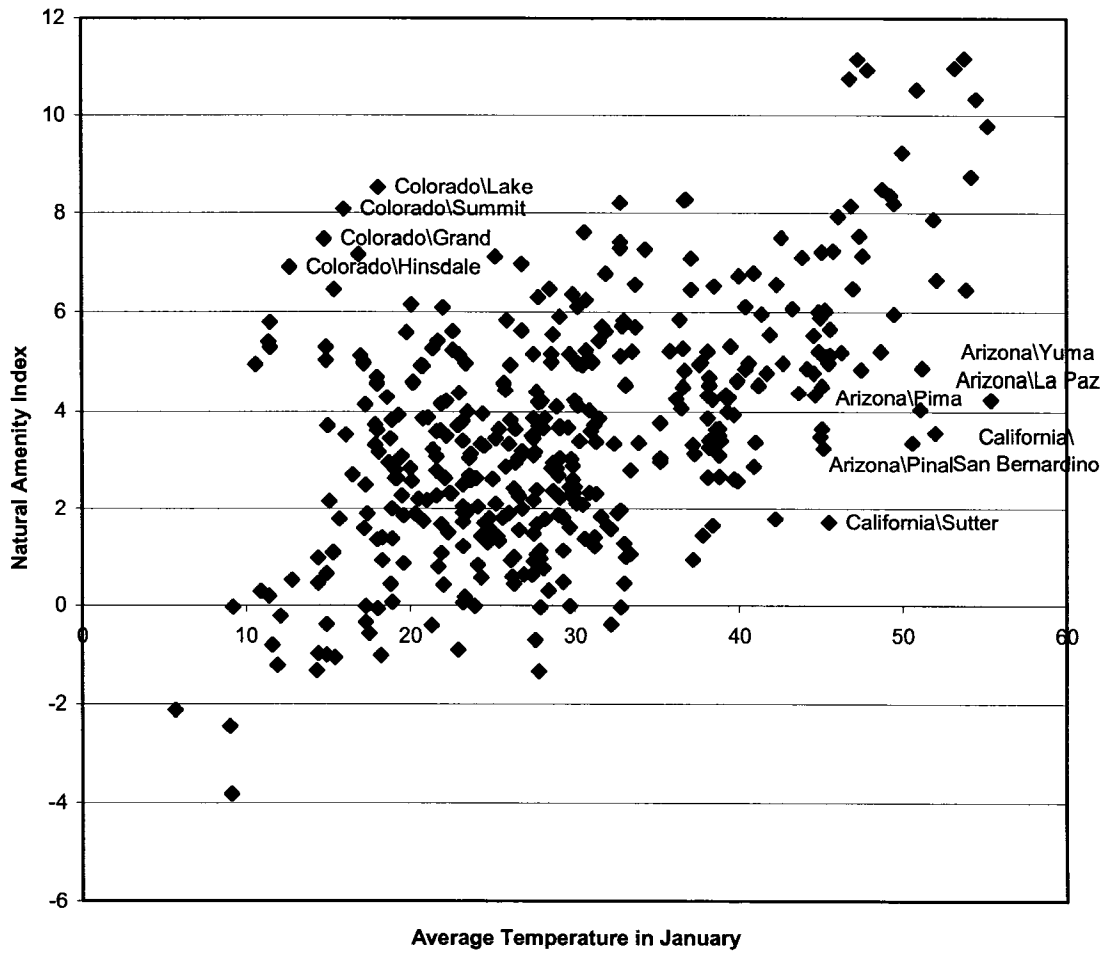


Figure 12 - Share of Total Acres in Vegetable Production

Natural Amenity vs. Average Temperature in January



CHAPTER TWO

Computable General Equilibrium Analysis of Population Growth and Water Policy in Colorado

Introduction

Water is often cited as a limiting resource in Colorado and throughout much of the American West (Jackson et. al 2001, Postel et. al 1996). As the population and the demographics of Colorado change, water has become the state's newest battleground, seemingly pitting historically agricultural communities against the urban corridors of the state. In the light of research that indicates water may not be a primary limit to economic or population growth in the American West (Barbier 2004), a computable general equilibrium modeling approach is implemented in this study to examine the effects of increased population growth on water demand, agriculture, and urban growth under a variety of scenarios.

The issue of water demand in the in the Western United States is often couched in terms of water demand increasing over time (Colorado Farm Bureau 1997). Water and land have been moving out of agriculture and into municipal, commercial, and industrial uses for at least the past decade (figures 1 and 2). This trend is expected to continue based on current population projections and water procurement plans being made by urban governments. Past studies have relied on fairly simplistic forecasts of the effects of increased population on water demand over time. This study will examine land and water demands explicitly as functions of population and economic growth and will contribute a computable general equilibrium (CGE) model of how a specific regional economy will adapt to this growth.

According to the Colorado State Demographer's office, the population of Colorado is expected to grow to over 7 million by the year 2030, up from 4.5 million in 2002. This population growth trend is typical of the American West and has persisted over the past century (Hobbs and Stoops 2002). The West has seen a fourteen fold increase in population over the 20th century, increasing from 4.3 million in 1900 to 60 million in 2000 (USDA 2000).

This population increase has been spurred by many factors, not the least of which is the region's climate and high natural amenities (Power 1996), a factor that was shown to be of significant importance to the financial performance of the agricultural sector in Chapter Two. Colorado is a high natural amenity state and, as such, the region has experienced steady population growth over the past century. The region's growth has been disproportionately centered on urban areas such as Colorado's Front Range. This population increase has had a profound effect on the demographic character of the West, transforming the region from an agrarian and extraction based economy to a diversified economy with the majority of the population and economic activity found in urban centers (Power 1996, Shumway and Otterstrom 2001, Vias and Carruthers 2005).

As the state's population continues to grow, water will need to be allocated to residential household use and related industries such as commercial development, golf courses and landscape management. Water in the Western United States is fast approaching full appropriation (Green and Hamilton 2000, Davis 2001); therefore increases in water usage in one sector must be offset by a reduction in water use in another sector or in a reduction in water usage in its own sector through conservation and technology improvements. The current owners of the state's water resources face

increasing opportunity costs associated with holding onto their water as demand increases and the willingness to pay for water in urban areas continues to grow.

Most of the projected population growth in Colorado is expected to take place in the Denver metropolitan region and in the northern Front Range. This region is among the fastest growing and most economically diverse regions in the state. The northern Front Range depends heavily on the South Platte River and its tributaries as the source of water for agricultural, industrial, and municipal uses.

History

When Eastern Colorado was first homesteaded, the opportunity costs of land and water were close to zero. The government encouraged development of the region through Bureau of Reclamation irrigation projects and free land. With low population densities, few potential nonagricultural activities in which to invest, and minimal environmental concerns, the competition for alternative uses of agricultural resources was low. Water not used for agriculture would simply flow out of the state without generating any economic activity. Low population pressure, together with ample and inexpensive land and water, created a climate where agriculture was a feasible and attractive economic activity in Eastern Colorado.

With the development of the West, water became valuable for many other uses including industry, residential, recreational, and environmental uses. These additional activities increased the opportunity cost of using water for agriculture. With the ongoing development and urbanization of the state, water scarcity emerged as a resource management issue as households and new industries moved into the region. Given the

state's Doctrine of Prior Appropriation, water is allocated to those who have the oldest claim on the water. In the case of Colorado, the oldest water rights belong to the agricultural sector.

The new residents and firms, then, faced a situation where a vast majority of the available water in the state was already appropriated to agricultural producers. This created a water scarcity issue in the state as water for new development was limited by available water or buying water rights from agricultural producers, a fairly political issue in and of itself. The opportunity to sell water between sectors made the opportunity cost of water for agricultural producers more transparent since water used in agriculture to produce crops could now be sold and the money invested in higher yielding investments. In short, agriculture finds itself in the position of owning the vast majority of the water rights in the state and, as such, controls a very valuable resource.

Agriculture

Primary recipient crops of irrigation water in the region include corn, spring wheat, beans, sugar beets, and hay as well as some limited, but more valuable crops including onions, potatoes and other vegetables. The region is also suited for dryland production of winter wheat, sunflowers, sorghum, and millet. Dry land corn is also grown on a limited basis in the region. The expected returns to field crops in many areas of Eastern Colorado are less than \$150 per acre, with net receipts for irrigated corn estimated at \$17.96 per acre before factor payments in 2005 and even less for irrigated winter wheat (Colorado State University Extension Service Crop Enterprise Budgets). Net returns to higher revenue but riskier and more capital intensive crops such as potatoes

and onions tend to be much higher, with expected net returns per acre for onions in Eastern Colorado approaching \$1,800, exceeding \$700 for potatoes, and over \$1700 for cabbage before factor payments (Colorado State University Extension Service Crop Enterprise Budgets).

It is expected that as population continues to grow, marginal agricultural operators will decide to sell their water to activities that generate more economic activity per acre than do field crops. There is friction, however, in the temporal response of operators who might remain in agriculture longer than would otherwise be expected, due to cultural and lifestyle considerations, and because they may see the investment in their water rights as having higher annual returns than comparable investment opportunities (Blank 2004), especially if one considers any perceived appreciation of water rights over time. This indicates that water will move from marginal agricultural activities to urban areas, but at a slower rate than might be anticipated.

Another aspect of this problem is the uncertain and stochastic nature of precipitation. Colorado is a semi-arid environment and, on average, the Front Range receives 14 inches of precipitation per year. In drought years, however, precipitation levels can be as low as 5 inches. Even with potential water transfers from agriculture alleviating most urban and industrial water constraints in normal years, drought years will likely require water rationing. Determining which policies serve to conserve water while minimizing the economic impacts on industries will be important to the state regardless of whether water is transferred from agriculture to urban uses.

Lastly, the structure of water demand in agriculture and in urban uses is likely to be very different. In urban uses, the value of water is very high up to the point where

lawns, parks, and golf courses are kept green. After that point, the marginal value of water decreases sharply as additional irrigation does little to increase utility. In agriculture the value of water is associated with the increases in yield or crop quality that it contributes. The initial acre-feet of water will have the largest marginal effect on crop yields with the marginal benefits of additional irrigation decreasing thereafter. Beyond some application level, additional irrigation only modestly increases yields, however it may allow more acres to be put into cultivation. It is unlikely that the derived demand curve for water in agriculture would be as high as it is for urban uses when supplies are low, or that the marginal value product of water for agriculture would drop off and go to zero as fast as one might expect with urban water demand.

Platte River Basin

Examining the relationship between population growth, economic growth, and resource use in Eastern Colorado is complicated by fact that the area is comprised of three watersheds. The southern most counties are in the Arkansas River basin, East Central counties are in the Republican River basin and the northern and west central counties are in the South Platte River basin (figure 3). Colorado water law is complicated and beyond the scope of this study but for an in depth overview and analysis of relevant issues see Hobbs 1997. Suffice it to say, court rulings dating back to 1891 (Strickler v. City of Colorado Springs) have ruled that water rights (and therefore water use) may be transferred between parties, providing that transfer does not harm other appropriations. Because of this ruling, transfers of water across basins are severely restricted and specific approval for any transfer must be granted by the Colorado Water Court.

Therefore, looking at the entire region as one unified water region is not realistic. Instead this study will focus only on the Platte River Basin, the most populous, fastest growing, and most economically diverse of the basins. The Platte River basin is comprised of the following counties: Adams, Arapaho, Boulder, Gilpin, Jefferson, Larimer, Broomfield, Clear Creek, Denver, Logan, Morgan, Sedgwick, Douglas, Elbert, Park, and Weld. Major cities in the region include Denver, Boulder, Fort Collins, and Greeley. The region spans 19,393 square miles and had a total population of 3,074,759 in 2002.

Study Topic

This study will examine the effects of population growth on the allocation of the fixed resources of land and water. The expected growth in the population of the Northern Front Range has implications for regional land and water demand. The goal of this study is twofold. The first objective is to analyze and describe the effects of increased population on the state's economy. This section of the study will examine the relationship between increased population on municipal water demand and on related industries that are expected to grow in line with population growth such as golf. But, it should be noted that the increased population also represents the opportunity for direct marketing of the state's agricultural production and new economic linkages between agricultural and municipal regions.

General Equilibrium Modeling

General equilibrium models are based on a Walrasian equilibrium view of an economy, where the circular flow of goods, factors, and payments between firms, households, government and the rest of the world is facilitated through product markets, factor markets, and institutions. These transactions take place as factor payments, goods expenditures, and taxes. A general equilibrium model is a mathematical representation of the economic relationships between the various industry sectors, households, and government institutions that comprise a local economy. General equilibrium models share a fundamental commonality with input-output models, as they represent the economic relationships within and between the sectors and households in a regional economy and, under certain restrictive assumptions, a general equilibrium model will reduce to an input-output model. Yet, the general equilibrium approach to regional modeling is a more general approach as it allows for non-linear relationships in production functions, changes in prices, and allows substitution between factors of production. Therefore, the opportunity costs associated with factor inputs are better reflected in general equilibrium framework.

In the competitive Walrasian model, equilibrium is achieved through the following neoclassical assumptions and characteristics of a regional economy: market clearance, the zero profit condition, and income balance. Together these conditions form the basis of general equilibrium analysis, which becomes a system of equations that represent the economy that then reacts to market forces while abiding by these neoclassical assumptions.

Market clearance relates to the situation where goods and factor prices are allowed to vary until all markets clear. Therefore, total supply equals total demand in

every market. This outcome is based on Walras Law, which states that there exists a vector of prices that will clear every market. Walras envisioned this as a process where an auctioneer starts with an arbitrary vector of prices in the goods market. The arbitrage process will occur and the auctioneer will then raise the price for goods for which there is excess demand and reduce the price for goods for which there was excess supply. This process will take place until excess supply and demand are driven to zero and supply equals demand. Mathematically, Walras appealed to the Brouwer Fixed Point Theorem to demonstrate the necessary existence of a fixed point in the price adjustment function so that it will reach the condition where excess demand is zero and supply equals demand.

The zero profit condition is insured by prices being determined so that the firms' equilibrium profits above normal profits are zero and all rents accrue to factors. This comes out of the Walrasian equilibrium assumptions and is ensured through the first order conditions on the firms' production functions. Additionally, all factors of production, such as land, labor, capital, and management, are owned by the households and therefore all rents return to households as payments to factors. This situation is fairly intuitive in an all-inclusive economy that includes firms, households, government, and exports. Because all revenues in the general equilibrium economy must both come from somewhere and go to somewhere, all income to firms must be accounted for as either input costs (including land, labor, and capital costs), taxes, or normal profits. However, in general equilibrium, all firms are owned by a household somewhere so these normal profits go back to households as income. These households may exist in the region or outside the region; therefore "profits" can be modeled as a leakage of revenues outside of the economy or as a return flow within the economy depending on assumptions.

Income balance relates to the assumption that households spend their entire income somewhere in the economy. Because households own all of the factors of production in the economy, they then derive income from returns to labor and returns to any other factor of production that they own. This income is then spent somewhere else in the economy, either on goods, taxes, or savings/investment. In most nationally based general equilibrium models, savings is equivalent to investment, where people's deposits in banks and their actual portfolio of investments are then loaned to firms for purchasing capital. This savings/investment is another form of income from returns to capital in the economy.

General equilibrium models represent all of the elements of the economy through a series of interrelated simultaneous equations where each of the aforementioned equilibrium outcomes hold. Once the equations have been specified, derivatives can be taken to analyze the effects of changes of one sector on the rest of the economy.

Computable general equilibrium (CGE) is an analytical tool that describes the Walrasian equilibrium through a systematic representation of an economy using actual regional data. However, instead of providing purely analytical solutions for the equilibrium outcome, CGE models use this actual regional data to calibrate themselves to an actual region's economy and numerical solutions can be found that describe actual outcomes of changes to one aspect of the model. CGE models are not solved as optimization models; rather they depend on the derived demand and supply functions that are the outcome of the neoclassical assumptions. Programs such as GAMS find numerical solutions using algorithms that are based on complementarity, fixed point theorems, or the Newton approach.

The first operational CGE model was developed by Johansen (1960) and was used to analyze multisectoral interactions and economic growth. Since then CGE models have been used extensively in regional analysis to address a wide range of scenarios and policies (Robinson 1989) including taxation (Shoven and Whaley 1984), trade policy (Robinson and Roland-Holst 1988), agricultural policy (Gunning and Keyser 1993) and natural resource policy (Robinson and Gehlar 1995).

The first step in constructing the CGE model is to specify the dimensions of the model. The economy to be modeled using a CGE is divided into sectors, which then produce goods; household groups, which demand goods, supply labor, and own the factors of production; government sectors, which collect taxes and redistribute wealth; institutions which facilitate transactions; outside trade, which brings in new income and generates economic leakages; and factors of production, which are used by the sectors to produce goods. Each of n sectors in the economy produces at least one type of good through an explicitly specified production function. Households are generally divided by income levels into h groups and use income generated through wages and returns to factors to purchase goods and make savings. Households are modeled using an explicitly stated utility function as utility maximizers who generate utility from consumption and savings; therefore their entire income will be spent on goods, services, or savings.

In the CGE economy, there is a fixed supply of i primary factors of production that can be moved between sectors and substituted for each other via a production relationship. In the production of goods, each sector also uses intermediate inputs from other sectors. The proportion of primary factors to intermediate inputs is generally exogenously determined and inserted into the model. Additionally, the elasticity of

substitution between the various intermediate inputs themselves is exogenously set and is often represented as Leontief fixed proportions.

The choice of specific functional forms for both the utility function of households and the production function of firms is exogenously determined by the researcher. The functional forms need to include outputs as a function of inputs, as well as be consistent with economic theory and be analytically tractable. In practice the functional form is often specified as a constant elasticity of substitution (CES) or Cobb-Douglas (CD) production function for convenience and because of their forms' fidelity to economic theory. Additionally, different functional forms may be specified for different types of inputs and factors. For instance, a CES function may be chosen to represent the different types of water inputs (irrigation and municipal) and a CD function may be chosen between the other factors of labor and capital.

The equations used in a CGE model can generally be broken into four main types: 1) pricing equations, 2) production equations, 3) institution equations, and 4) system constraint equations.

The pricing equations are among the most key aspects of the CGE model. In the CGE, prices and quantities are allowed to adjust to solve for a new equilibrium after an initial change to the model. The way this model is set up, import prices (PM_c) are allowed to deviate from the export price (PE_c). Therefore prices in the region and prices outside of the region are not necessarily the same.

The production and commodity block equations are used to determine the outputs associated with levels of inputs. These equations relate output levels of activities to

primary factor inputs and determine the marginal cost of factors used in activities. They also relate the amount of intermediate inputs to the output level of activities.

Armington equations are often incorporated to allocate domestic output and transform domestic output to exports and domestic sales. These equations arise due to the possibility of imperfect substitutability between imported and domestic output by domestic demand agents. The relationship is generally modeled as a constant elasticity of substitution (CES) function. This means that demand preferences over imports and domestic output are expressed as a CES function. This function also serves the same function as a regional absorption coefficient, allocating regional demand between imports and local production and allowing for cross hauling of goods.

The institution block specifies the equations for household income, demand of commodities, and investment as well as government revenues and expenditures. In this model, households derive income from labor and owning other factors of production, as well as from transfers from the government and from outside the region (nonlabor income). Government spending is constrained to tax revenue, tariffs, and transfers from outside the region. The system constraint equations simply provide identities and ensure that the model is internally consistent.

The base period data used by the CGE model to calibrate the coefficients in the equations is most often organized in a social accounting matrix (SAM), which represents the various transactions in the economy. The primary elements of the SAM are the production sectors, commodities supplied, factors of production, and institutions such as households and government. The columns of the SAM represent the demand of the given element for a corresponding element in the row. The rows represent the supply of the

given element to the corresponding element in the columns. In this way the columns are thought of as the expenditures or costs and the rows represent sources of demand.

Because of the neoclassical assumptions of the model, such as market clearing, income balance, and zero profits, the row and column totals will be equivalent. The SAM is the core of the CGE model and is what the model will use to calibrate itself. The CGE model will calibrate the variables in the equations of the model to the point where the outcomes will exactly replicate the original SAM that was inputted into the model from actual regional data. In the initial condition, all variables will be consistent with base data.

The general requirements of the SAM are commodity balance, where supply equals demand for every commodity and factor; flow of funds balance, where total income equals total expenditure for each institution; and balance of payments, where savings equals investment. Once the equations have been specified and the data organized into the SAM, the next step in constructing the CGE model is to calibrate and replicate the model.

Data

The data for the SAM came primarily from the IMPLAN input-output regional modeling system (MIG 2002). A detailed description of how data is compiled by IMPLAN can be found in the IMPLAN Data Guide (Olson and Lindall 1999). IMPLAN constructs county level social accounts based on a variety of data sources including the U.S. Census Bureau, U.S. Bureau of Economic Analysis (BEA), ES-202 employment data. The procedure that IMPLAN uses to generate a SAM consists of two main components. The first is the national make and use transaction tables and the second is

the county specific data on industry output, employment, value added, and final demands. Final demands, in turn, consist of household, government, and export purchases. The national make and use transaction tables are based on the 1992 Benchmark Input-Output (92IO) study conducted by the BEA. This study estimated the amount of purchases each industry made from other sectors. An absorption table is then created by dividing each of the elements of the use matrix by the respective industry's total output. This yields the percent of each dollar of output spent on intermediate inputs from other sectors. A column, then, represents the industry's production function or the proportion of intermediate inputs used to produce one dollar of output. Because the absorption coefficients and subsequent production functions are based on national data, they will be identical for a given industry across all counties in the United States. This means that a given industry on the East Coast and on the West Coast will use the same inputs in the same proportions to make a dollars worth of output. Additionally, a production function will vary due to different levels of aggregation used in the model.

The actual industry mix, or the size of each industry in a region, is specific to the study area. IMPLAN uses county specific ES-202 data, county business patterns data from the U.S. Census Bureau, Bureau of Labor Statistics, and REIS data to estimate employment for every sector in the region. Value-added components such as employee compensation, proprietor's income, and other property income are derived from National Income and Product Accounts data from the BEA. Estimates of total industry output primarily come from the BEA's output series and from the Annual Survey of Manufactures.

Data on land and water were not obtained from IMPLAN. Data for land values was taken primarily from the Colorado Assessed Values 1991-2004 Report published by the Colorado Division of Property Taxation. This report lists the assessed value of land for every county in Colorado by land use type. The report lists nine categories of land use: residential, commercial, industrial, vacant, agricultural, natural resources, mining, oil and gas, and state assessed. The sum of each of these categories was totaled across the 16 counties in the study. The values given by the Colorado Division of Property Taxation represent assessed stock values of land. These values need to be annualized to be used in a CGE model. A simple 10% conversion of the stock value to an annualized flow value was employed. In the case that a sector (such as commercial) needed to be further broken down to match the industries used in the CGE, the relative size of the industry was used to scale the figure given by the Colorado Division of Property Taxation.

Data on land use was obtained from the 2002 Census of Agriculture and the 2002 Economic Census. The total acreage in each county of the study area and the proportion that is in pastureland and cropland was obtained from the 2002 Census of Agriculture. The residual land that was not in agriculture was then divided up into the other sectors. Data from the State Assessors' Office indicated that roughly half of the value of non-agricultural land was in residential property. Based on the assumption that, on average, residential land is similar to but slightly less expensive than commercial land, just under 50% of the total acreage of non-agricultural land was put into residential property. The remaining acreage was divided up into the industrial and commercial sectors based on data on the number of establishments by 2 digit NAICS code for each county in the study

area was obtained from the 2002 Economic Census. Adjustments were then made to account for sectors that were relatively more land intensive or less land intensive.

Water data was obtained from the 2004 Cumulative Yearly Statistics of the Colorado Division of Water Resources published by the Colorado State Department of Natural Resources. Total water deliveries in the South Platte Basin by sector are published annually and were incorporated into the model. The value of water was then based on an average lease rate of \$195 per acre foot of water and an average municipal water price of \$1.91 per thousand gallons of water. In this CGE model, water was only used as a primary factor by agriculture and by municipal water providers. The municipal water provider sector used raw water to create an output called municipal water that was then used by other sectors and by households.

Similarly, according to Data from the 2004 Cumulative Yearly Statistics of the Colorado Division of Water Resources from the State Department of Natural Resources in 2002 there were a total of 3,248,984 acre feet of water supplied in the basin. Of this, 1.5 million acre feet went to agriculture. When looking at consumptive water use, agriculture accounts for closer to 90% of total water use. Water values were assigned based on an average lease rate in the basin of \$195 per acre foot for agricultural land and a municipal water rate of \$1.91 per thousand gallons of water.

For the non agricultural land, the 1,632,925 acres were divided up based on the value of land estimated above. This yielded estimates of land values per acre in agricultural and nonagricultural lands that were vastly different while estimates of land values per acre used between nonagricultural sectors were similar. It was also found that

of the nonagricultural land, roughly half of the land use and value was in residential property.

Colorado Model

The model used in this study is based on the Washington State regional computable general equilibrium modeling system developed by David Holland, Leroy Stodick and Stephen Devadoss. The model they developed was based, in turn, on a model by Hans Lofgren (2003).

The bulk of the structural equations used in this model are borrowed from the Washington State model with specific equations added or altered to better reflect water and land as primary factors of production.

The elements of the full model used in this study are presented in Appendix 1. The contribution of this study was to add water and land as primary factors of production to the existing model and to analyze the effects of population growth. For the purposes of this study, some key assumptions were specified in the model:

- 1) The exchange rate between the foreign currency and domestic currency is fixed at base year conditions. This is due to the Platte River basin of Colorado being small enough that internal changes will not be sufficiently large to affect the relative value of the dollar on the global market.
- 2) Capital is considered to be mobile and the supply is variable. This assumption seems reasonable as industries are able to purchase capital from local, domestic, and international sources as needed.
- 3) Labor is considered to be mobile and the supply is variable. It is assumed that industries can hire as much labor as is optimal for their production. The wage distortion factor, which makes labor more or less valuable to different sectors, is fixed at initial conditions.

- 4) Land is transferable between sectors but its total supply is fixed. This is a fairly straight forward assumption as land can be bought and sold, but new land can not be brought into the region.
- 5) Water is transferable between sectors but its total supply is fixed. Again, water can be transferred between sectors within the basin, but the amount of water within the basin in any given year is taken as an endowment. For the purpose of this study the total supply is fixed at 2002 levels.
- 6) The elasticity of substitution between factors of production are assumed to be lower for agricultural activities than they are for nonagricultural activities. This is because agriculture is limited in its ability to substitute land for water.
- 7) The Armington elasticity of transformation between local and imported commodities is assumed to be much higher for manufactured goods than for services.
- 8) The demand elasticity for factors of production is assumed to be dependent on their degree of local fixity. It is assumed that the elasticity for capital is very high, more moderate for labor, and low for land and water.

In the Platte River model, agricultural producers and municipal water providers are allowed to use water as a primary input. The municipal water sector, then, uses raw water to create a municipal water commodity that is used by other sectors and by households. If non-agricultural sectors are going to use more water they must get it from the municipal water sector which must, in turn, compete with agriculture for the fixed supply of raw water.

Land is modeled as a primary factor that is used by all sectors and by households. Producing sectors use land to the point where the marginal value product equals the price of land. Therefore, any expansion of a sector will require that sector to purchase more land, however, land is relatively more valuable to some sectors than to others and an expansion will result in a relatively higher demand for land.

Households use land through a producing sector called 'owner occupied dwellings'. This sector takes land, construction, and materials to produce housing. This

housing is then demanded by households. The owner occupied dwellings sector is then demanded by households.

Population growth in this model is tied to growth in the labor supply. On average there are 1.46 people per employee in the basin. This ratio is slightly lower than it is in Colorado as a whole (1.51) and significantly lower than it is in the entire United States (1.73). As labor increases, population is modeled to increase linearly by 1.46 people per laborer. Additionally, an increase in labor income increases household income. This increase in household income, then, increases the demand for the owner occupied dwelling sector. This, in turn, increases the demand for land from housing. These constitute the primary modifications that were made to the baseline model for the purposes of this study.

The initial version of this model included only one unified labor market. It was discovered, however, that this feature of the model created some unrealistic scenarios. For example, when the labor supply was exogenously shifted out, thereby simulating an increase in population through exogenous migration, the price of all labor declined. This lowered the cost of production for labor intensive sectors such as the food processing sector and they expanded production significantly. Additionally, the original model included only one livestock sector which included both feedlots and cattle ranching. An increase in the food processing sector, which demands inputs from the feedlots, had a large impact on the also on the entire livestock sector, including the ranching industry. The ranching industry is the single largest land user in the basin so an expansion of this sector creates a large demand for land. Therefore, through these interactions, the combined effects of the unified labor market, an aggregated livestock sector, and an

exogenous increase in the single labor supply resulted in large amounts of land being put into livestock production. This was not considered to be an accurate representation of the economic relationships present in the basin. To resolve this issue, the unified labor market was disaggregated into three labor groups: 1) agricultural labor, 2) low services and non-technology manufacturing, and 3) high services and technological manufacturing. Additionally, the unified livestock sector was split into the feedlot sector and the ranching sector. This was found to more accurately represent the economic relationships in the South Platte River Basin.

Simulations

In order to examine the affects of economic and population growth on the region, a series of simulations were incorporated into the CGE model. The first simulation models the effect of increased population on the region that is tied to in migration from people wanting to live in a region with high natural amenities. This simulation is designed to mimic the natural amenity based of growth predicted by Power (1996) and Deller (2005), among others. In this model, laborers, especially young and highly educated laborers, are attracted to high amenity areas and move to the region exogenously (Franklin 2003) and look for jobs when they arrive. In this way, the growth in the labor market drives economic growth. The second simulates the economic growth preceding population growth. In this model it is the expansion of final demands of high growth industries that drives the economic growth. This, in turn, increases the demand for labor and therefore the population. The last simulates simultaneous growth in

population and in economic growth. The results and implications of all three of these simulations are then discussed.

SAM Results

The SAM that was constructed for the Platte River basin is presented in figure 4 and characterizes all the monetary transactions present in the region. The Colorado State Assessor reported that the total assessed value of land in these 16 counties was \$39.3 billion. Of this, 50% was in residential properties, 39% was in commercial property and 5% of the value was in industrial property (figure 5). According to IMPLAN data, the total value added, which comprises the gross regional product (GRP) of these counties, totaled \$155 billion in 2002 (figure 6). The information and information technology sector was the largest contributor to GRP, accounting for 12.4% of the total. Other large contributors include real estate (9.9%), professional services (8.9%), government services (8.7%), and manufacturing (8.2%). Agriculture, while still important in some communities, is estimated to contribute only 0.04% of the regions GRP.

Although agriculture is not a large contributor to GRP, it does control a great deal of the region's land and water. It was determined that roughly 86% of the 12,411,520 total acres in the region were in agriculture. This yields 10,778,595 agricultural acres and 1,632,925 nonagricultural acres. Of the acres in agriculture, 60% were estimated to be in crops and 40% in livestock. This yields 6,467,157 acres in cropland and 4,311,438 acres under livestock production (figure 7).

Although agriculture is not the dominant driver of the regional economy, it controls the two major fixed resources that are necessary for growth. Labor and capital

are mobile and can migrate to the region. Land is fixed and after all vacant or fallow land is put into production, the only way to acquire more is to buy it away from another sector. The annual endowment of water is stochastic in nature and the availability of this resource from year to year is not completely predictable. Regional planners can only use precipitation averages and past data to make an educated guess at how much water will be available for any give year.

Simulation Results

Simulation 1

The labor supply for the region that was obtained from IMPLAN was disaggregated to form three labor groups; agricultural labor, low-services and industrial manufacturing, and high-services and technology manufacturing. This disaggregation was performed to provide greater fidelity to data indicating that migration of labor to the high amenity areas of the West, such as the front range of Colorado, is highly comprised of young and highly educated laborers. The first simulation examined in this study induced a 10% increase in the population by exogenously shifting out the three labor supply curves (table 1). This total increase in labor amounted to just over 220,000 jobs added to the regional economy, with 57% of the exogenous shock taking place in labor group three (high services and technology manufacturing). The high service sector added almost 85,000 jobs while low services added over 35,000. Technological manufacturing added over 28,000 jobs. The exogenous increase in the labor supply was found to drive down the relative cost of labor in labor groups 1 and 3. In this simulation, the average real wage of labor for labor groups 1 and 3 decreased by 5.3% and 8.0% respectively,

while the real wage rate for labor group 2 remained constant. The reduction in overall labor costs creates an incentive for sectors to increase production because the cost of one of the primary factors of production has decreased. This expansion, however, is mediated by a limitation of two resources, land and water. The pressure for increased production due to lowered labor costs causes an upward pressure on the cost of other factors of production, capital, land, and water. In this model capital is not constrained so it can be easily imported into the region, and therefore the upward pressure on capital prices is modest. However, the supply of land and water are fixed in this simulation. In simulation one, the marginal cost of land increased just over 9% over the base model when the labor supply was exogenously increased. The average wage of water also increased in this scenario, but at a lower rate than that of land. The increase in the price of these inputs resulted in their marginal cost exceeding the marginal productivity for extensive crop production, thus driving these resources out of this sector. This resulted in a 1.3% decrease in the total water demand and a 1.0% reduction in land demand for agriculture.

Real net household income in this simulation increases for every household group, with the lowest 3 groups having the least increase in income. Although total household income increases, per capita household income decreases as household income does not keep pace with the population increase. This is due to the price of labor decreasing, thus decreasing a primary contributor to household income. As a whole, regional gross domestic product increased over 8% in real terms.

Simulation 2

The second simulation starts with economic growth as the primary driver of population growth, with the increase in economic activity demanding more labor, which then increases the population. This simulation increased the export demands for high growth sectors such as manufacturing, technology, oil and gas, and services. A summary of the results of this simulation are presented in table 2. In this simulation the 10% growth in population that the state demographer's office estimates will occur in this region over the coming decade was spurred by a 23% shift in the export demand for these high growth commodities and a 13% efficiency gain in the manufacturing sector. These two assumptions resulted in expansion of the level of output in nominal terms for every sector and real growth in every sector except extensive agriculture. After accounting for the 7.4% increase in the CPI, aggregate agricultural output was flat while total output level across all activities grew by 16.6%. The sectors that experienced the greatest growth were the manufacturing and oil and gas sectors, not surprisingly given the exogenous shocks used in this simulation.

As a whole, agriculture experienced a 5% reduction in water demand in this simulation, transferring a total of 38,700 million gallons out of extensive crop production. However not every component of the agricultural industry reduced water demand. Intensive agriculture and livestock production water use increased slightly, up 1,900 and 200 million gallons respectively. The remaining water taken out of agriculture went to municipal water districts which then redistributed it to the remaining sectors. Municipal water demand was up 37,400 million gallons.

Similarly, land demand for all of agriculture decreased 1.3%, or just under 99,000 acres. Again, most of the decrease came from extensive agriculture, with intensive agriculture adding 30% more acres and livestock adding 4.7% more acres. Of the 99,000 acres that transferred from agricultural to non-agricultural uses, 83,800 acres were put into residential development.

In this simulation, real wages increased 4%, while the real aggregate land price increased by over 18%. The price of capital and water actually decreased slightly in real terms over this simulation. The decrease in capital is relatively straight forward to explain. Capital, in this model, is easy to import and therefore if the local price increases by more than the import price, capital will simply be brought in from outside the region. So as other prices in the region increase and drive up the CPI, the increase in the price of capital is constrained by the ability to import capital.

Likewise, the price of water increased in nominal terms, but decreased by 1.7% in real terms. This is likely due to the large supply of relatively low value water in agriculture. Agriculture can release a relatively small percentage of its water and easily meet the demand of other users. Therefore, increased demand from high growth sectors in the economy can be easily met by relatively low value water from agriculture. In this way the supply of water, while fixed in absolute terms, is easily available for sectors that demand it. In reality, the transfer of water from agriculture to other uses, even in the same basin, experiences far more friction in the economy than is modeled here. An extension of this model could be to make the transfer of water more difficult and examine the effects.

Simulation 3

The last simulation examined a simultaneous increase in the labor supply and an economic expansion. The labor supply increase is spurred in the same manner as simulation 1 and the economic expansion is spurred in the same manner as in simulation 2. The magnitudes of the respective shocks are scaled back to obtain the desired 10% increase in population. In real terms, the total level of economic activity in the region expanded by 9% in this simulation with GDP similarly increasing by 10% (table 3). The technology and manufacturing sector was again, not surprisingly, found to be most impacted by this shock. Agriculture as a whole was found to increase in economic activity with extensive agriculture losing almost \$26 million in total sales, but intensive agriculture increasing \$24 million and the livestock sector increasing \$88 million dollars in total sales. Again, much of the gains in the livestock sector are an artifact of the impact of decreased wage rate which, in turn, expands the food processing sector.

In this simulation, agriculture as a whole loses an estimated 2% of its land or 163,000 acres. However, within this reduction extensive agriculture loses 237,000 acres but intensive agriculture increases land use by 1,100 acres and livestock increases 81,000 acres. Non-agricultural industrial and commercial sectors are expected to add 51,800 acres and housing is estimated to demand an additional 110,000 acres.

Agriculture is expected to transfer roughly 4.5% of its water to the non-agricultural sectors in this simulation. Again, however, only extensive agriculture is expected to reduce water use, transferring an estimated 35,400 million gallons to other uses. Extensive agriculture is expected to increase water use by 510 million gallons. As

a whole, agriculture is expected to transfer 35,000 million gallons of water to municipal uses to meet the demands of the growing economy and population.

Overall Conclusions

The results of this study provide further evidence to the conclusions made in the previous chapter, that a complex force of economic factors will lead to land being transferred out of commodity agricultural production and into sectors that can generate higher returns per unit of land. This study goes on to predict that a similar trend will be seen in water transfers.

These simulations indicate that economic growth in Colorado will, in equilibrium, create a pull on land and water and will take them out of extensive agriculture and into other sectors in the economy. What may mediate this, however, is a rise in the food manufacturing sector, which now purchases a great deal of livestock from the local agricultural sector, and an increased demand for local vegetables. An increase in the level of output of the food manufacturing sector creates a great deal of local demand for local feedlots which, in turn, creates a large demand on land. Similarly, an increase in population creates an increased demand for agricultural goods. According to the data used in this study, high value produce and specialty crops are purchased locally at a higher rate than are commodity crops. Therefore the population increases will have a greater effect on the intensive agricultural crop production sector than on the extensive crop sector, which sells its output on an even more global market. While the direct marketing of agricultural goods is increasing (Thilmany and Watson 2004), according to Economic Census data, the total value of shipments in the food processing sector

decreased in real terms from 1997 to 2002. Therefore it is reasonable think that the intensive agricultural crop sector will continue to grow with the increase in population while the livestock, feedlot, and food processing sector likely will not.

A consistent finding across the simulations was that, depending on how the growth is modeled, a 10% growth in the population and the corresponding economic expansion is expected to result in roughly 2% to 4% of the water that is currently in agriculture to be transferred to other sectors. This amounts to a transfer of roughly 200,000 to 380,000 million gallons of water. Having agriculture lose 2% to 4% of its water, while not insignificant, does not spell wholesale disaster for agriculture in the basin. In fact, only extensive crop production is expected to lose water in any of the simulations. In real terms, the total value of agricultural production is actually expected to increase by 1.5%, 7.3%, and 4.3% in the three simulations respectively.

The consistent finding for land use is that agriculture will lose around 1% to 2% of its land while the other industrial and commercial sectors will increase land use a total of 2% to 3% and housing land use will increase an estimated 4% to 5%. Again, this finding masks the finding that extensive agriculture is expected to decrease land use by 7% to 8% while intensive agriculture is expected to increase land use by an estimated 20% or over 1,000 acres. Likewise, livestock production is likely to increase in all simulations.

In simulation 3, where population growth is spurred by both economic expansion in growth industries and exogenous growth in the labor supply, intensive agriculture is expected to increase their demands for water by 13% or 670 million gallons and livestock production is expected to increase water demands by 8% or 200 million gallons. This

simulation is expected to represent the most likely scenario. The extensive agricultural sector is expected to decline, however, intensive agriculture is expected to increase in real terms by 13% and livestock production is expected to increase by 7%. Rather than being a serious threat to agriculture, population growth and economic expansion represent, in real terms, a 4% increase in the value of output in the aggregate agricultural sector.

Conventional wisdom often assumes that the decrease in water to agriculture will necessarily result in a net loss in total receipts in the agricultural sector. This, however, is not necessarily the case. The results of this study support the findings of other studies (Landry 1998) that the reduction in agricultural water use does not have a negative effect on total agricultural sector profitability. Nominal and real agricultural output is expected to increase in this study. Figure 8 shows the relationship between the percent in irrigated acres and gross agricultural crop values in the Western United States. It is clear that gross crop revenues have remained relatively stable or increased from 1988 to 1999, while the percent change in irrigated acres is becoming increasingly negative. Overall, the total quantity of agricultural activity is expected to increase over the coming decade. In every simulation examined in this study, output of the aggregate agricultural sector increased as water was transferred out of the sector. The results of this study support this finding, indicating that although extensive agriculture is expected to decrease over time, intensive agriculture and livestock production are likely to increase. Extensive agriculture is expected to decline by about 6%, however, the increases to extensive agricultural production and livestock production are expected to more than offset these losses.

This decrease in the output from extensive agriculture corresponds to an overall expansion in the regional economy in all simulations. GRP, in real terms, increased in both simulations 2 and 3 by 15.5% and 14.5%, respectively. Although the losses to extensive agriculture will likely be offset by gains in other agricultural and non-agricultural sectors, there are many communities which will be severely and adversely affected by the decline of extensive agriculture. When a farmer sells their water right, they are compensated in the form of payments they receive for the water. The local community that has for decades depended on the revenue from agriculture faces the highest risk of losing out in these scenarios. The local fertilizer supplier depends on farming operations and the revenues from agriculture for their existence. Likewise, the local diner and hardware store depend on the farmer's revenue for their patronage. These types of operations are likely to be adversely affected by the loss of extensive agricultural operations in communities that are dependent on extensive agriculture for their economic base. The solutions to this problem are complex and beyond the scope of this study. The results of this study, however, do indicate that the gains from the transfer of water out of extensive agriculture are sufficiently large to warrant investigation of how to facilitate that transfer and mediate third party impacts to communities.

An implication of the findings of this and the previous chapters is that commodity crop programs may serve to keep land and water under extensive crop production regimes in areas where economic forces indicate that these resources should be moving out of commodity crop production. Government farm programs described in the Federal Agricultural Improvement and Reform legislation (farm bill) affect agricultural sector returns in two primary capacities: 1) They increase the expected returns to farming

program crops and 2) They reduce the risk (variance in returns) associated with growing program crops (Gray et al. 2004). As seen in the previous chapter, the expected returns to agricultural operations is the primary component to the economic gravitational forces that act upon agricultural producers. The artificial boosting of these expected returns, therefore, distorts the forces that attract producers and make land and water more desirable to the production of commodity crops than it should otherwise be. Despite the economic benefits of freeing up land and water to move from low return endeavors like commodity crop production (such as increased regional GDP and personal incomes), these resources are artificially being kept in extensive production by government programs that support program crop prices.

One potential solution to this is the increased implementation of the Environmental Quality Incentives Program (EQIP), which was reauthorized in the 2002 Farm Bill. This program provides assistance to farmers who wish to increase irrigation efficiencies, thus freeing up water to move to other uses. The potential gains to regional GDP (\$3.15 billion for the 4% transfer projected in this study) from allowing this transfer would more than make up for the cost of subsidizing the farmer's technology adoption.

Future Research

The results of this study raise the prospects for future research. Further investigations would include adding multiple labor categories to the model. Although the model presented here allows for activity specific wage distortion factors, the labor itself is homogeneous and new labor entering the economy is simply allocated to the activity that has the greatest demand for it. In simulations 1 and 3, the exogenous increase in the

labor supply was shown to be allocated to sectors that had the highest marginal value for labor. This resulted in an increase in labor usage by the food processing sector and a corresponding increase in output from that sector. Because of the internal linkages between this sector and the livestock sector and because of the extensive use of land by the livestock sector, even a modest increase in the food processing sector resulted in a large expansion of land in the basin devoted to livestock. The ability to exogenously shift a specific component of the labor market and not the labor market as a whole may be a more realistic approach to this study.

Another aspect of this study that could be improved is the addition of friction or a tax to the water transfer market. Even within a watershed, the transfer of water between users is not completely without friction. It was proven that the transfer will not harm downstream holders of water rights and a mechanism for transferring the water from the buyer to the seller must be in place. One way to model this friction would be to incorporate a tax on water transfers. This tax could proxy both the actual cost of moving the water from one user to another and the potential compensation that may be levied to mediate the economic impacts of the transfer on third-parties.

Lastly, the way that land and water are related to each other in this model is an obvious over simplification. Land and water are in some ways a compliment and in some ways a substitute. On a given isoquant of output for an agricultural operation, water can be decreased by adding more land or water can be added and less land used. This can be thought of as the ability to use more water on less land for intensive agricultural production of vegetables or using less water on more land for extensive production of field crops such as feed corn. Therefore, in this way land and water are substitutes.

However, if extensive agriculture and intensive agriculture are seen as separate enterprises, and an agricultural operation can not switch between the two outputs, then land and water are compliments. Output of vegetables can not be increased by adding more land and less water. One way to incorporate this into the CGE model is to allow agriculture to produce different outputs based on relative values, and the different relative prices of inputs.

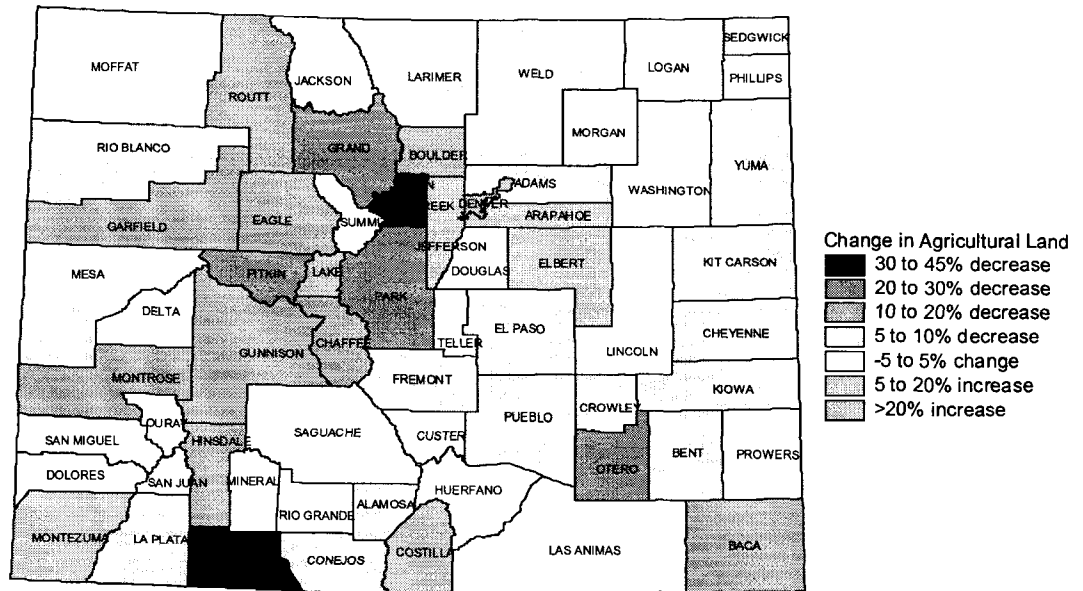


Figure 1 - Agricultural Land Conversion 1987 – 1997. Source: Colorado Dept of Agriculture, National Agricultural Statistics Service (USDA), Natural Resources Conservation Service (USDA)

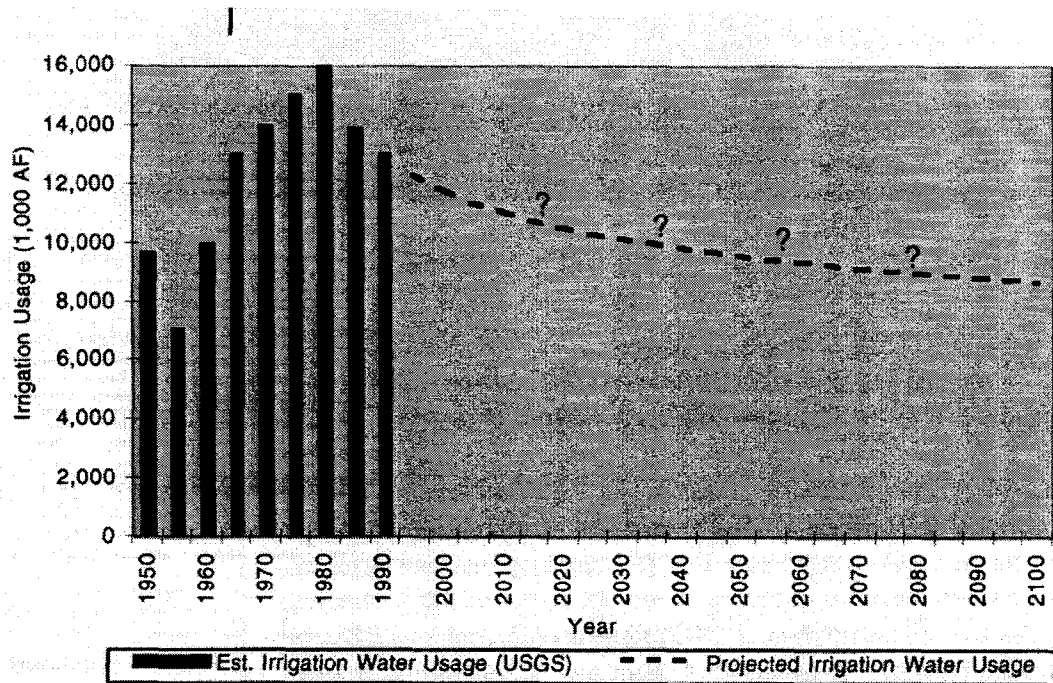


Figure 2 – Projected Agricultural Water Use. Source: Colorado Farm Bureau, Colorado Water Development Study, 1997

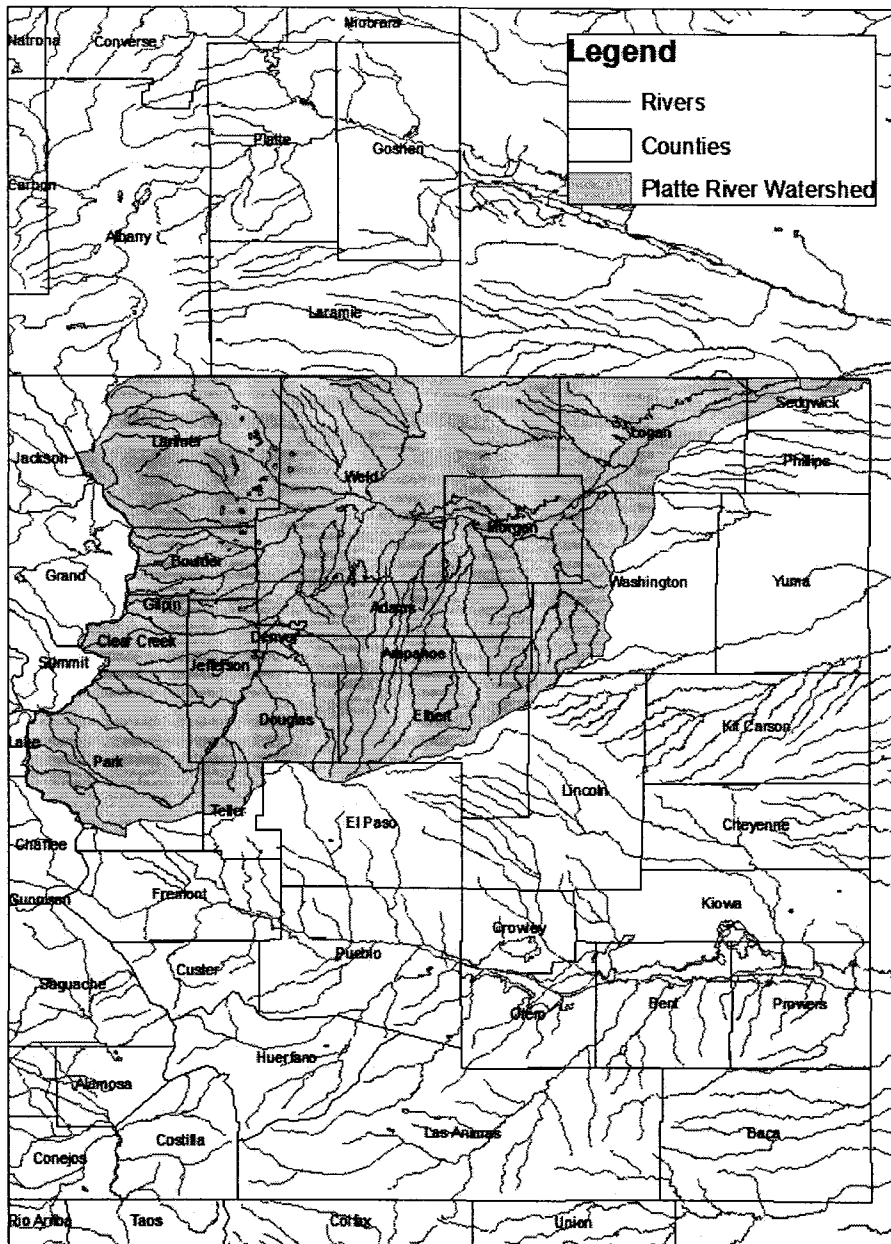


Figure 3 - Colorado's South Platte River basin

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | |
|-------------|--------|--------|----------|-------|-------|-----------|----------|--------|----------|-----------|----------|----------|-----------|-----------|-----------|-----------|----------|--------|--------|----------|--------|--------|-----------|----------|----------|----------|-----------|----------|------|
| 1 AGREX-A | | | | | | | | | | | | | | | | | | 483.84 | | | | 4.54 | | | | | | 1.73 | |
| 2 AGRIN-A | | | | | | | | | | | | | | | | | | | 245.48 | | | 1.07 | | | | | | 0.38 | |
| 3 AGRIS-A | | | | | | | | | | | | | | | | | | | | 1,063.50 | 0.45 | 8.95 | | | | | | 5.77 | |
| 4 AGRNR-A | | | | | | | | | | | | | | | | | | | 0.06 | | 34.85 | 0.01 | | | | | | 0.00 | |
| 5 AGRSP-A | | | | | | | | | | | | | | | | | | | | | | 92.15 | | | | | | | |
| 6 CONST-A | | | | | | | | | | | | | | | | | | | | | | | 20,649.10 | | | | | | |
| 7 UTIL-A | | | | | | | | | | | | | | | | | | | | | | | | 3,573.13 | | | | 2.79 | |
| 8 WAT-A | | | | | | | | | | | | | | | | | | | | | | | | | 625.55 | | | | |
| 9 REC-A | | | | | | | | | | | | | | | | | | | | | | | | | | 2,416.57 | | | |
| 10 TRAD-A | | | | | | | | | | | | | | | | | | | | | | | | | | | 26,242.28 | | |
| 11 MIN-A | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5,287.84 | |
| 12 FOOD-A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 13 MAN-A | | | | | | | | | | | | | | | | | | | | | | | | 0.01 | | | | 10.57 | |
| 14 PROSER-A | | | | | | | | | | | | | | | | | | | | | | | | | | 0.26 | 0.46 | | |
| 15 OTRSER-A | | | | | | | | | | | | | | | | | | | | | | | | | | 0.04 | 2.17 | 15.67 | |
| 16 MISC-A | | | | | | | | | | | | | | | | | | | | | | | | 89.72 | 600.09 | 9.20 | 63.32 | | |
| 17 OOC-A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 18 AGREX-C | 15.60 | 0.08 | 260.70 | | | 33.00 | 0.00 | 0.32 | 0.65 | 0.02 | | 99.67 | 28.81 | 1.73 | 15.42 | 0.00 | 2.76 | | | | | | | | | | | | |
| 19 AGRIN-C | 0.19 | 4.05 | 1.68 | | 3.42 | 4.97 | 0.01 | | 1.30 | 0.47 | 0.01 | 71.32 | 2.58 | 2.26 | 70.70 | 0.32 | 0.50 | | | | | | | | | | | | |
| 20 AGRIS-C | | | 172.29 | 0.01 | 3.38 | | | | 1.25 | | | 1,635.22 | 0.23 | 0.72 | 14.95 | 0.00 | | | | | | | | | | | | | |
| 21 AGRNR-C | | 0.03 | | 11.84 | 0.16 | | | | 0.05 | 0.01 | 0.00 | 5.87 | 38.70 | 0.59 | 39.68 | 0.08 | | | | | | | | | | | | | |
| 22 AGRSP-C | 40.64 | 11.08 | 47.56 | 5.04 | | | | | | | | | | 20.90 | | | | | | | | | | | | | | | |
| 23 CONST-C | 1.67 | 0.45 | 4.74 | 0.28 | 0.22 | 26.47 | 67.30 | 7.67 | 28.10 | 81.62 | 0.44 | 11.02 | 69.06 | 507.81 | 249.66 | 96.07 | 110.03 | | | | | | | | | | | | |
| 24 UTIL-C | 5.10 | 2.78 | 27.62 | 0.21 | 0.41 | 98.65 | 0.39 | 3.27 | 48.09 | 292.64 | 79.60 | 111.40 | 330.60 | 910.01 | 550.08 | 66.59 | | | | | | | | | | | | | |
| 25 WAT-C | 5.99 | 1.02 | 5.12 | 0.01 | | 16.04 | 16.47 | 0.24 | 9.27 | 18.90 | 4.52 | 0.83 | 1.04 | 113.79 | 89.14 | 27.10 | | | | | | | | | | | | | |
| 26 REC-C | 0.05 | 0.03 | 0.27 | 0.03 | 0.39 | 7.92 | 0.67 | 0.17 | 72.84 | 18.43 | 5.05 | 6.87 | 18.53 | 66.56 | 184.81 | 1.12 | | | | | | | | | | | | | |
| 27 TRAD-C | 21.25 | 5.84 | 62.84 | 0.95 | 3.47 | 2,460.95 | 19.16 | 27.86 | 28.21 | 596.43 | 65.15 | 553.05 | 1,707.67 | 724.23 | 1,533.49 | 64.29 | 179.21 | | | | | | | | | | | | |
| 28 MIN-C | 1.34 | 0.08 | 0.30 | 0.01 | 0.01 | 133.20 | 490.39 | 0.18 | | | 731.50 | 2.44 | 751.95 | 3.79 | 18.99 | 25.43 | 5.83 | | | | | | | | | | | | |
| 29 FOOD-C | 0.12 | | 13.24 | 0.04 | 0.02 | | | | 7.95 | 2.28 | | 654.94 | 115.87 | 53.79 | 934.61 | 4.31 | | | | | | | | | | | | | |
| 30 MAN-C | 68.59 | 12.42 | 179.81 | 1.10 | 6.60 | 5,211.82 | 94.36 | 134.46 | 79.95 | 684.77 | 295.65 | 921.94 | 7,498.05 | 2,138.17 | 3,965.13 | 280.47 | 209.47 | | | | | | | | | | | | |
| 31 PROSER-C | 67.37 | 10.35 | 145.72 | 0.96 | 7.39 | 1,835.17 | 144.35 | 65.08 | 357.46 | 3,306.03 | 388.24 | 596.73 | 2,421.48 | 16,217.57 | 6,497.02 | 496.09 | 1,168.99 | | | | | | | | | | | | |
| 32 OTRSER-C | 14.47 | 3.56 | 49.38 | 1.12 | 1.99 | 1,463.55 | 253.37 | 55.62 | 280.11 | 1,799.54 | 752.42 | 496.33 | 1,592.95 | 6,725.84 | 9,936.09 | 268.51 | 131.60 | | | | | | | | | | | | |
| 33 MISC-C | 0.49 | 0.28 | 3.16 | 0.02 | 0.00 | 63.66 | 2.10 | 1.32 | 10.92 | 119.61 | 12.28 | 56.96 | 306.62 | 509.58 | 767.50 | 57.66 | 135.91 | | | | | | | | | | | | |
| 34 OOC-C | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 35 LAB | 36.07 | 69.74 | 92.45 | 1.59 | 45.05 | 6,378.54 | 418.76 | 9.42 | 948.29 | 10,428.76 | 679.96 | 1,142.14 | 6,827.60 | 25,367.75 | 15,841.63 | 12,705.01 | | | | | | | | | | | | | |
| 36 CAP | 14.42 | 108.50 | 4.94 | 3.07 | 14.62 | 2,731.70 | 1,715.65 | 171.94 | 405.11 | 4,732.78 | 2,168.31 | 1,097.74 | 2,783.21 | 20,857.15 | 15,098.71 | 989.98 | 4,597.42 | | | | | | | | | | | | |
| 37 LAND | 14.00 | 4.00 | 4.50 | 4.00 | 1.00 | 54.63 | 34.31 | 2.44 | 12.14 | 141.81 | 75.00 | 21.95 | 55.66 | 624.97 | 452.42 | 29.66 | 1,934.00 | | | | | | | | | | | | |
| 38 WAT | 149.00 | 9.00 | 0.50 | 4.00 | 0.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | | | | | | | | |
| 39 IND | 13.74 | 3.85 | 32.15 | 0.49 | 1.03 | 108.63 | 341.62 | 6.86 | 173.90 | 4,018.16 | 421.11 | 560.49 | 196.76 | 2,877.68 | 2,582.50 | 1.23 | 1,297.24 | | | | | | | | | | | | |
| 40 HHD1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 41 HHD2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 42 HHD3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 43 HHD4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 44 HHD5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 45 HHD6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 46 HHD7 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 47 HHD8 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 48 HHD9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 49 FGOVND | | | | | | | | | | | | | | | | | | 2.84 | | | 0.45 | | | | | | | 4.70 | |
| 50 FGOVD | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 51 FGOVI | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 52 SGOVNE | | | | | | | | | | | | | | | | | | | | | 2.28 | 3.18 | 9.86 | | | | 49.37 | 1.96 | |
| 53 SGOVE | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 54 SGOVI | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 55 INV | | | | | | | | | | | | | | | | | | | | | 2.82 | | | | | | | | 0.23 |
| 56 FT | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 57 DT | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SUM | 470.12 | 246.93 | 1,108.96 | 34.77 | 92.15 | 20,649.10 | 3,598.92 | 636.66 | 2,465.59 | 26,242.28 | 5,679.25 | 8,047.93 | 24,717.38 | 77,724.71 | 58,843.13 | 15,004.12 | 9,771.16 | 817.02 | 753.11 | 1,949.21 | 195.04 | 212.32 | 20,649.10 | 4,710.61 | 1,336.43 | 2,848.74 | 28,062.91 | 6,576.00 | |

| | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | SUM |
|------|------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|------------|
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 470.12 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 246.63 |
| 0.29 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1,108.96 |
| | 0.05 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 34.77 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 92.15 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 20,649.10 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3,588.82 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 838.88 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2,485.59 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 26,242.28 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5,879.25 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 8,047.63 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 24,717.38 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 77,724.71 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 58,843.13 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 15,004.12 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 9,771.16 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 817.02 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 753.11 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1,949.21 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 195.04 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 212.32 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 20,649.10 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 4,710.81 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1,336.43 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2,848.74 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 28,062.91 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 6,578.00 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 11,778.99 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 55,003.74 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 102,736.57 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 17,722.35 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 80,992.77 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 57,495.24 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3,466.50 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 312.50 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 12,637.23 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2,880.12 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2,499.29 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 5,837.65 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 8,167.99 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 16,892.95 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 30,228.16 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 24,997.55 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 28,965.87 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 22,848.96 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 58,894.99 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 11,137.96 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 81,313.12 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 81,313.12 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 81,313.12 |

Figure 1 - Social Accounting Matrix for the Platte River Basin

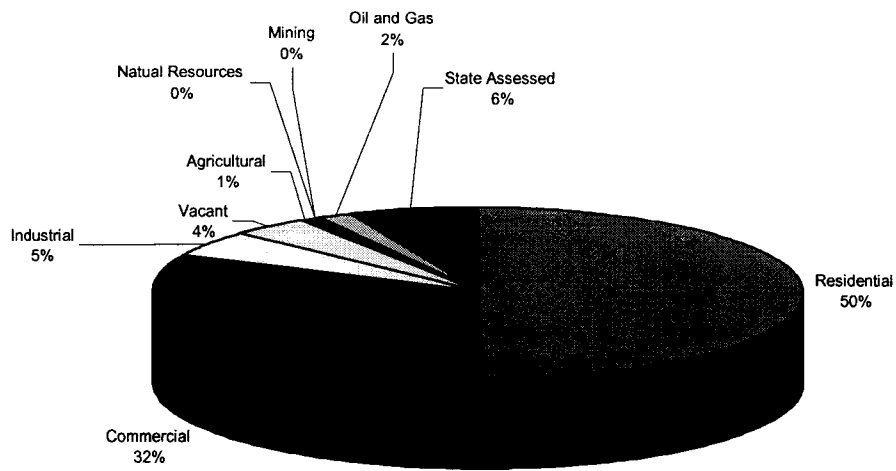


Figure 5 - 2002 Assesed Land Values for the Platte River Basin in Colorado by Land Type (\$39.3 billion total Assesed Land Value in Basin)

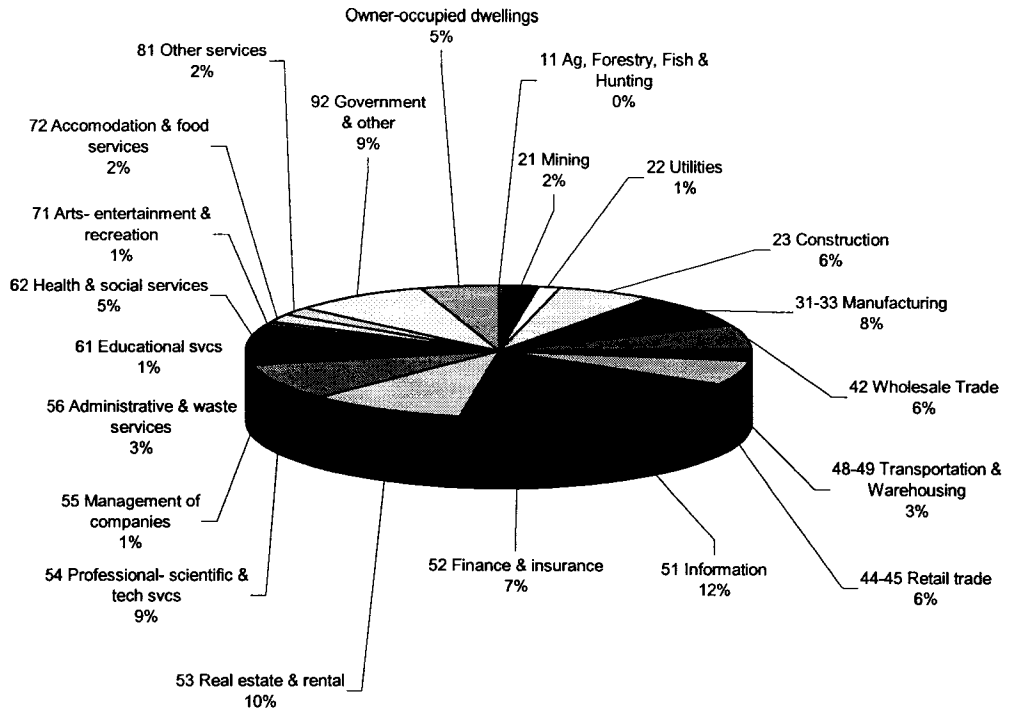


Figure 6 - Total Value Added (GRP) by 2 digit NAICS Sector of the 16 Counties Comprising the Platte River Basin for 2002 (1.55 billion total GRP) – Source: IMPLAN

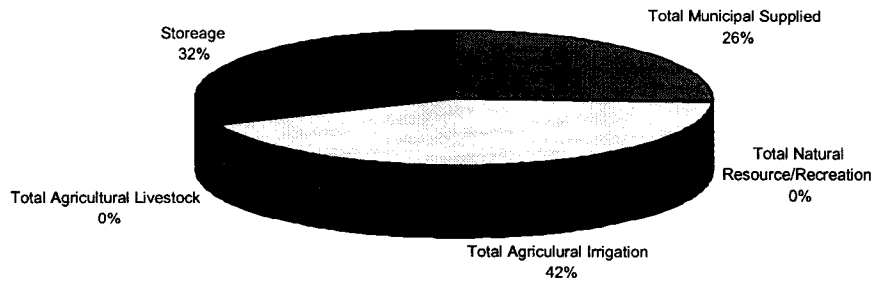


Figure 7 – Platte River Basin Water Deliveries by Use in 2002 (3,284,984 total acre-feet delivered)

Simulations: Output in million dollars, land in 100 acres, water in 100 million gallons

Table 1 - Exogenous population (labor) growth drives economic base growth

| Value of Output | Base | Simulation | Difference | % Diff - Nominal | % Diff - Real |
|-------------------------------|------------|------------|------------|------------------|---------------|
| Agricultural Sectors | 1,966.08 | 1,945.99 | -20.09 | -1.02 | 1.48 |
| Non-Agricultural Sectors | 246,490.34 | 263,282.28 | 16,791.94 | 6.81 | 9.32 |
| Housing | 9,771.16 | 10,162.54 | 391.37 | 4.01 | 6.51 |
| Total | 258,227.59 | 275,390.80 | 17,163.21 | 6.65 | 9.15 |
| Land Demand | | | | | |
| Agricultural Sectors | 74,523.00 | 73,744.50 | -778.50 | -1.04 | -1.04 |
| Non-Agricultural Sectors | 15,741.00 | 16,044.81 | 303.81 | 1.93 | 1.93 |
| Housing | 23,063.00 | 23,537.69 | 474.69 | 2.06 | 2.06 |
| Total | 113,327.00 | 113,327.00 | 0.00 | 0.00 | 0.00 |
| Water Demand | | | | | |
| Agricultural Sectors | 7,775.00 | 7,670.61 | -104.39 | -1.34 | -1.34 |
| Municipal Water | 3,223.00 | 3,327.39 | 104.39 | 3.24 | 3.24 |
| Total | 10,998.00 | 10,998.00 | 0.00 | 0.00 | 0.00 |
| Gross Domestic Product | | | | | |
| GDP | 154,904.24 | 163,953.56 | 9,049.32 | 5.84 | 8.35 |

Table 2 - Exogenous economic base growth drives population (labor) growth

| Value of Output | Base | Simulation | Difference | % Diff - Nominal | % Diff - Real |
|-------------------------------|------------|------------|------------|------------------|---------------|
| Agricultural Sectors | 1,966.08 | 2,253.34 | 287.26 | 14.61 | 7.23 |
| Non-Agricultural Sectors | 246,490.34 | 306,600.03 | 60,109.69 | 24.39 | 17.01 |
| Housing | 9,771.16 | 11,406.20 | 1,635.03 | 16.73 | 9.35 |
| Total | 258,227.59 | 320,259.57 | 62,031.98 | 24.02 | 16.64 |
| Land Demand | | | | | |
| Agricultural Sectors | 74,523.00 | 73,535.96 | -987.04 | -1.32 | -1.32 |
| Non-Agricultural Sectors | 15,741.00 | 15,890.25 | 149.25 | 0.95 | 0.95 |
| Housing | 23,063.00 | 23,900.79 | 837.79 | 3.63 | 3.63 |
| Total | 113,327.00 | 113,327.00 | 0.00 | 0.00 | 0.00 |
| Water Demand | | | | | |
| Agricultural Sectors | 7,775.00 | 7,385.74 | -389.26 | -5.01 | -5.01 |
| Municipal Water | 3,223.00 | 3,612.26 | 389.26 | 12.08 | 12.08 |
| Total | 10,998.00 | 10,998.00 | 0.00 | 0.00 | 0.00 |
| Gross Domestic Product | | | | | |
| GDP | 154,904.24 | 190,379.31 | 35,475.06 | 22.90 | 15.52 |

Table 3 - Simultaneous growth in labor supply and economic base output

| Value of Output | Base | Simulation | Difference | % Diff - Nominal | % Diff - Real |
|-------------------------------|------------|------------|------------|------------------|---------------|
| Agricultural Sectors | 1,966.08 | 2,166.79 | 200.71 | 10.21 | 4.34 |
| Non-Agricultural Sectors | 246,490.34 | 300,813.69 | 54,323.35 | 22.04 | 16.17 |
| Housing | 9,771.16 | 11,233.60 | 1,462.44 | 14.97 | 9.09 |
| Total | 258,227.59 | 314,214.08 | 55,986.49 | 21.68 | 15.81 |
| Land Demand | | | | | |
| Agricultural Sectors | 74,523.00 | 72,897.59 | -1,625.41 | -2.18 | -2.18 |
| Non-Agricultural Sectors | 15,741.00 | 16,259.30 | 518.30 | 3.29 | 3.29 |
| Housing | 23,063.00 | 24,170.11 | 1,107.11 | 4.80 | 4.80 |
| Total | 113,327.00 | 113,327.00 | 0.00 | 0.00 | 0.00 |
| Water Demand | | | | | |
| Agricultural Sectors | 7,775.00 | 7,425.50 | -349.50 | -4.50 | -4.50 |
| Municipal Water | 3,223.00 | 3,572.50 | 349.50 | 10.84 | 10.84 |
| Total | 10,998.00 | 10,998.00 | 0.00 | 0.00 | 0.00 |
| Gross Domestic Product | | | | | |
| GDP | 154,904.24 | 186,394.02 | 31,489.78 | 20.33 | 14.46 |

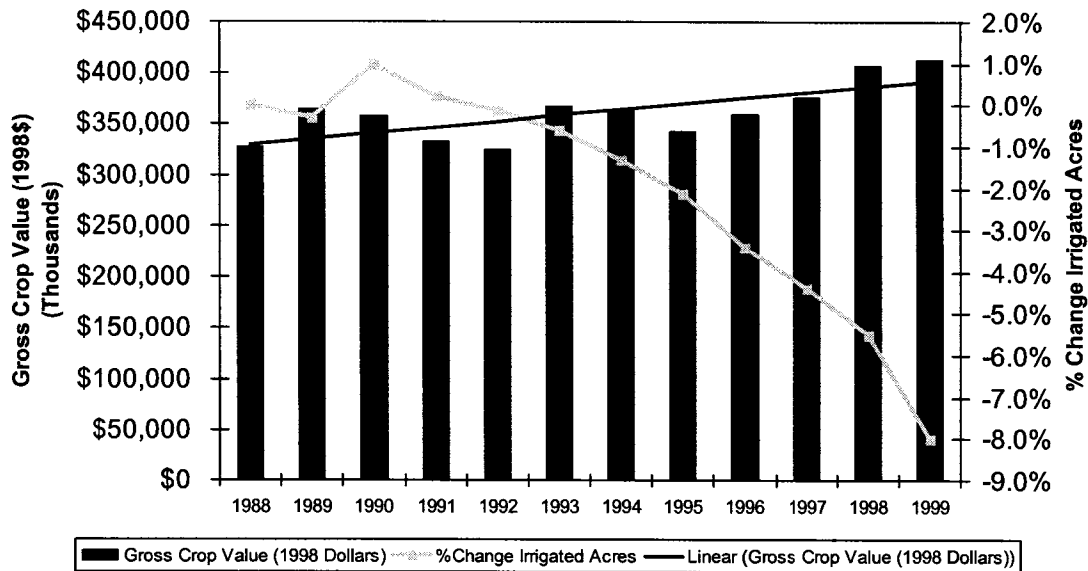


Figure 8 - The relationship between % change in irrigated acres and gross crop value from 1988 to 1999. Source: WestWater Research LLC – Wading into Water Markets.

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Appendix 1: Base Model – From Washington State Model

Index sets used in the model:

| | | |
|-----------------|---|---|
| A | – | activities |
| C | – | commodities |
| CM \subset C | – | commodities which have at least one source of imports (from ROW or from RUS or from both) |
| CE \subset C | – | commodities which have at least one destination for exports (to ROW or to RUS or to both) |
| CNM \subset C | – | commodities which are not imported |
| CNE \subset C | – | commodities which are not exported |
| CM1 \subset C | – | commodities which have exactly one import source |
| CE1 \subset C | – | commodities which have exactly one export destination |
| CM2 \subset C | – | commodities which are imported from both sources |
| CE2 \subset C | – | commodities which are exported to both destinations |
| F | – | factors of production and indirect business taxes |
| FF \subset F | – | factors of production |
| I | – | institutions |
| H \subset I | – | households |
| G \subset I | – | government units |
| HG \subset I | – | households and government units |
| FG \subset G | – | federal government units |
| SG \subset G | – | state government units |
| T | – | trading regions (FT: rest of world, DT: rest of US) |

Aliases:

FF – FFF
C – CC
H – HH
G – GG
FG – FGG
SG – SGG

Base Parameters:

Prices (set by user):

XRO_T – Initial exchange rate
PMRO_{T,C} – Initial regional import price in regional currency
PWEO_{C,T} – Initial world export price in foreign currency
PERO_{C,T} – Initial regional export price in regional currency
PMO_C – Initial composite import price in regional currency
PEO_C – Initial composite export price in regional currency
PQO_C – Initial composite commodity price
PDO_C – Initial regional price of regional output
PXO_C – Initial producer price
PAO_A – Initial activity price
PVAO_A – Initial value added price
WFO_{FF} – Initial average wage or rental rate for factor FF
pwm_{T,C} – World import price in foreign currency (exogenous)

Quantities (calculated from initial data):

QMRO_{T,C} – Initial regional imports
QERO_{C,T} – Initial regional exports
QMO_C – Initial composite import quantity
QEO_C – Initial composite export quantity
QQO_C – Initial composite quantity supplied to regional demanders
QDO_C – Initial quantity of regional output supplied to regional demanders
QXO_C – Initial quantity of regional output
QAO_A – Initial activity level
QINTO_{C,A} – Initial quantity of intermediate use of commodity C by activity A
IMAKEQO_{T,C} – Initial institutional make matrix (quantity)
QFO_{FF,A} – Initial quantity of factor FF demanded by activity A
QHO_{C,H} – Initial household consumption
QINVO_C – Initial investment demand
QIINVO_I – Initial institutional investment demand
QFSO_{FF} – Initial factor supply
INDTO_G – Initial indirect business taxes receipts for each government unit
EMPLOY_A – Employment data (actual number of jobs in each sector)

Accounting variables (calculated from initial data):

| | | |
|--------------|---|--|
| $YFO_{I,FF}$ | – | Initial transfer of income to institution I from factor FF |
| YHO_H | – | Initial gross household income |
| $NYHO_H$ | – | Initial net household income |
| $YFGO$ | – | Initial federal government income |
| $EFGO$ | – | Initial federal government spending |
| $YSGO$ | – | Initial state government income |
| $ESGO$ | – | Initial state government spending |
| $FSAVXO$ | – | Initial foreign savings (export column) |
| $FSAVMO$ | – | Initial foreign savings (import row) |
| $DSAVXO$ | – | Initial savings for RUS (export column) |
| $DSAVMO$ | – | Initial savings for RUS (import row) |
| $CPIO$ | – | Initial consumer price index |

Factors:

| | | |
|------------------|---|---|
| $WFDISTO_{FF,A}$ | – | Initial factor price distortion factor |
| $IADJO$ | – | Initial investment adjustment factor |
| $SADJO$ | – | Initial savings adjustment factor |
| $SGADJO$ | – | Initial state government spending adjustment factor |
| $SHIFTFO_{FF}$ | – | Initial shift variable for factor supply equation |

Parameters set by user:

| | | |
|-------------|---|---|
| $frisch_C$ | – | Frisch parameter for Stone-Geary utility function |
| $inc_{C,H}$ | – | Income elasticity |
| $xed_{C,T}$ | – | Elasticity of demand for world export demand function |
| $esubp_A$ | – | Elasticity of substitution for production function |
| $esubd_C$ | – | Elasticity of substitution between regional output and imports |
| $esubs_C$ | – | Elasticity of transformation between regional output and exports |
| $esubec_C$ | – | Elasticity of transformation between foreign and regional exports |
| $esubm_C$ | – | Elasticity of substitution between foreign and regional imports |
| tq_C | – | Sales tax rate |
| tc_C | – | Consumption tax rate (paid only by households) |
| tq_{SC} | – | Sales tax rate on services not previously taxed |
| $tm_{T,C}$ | – | Import tax rate |
| $te_{C,T}$ | – | Export tax rate |
| $efac_{FF}$ | – | Demand elasticity for factors of production |

Parameters calculated from initial data:

| | | |
|----------------|---|--|
| $\theta_{A,C}$ | – | Yield of output C per unit of activity A |
| $ica_{C,A}$ | – | Quantity of C as intermediate input per unit of activity A |
| tb_A | – | Indirect business tax rate |

| | |
|----------------|--|
| $ty_{G,H}$ | - Household income tax rate |
| $trh_{H,HH}$ | - Inter-household transfers |
| mp_{SH} | - Marginal propensity to save |
| cw_{tSC} | - Weight of commodity C in the consumer price index |
| $wfa_{FF,A}$ | - Price for factor FF in activity A |
| $xshift_{C,T}$ | - Shift parameter for world export demand function |
| $lambda_{C,H}$ | - Subsistence level parameter for Stone-Geary utility function |
| $beta_{C,H}$ | - Marginal budget share parameter for Stone-Geary utility function |
| $engelw_{tH}$ | - Engel aggregation weight |
| $qg_{C,G}$ | - Government consumption |
| $shry_{I,FF}$ | - Institutional share of factor income |
| $tbshr_{TG}$ | - Government unit share of indirect business taxes |
| $sgovbal$ | - Initial state government budget balance |
| ad_A | - Shift parameter for production function |
| $del_{F,A}$ | - Share parameter for production function |
| rho_A | - Exponent for production function |
| aq_C | - Shift parameter for armington demand function |
| $adel_C$ | - Share parameter for armington demand function |
| $arhoc$ | - Exponent for armington demand function |
| asc | - Shift parameter for supply transformation function |
| $sdel_C$ | - Share parameter for supply transformation function |
| $srhoc$ | - Exponent for supply transformation function |
| aec | - Shift parameter for export transformation function |
| $edel_C$ | - Share parameter for export transformation function |
| $erhoc$ | - Exponent for export transformation function |
| am_C | - Shift parameter for armington import function |
| $mdel_C$ | - Share parameter for armington import function |
| $mrhoc$ | - Exponent parameter for armington import function |

Calculation of base values (SAM is the adjusted data from IMPLAN):

$$PMRO_{T,C} = pwm_{T,C} * (1 + tm_{T,C}) * XRO_T$$

$$PERO_{C,T} = PWEO_{C,T} * (1 - tc_{C,T}) * XRO_T$$

$$PVAO_A = \frac{\sum_{FF} SAM_{FF,A}}{SAM_{TOTAL,A} * PAO_A}$$

$$QMRO_{T,C} = \frac{SAM_{T,C}}{PMRO_{T,C}}$$

$$QERO_{C,T} = \frac{SAM_{C,T}}{PMRO_{C,T}}$$

$$QMO_C = \frac{\sum_T SAM_{T,C}}{PMO_C}$$

$$QEO_C = \frac{\sum_T SAM_{C,T}}{PEO_C}$$

$$QQO_C = \frac{SAM_{TOTAL,C} - \sum_T SAM_{C,T}}{PQO_C}$$

$$QDO_C = \frac{\sum_A SAM_{A,C} + \sum_I SAM_{I,C} - \sum_T SAM_{C,T}}{PDO_C}$$

$$QXO_C = \frac{\sum_A SAM_{A,C} + \sum_I SAM_{I,C}}{PXO_C}$$

$$QAO_A = \frac{SAM_{TOTAL,A}}{PAO_A}$$

$$QINTO_{C,A} = \frac{SAM_{C,A}}{PQO_C}$$

$$IMAKEQO_{I,C} = \frac{SAM_{I,C}}{PXO_C}$$

$$QFO_{CAP,A} = SAM_{CAP,A}$$

$$\text{IF LBR = NO: } QFO_{LAB,A} = SAM_{LAB,A}$$

$$\text{ELSE: } QFO_{LAB,A} = EMPLOY_A$$

$$WFO_{FF} = \frac{\sum_A SAM_{FF,A}}{\sum_A QFO_{FF,A}}$$

$$QHO_{C,H} = \frac{SAM_{C,H}}{(1 + tcc) * PQO_C}$$

$$QINVO_C = \frac{SAM_{C,INV}}{PQO_C}$$

$$QIINVO_{HG} = SAM_{HG,INV}$$

$$QFSO_{FF} = \frac{\sum_A SAM_{FF,A}}{WFO_{FF,A}}$$

$$INDTO_G = SAM_{G,INDT}$$

$$YFO_{I,FF} = SAM_{I,FF}$$

$$YHO_H = \sum_{FF} SAM_{H,FF} + \sum_I SAM_{H,I} + \sum_T SAM_{H,T} + \sum_C PX_C * SAM_{H,C}$$

$$NYHO_H = \sum_C SAM_{C, H}$$

$$YFGO = \sum_{FG} SAM_{FG, TOTAL}$$

$$EFGO = \sum_{FG} SAM_{TOTAL, FG} - \sum_{FG} SAM_{INV, FG}$$

$$YSGO = \sum_{SG} SAM_{SG, TOTAL}$$

$$ESGO = \sum_{SG} SAM_{TOTAL, SG} - \sum_{SG} SAM_{INV, SG}$$

$$FSAVXO = \frac{SAM_{INV, 'FT}}{XRO_{FT}}$$

$$DSAVXO = \frac{SAM_{INV, 'DT}}{XRO_{DT}}$$

$$FSAVMO = \frac{SAM_{FT, 'INV}}{XRO_{FT}}$$

$$DSAVMO = \frac{SAM_{DT, 'INV}}{XRO_{DT}}$$

$$wfa_{FF,A} = \frac{SAM_{FF,A}}{QFO_{FF,A}}$$

$$WFDISTO_{FF,A} = \frac{wfa_{FF,A}}{WFO_{FF}}$$

$$SHIFTFFO_{FF} = \frac{QFSO_{FF}}{WFO_{FF}^{efactr}}$$

$$CPIO = \sum_C cwtsc * PDO_C$$

Calibration of parameters:

$$\theta_{A,C} = \frac{SAM_{A,C}}{PXOC * QAO_A}$$

$$ica_{C,A} = \frac{QINTOC_{C,A}}{QAO_A}$$

$$tb_A = \frac{SAM_{INDT, A}}{SAM_{TOTAL, A}}$$

$$ty_{G,H} = \frac{SAM_{G,H}}{SAM_{TOTAL, H}}$$

$$\text{trh}_{H,HH} = \frac{\text{SAM}_{H,HH}}{(1 - \sum_G \text{ty}_{G,HH}) \text{SAM}_{\text{TOTAL},H}}$$

$$\text{mps}_H = \frac{\text{SAM}_{\text{INV},H}}{(1 - \sum_G \text{ty}_{G,H}) \text{SAM}_{\text{TOTAL},H}}$$

$$\text{cwts}_C = \frac{\sum_H \text{SAM}_{C,H}}{\sum_{CC} \sum_H \text{SAM}_{CC,H}}$$

$$\text{xshift}_{C,T} = \frac{\text{QERO}_{C,T}}{\text{PWEOC}_{C,T}^{\text{xedc},T}}$$

$$\text{engelwt}_H = \frac{1}{\sum_C \frac{\text{QHO}_{C,H} * \text{PQOC} * \text{inec}_{C,H}}{\text{NYHO}_H}}$$

$$\text{inec}_{C,H} = \text{engelwt}_H * \text{inec}_{C,H}$$

$$\text{beta}_{C,H} = \frac{\text{QHO}_{C,H} * \text{PQOC} * \text{inec}_{C,H}}{\text{NYHO}_H}$$

$$\text{lambda}_{C,H} = \frac{\text{QHO}_{C,H} * \text{PQOC} + \frac{\text{beta}_{C,H} * \text{NYHO}_H}{\text{frischc}}}{\text{PQOC}}$$

$$\text{qg}_{C,G} = \frac{\text{SAM}_{C,G}}{\text{PQOC}}$$

$$\text{shry}_{I,FF} = \frac{\text{SAM}_{I,FF}}{\text{SAM}_{\text{TOTAL},FF} - \sum_T \text{SAM}_{T,FF}}$$

$$\text{tbshr}_G = \frac{\text{SAM}_{G,'INDT'}}{\sum_{GG} \text{SAM}_{GG,'INDT'}}$$

$$\text{sgovbal} = \sum_{SG} \text{SAM}_{\text{INV},SG}$$

$$\text{rho}_A = \frac{1}{\text{esubp}_A} - 1$$

$$\text{del}_{FF,A} = \frac{\text{WFDIST}_{FF,A} * \text{WFO}_{FF} * \text{QFO}_{FF,A}^{\text{rho}_A+1}}{\sum_{FFF} \text{WFDIST}_{FFF,A} * \text{WFO}_{FFF} * \text{QFO}_{FFF,A}^{\text{rho}_A+1}}$$

$$ad_A = \frac{QA_{OA} * (1 - tb_A - \sum_C ic_{ac, A})}{\left(\sum_{FF} del_{FF, A} * QFO_{FF, A} \right)^{\frac{-1}{rho_A}}}$$

$$arho_{CM} = \frac{1}{esub_{dCM}} - 1$$

$$adel_{CM} = \frac{PMO_{CM} * QMO_{CM}^{1+arho_{CM}}}{PMO_{CM} * QMO_{CM}^{1+arho_{CM}} + PDO_{CM} * QDO_{CM}^{1+arho_{CM}}}$$

$$aq_{CM} = \frac{QO_{CM}}{\left(adel_{CM} * QMO_{CM}^{-arho_{CM}} + (1 - adel_{CM}) * QDO_{CM}^{-arho_{CM}} \right)^{\frac{-1}{arho_{CM}}}}$$

$$srho_{CE} = \frac{1}{esub_{sCE}} + 1$$

$$sdel_{CE} = \frac{PEO_{CE} * QEO_{CE}^{1-srho_{CE}}}{PEO_{CE} * QEO_{CE}^{1-srho_{CE}} + PDO_{CE} * QDO_{CE}^{1-srho_{CE}}}$$

$$as_{CE} = \frac{QXO_{CE}}{\left(sdel_{CE} * QEO_{CE}^{srho_{CE}} + (1 - sdel_{CE}) * QDO_{CE}^{srho_{CE}} \right)^{\frac{1}{srho_{CE}}}}$$

$$erho_{CE2} = \frac{1}{esub_{eCE2}} + 1$$

$$edel_{CE2} = \frac{PERO_{CE2, FT} * QERO_{CE2, FT}^{1-erho_{CE2}}}{PERO_{CE2, FT} * QERO_{CE2, FT}^{1-erho_{CE2}} + PERO_{CE2, DT} * QERO_{CE2, DT}^{1-erho_{CE2}}}$$

$$ae_{CE2} = \frac{QEO_{CE2}}{\left(edel_{CE2} * QERO_{CE2, FT}^{erho_{CE2}} + (1 - edel_{CE2}) * QERO_{CE2, DT}^{erho_{CE2}} \right)^{\frac{1}{erho_{CE2}}}}$$

$$mrho_{CM2} = \frac{1}{esub_{mCM2}} - 1$$

$$mdel_{CM2} = \frac{PMRO_{FT, CM2} * QMRO_{FT, CM2}^{1+mrho_{CM2}}}{PMRO_{FT, CM2} * QMRO_{FT, CM2}^{1+mrho_{CM2}} + PMRO_{DT, CM2} * QMRO_{DT, CM2}^{1+mrho_{CM2}}}$$

$$am_{CM2} = \frac{QMO_{CM2}}{\left(mdel_{CM2} * QMRO_{FT, CM2}^{-mrho_{CM2}} + (1 - mdel_{CM2}) * QMRO_{DT, CM2}^{-mrho_{CM2}} \right)^{\frac{-1}{mrho_{CM2}}}}$$

Endogenous variables:

Prices:

| | | |
|-------------|---|---|
| XR_T | – | Exchange rate |
| CPI | – | Consumer price index |
| $PMR_{T,C}$ | – | Regional import price in regional currency |
| $PWE_{C,T}$ | – | World export price in foreign currency |
| $PER_{C,T}$ | – | Regional export price in regional currency |
| PM_C | – | Composite import price in regional currency |
| PE_C | – | Composite export price in regional c currency |
| PQ_C | – | Composite commodity price |
| PD_C | – | Regional price of regional output |
| PX_C | – | Producer price |
| PA_A | – | Activity price |
| PVA_A | – | Value added price |
| WF_{FF} | – | Average wage or rental rate for factor FF |

Quantities:

| | | |
|----------------|---|--|
| $QMR_{T,C}$ | – | Regional imports |
| $QER_{C,T}$ | – | Regional exports |
| QM_C | – | Composite import quantity |
| QE_C | – | Composite export quantity |
| QQ_C | – | Composite quantity supplied to regional demanders |
| QD_C | – | Quantity of regional output supplied to regional demanders |
| QX_C | – | Quantity of regional output |
| QA_A | – | Activity level |
| $QINT_{C,A}$ | – | Quantity of intermediate use of commodity C by activity A |
| $IMAKEQ_{I,C}$ | – | Institutional make matrix (quantity) |
| $QF_{FF,A}$ | – | Quantity of factor FF demanded by activity A |
| $QH_{C,H}$ | – | Household consumption |
| $QINV_C$ | – | Investment demand |
| $QIINV_I$ | – | Investment demand by institutions |
| QFS_{FF} | – | Factor supply |
| $INDT(G)$ | – | Indirect business taxes receipts for each government unit |

Accounting variables

| | | |
|-------------|---|--|
| $YF_{I,FF}$ | – | Transfer of income to institution I from factor FF |
| YH_H | – | Gross household income |
| NYH_H | – | Net household income |
| YFG | – | Federal government income |
| EFG | – | Federal government expenditure |
| YSG | – | State government revenue |
| ESG | – | State government expenditure |
| $FSAVX$ | – | Foreign savings (export column) |
| $FSAVM$ | – | Foreign savings (import row) |
| $DSAVX$ | – | RUS savings (export column) |

DSAVM – RUS savings (import row)

Factors:

- WFDIST_{FF,A} – Factor price distortion factor
- IADJ – Investment adjustment factor
- SADJ – Savings adjustment factor
- SGADJ – State government spending adjustment factor
- SHIFTF_{FF} – Factor supply equation shift variable
- WALRAS – WALRAS dummy variable (should be 0)

Equations:

Regional foreign import price equation:

$$PMR_{FT,CM} = pwm_{FT,CM} * (1 + tm_{FT,CM}) * XR_{FT}$$

Regional foreign export price equation:

$$PER_{CE,FT} = PWE_{CE,FT} * XR_{FT} * (1 - te_{CE,FT}) \text{ if } QERO_{CE,FT} \neq 0$$

Regional RUS import price equation:

$$PMR_{DT,CM} = CPI * pwm_{DT,M} * (1 + tm_{DT,CM}) * XR_{DT}$$

Regional RUS export price equation:

$$PER_{CE,DT} = CPI * PWE_{CE,DT} * XR_{DT} * (1 - te_{CE,DT}) \text{ if } QERO_{CE,DT} \neq 0$$

World export demand function:

$$QER_{CE,T} = xshift_{CE,T} * PWE_{CE,T}^{\alpha_{CE,T}} \text{ if } QERO_{CE,T} \neq 0$$

Armington import composite equation:

$$QM_{CM2} = am_{CM2} * \left(mdel_{CM2} * QMR_{FT,CM2}^{-\rho_{CM2}} + (1 - mdel_{CM2}) * QMR_{DT,CM2}^{-\rho_{CM2}} \right)^{\frac{-1}{\rho_{CM2}}}$$

ROW-RUS import ratio:

$$\frac{QMR_{FT,CM2}}{QMR_{DT,CM2}} = \left(\frac{PMR_{DT,CM2}}{PMR_{FT,CM2}} * \frac{mdel_{CM2}}{1 - mdel_{CM2}} \right)^{\frac{1}{1 + \rho_{CM2}}}$$

Import quantity for imports from exactly one source:

$$QM_{CM1} = QMR_{DT,CM1} \text{ (if } QMRO_{DT,CM1} \neq 0) + QMR_{FT,CM1} \text{ (if } QMRO_{FT,CM1} \neq 0)$$

Import price for imports from exactly one source:

$$PM_{CM1} = PMR_{DT,CM1} \text{ (if } QMRO_{DT,CM1} \neq 0) + PMR_{FT,CM1} \text{ (if } QMRO_{FT,CM1} \neq 0)$$

Value of imports:

$$PM_{CM2} * QM_{CM2} = \sum_T PM_{T, CM2} * QM_{T, CM2}$$

Export composite transformation equation:

$$QE_{CE2} = a_{CE2} * \left(edel_{CE2} * QER_{CE2, FT}^{\rho_{CE2}} + (1 - edel_{CE2}) * QER_{CE2, DT}^{\rho_{CE2}} \right)^{\frac{1}{\rho_{CE2}}}$$

ROW-RUS export ratio:

$$\frac{QER_{CE2, DT}}{QER_{CE2, FT}} = \left(\frac{PER_{CE2, DT}}{PER_{CE2, FT}} * \frac{edel_{CE2}}{1 - edel_{CE2}} \right)^{\frac{1}{\rho_{CE2} - 1}}$$

Export quantity for exports to exactly one destination:

$$QE_{CE1} = QER_{CE1, DT} \text{ (if } QERO_{CM1, DT} \neq 0) + QER_{CE1, FT} \text{ (if } QERO_{CM1, FT} \neq 0)$$

Export price for exports to exactly one destination:

$$PE_{CE1} = PER_{CE1, DT} \text{ (if } QERO_{CM1, DT} \neq 0) + PER_{CE1, FT} \text{ (if } QERO_{CM1, FT} \neq 0)$$

Value of exports:

$$PE_{CE2} * QE_{CE2} = \sum_T PER_{CE2, T} * QER_{CE2, T}$$

Absorption equation:

$$PQ_C * QQ_C = (1 + tq_C) * PM_C * QM_C \text{ (if } C \subset CM) + (1 + tq_C + tq_{SC}) * PD_C * QD_C$$

Value of regional output:

$$PX_C * QX_C = PD_C * QD_C + PE_C * QE_C \text{ (if } C \subset CE)$$

Activity price equation:

$$PA_A = \sum_C PX_C * \theta_{A, C}$$

Value added price equation:

$$PVA_A = PA_A * (1 - tb_A) - \sum_C PQ_C * ic_{A, C}$$

Leontief-CES production function:

$$QA_A = \frac{ad_A}{1 - tb_A - \sum_C ic_{A, C}} * \left(\sum_{FF} del_{FF, A} * Q_{FF, A}^{-\rho_{FF, A}} \right)^{\frac{-1}{\rho_{FF, A}}}$$

Factor demand equation:

$$WFDIST_{FF, A} * WF_{FF} = \frac{PVA_A * ad_A}{1 - tb_A - \sum_C ic_{A, C}} * \left(\sum_{FFF} del_{FFF, A} * Q_{FFF, A}^{-\rho_{FFF, A}} \right)^{\frac{-1}{\rho_{FFF, A}} - 1} * del_{FF, A} * Q_{FF, A}^{-\rho_{FF, A} - 1}$$

Intermediate input demand equation:

$$QINT_{C,A} = ica_{C,A} * QA_A$$

Output function:

$$QX_C = \sum_A \theta_{A,C} * QA_A + \sum_I IMAKEQ_{I,C}$$

Armington commodity composite equation:

$$QQ_{CM} = aq_{CM} * \left(adel_{CM} * QM_{CM}^{-\rho_{CM}} + (1 - adel_{CM}) * QD_{CM}^{-\rho_{CM}} \right)^{\frac{-1}{\rho_{CM}}}$$

Import regional demand ratio:

$$\frac{QM_{CM}}{QD_{CM}} = \left(\frac{PD_{CM}}{PM_{CM}} * \frac{adel_{CM}}{1 - adel_{CM}} \right)^{\frac{1}{1 + \rho_{CM}}}$$

Composite supply for non-imported commodities:

$$QQ_{CNM} = QD_{CNM}$$

Output transformation equation:

$$QX_{CE} = as_{CE} * \left(sdel_{CE} * QE_{CE}^{\rho_{CE}} + (1 - sdel_{CE}) * QD_{CE}^{\rho_{CE}} \right)^{\frac{1}{\rho_{CE}}}$$

Export regional supply ratio:

$$\frac{QE_{CE}}{QD_{CE}} = \left(\frac{PE_{CE}}{PD_{CE}} * \frac{1 - sdel_{CE}}{sdel_{CE}} \right)^{\frac{1}{\rho_{CE} - 1}}$$

Output transformation for non-exported commodities:

$$QX_{CNE} = QD_{CNE}$$

Factor income equation:

$$YF_{I,FF} = shry_{I,FF} \left(\sum_A WFDIST_{FF,A} * QF_{FF,A} * WF_{FF,A} - CPI * \sum_T SAM_{T,FF} \right)$$

Household income equation:

$$YH_H = \sum_{FF} YF_{H,FF} + \sum_C PX_C * IMAKEQ_{H,C} + cpi * \sum_T SAM_{T,H} \\ + QIINV_H + CPI * \sum_G SAM_{H,G} + \sum_{HH} (tr_{HH,HH} * (1 - \sum_G ty_{G,HH}) * YH_{HH})$$

Net household income equation:

$$NYH_H = YH_H - \sum_{HH} tr_{HH,H} * (1 - \sum_G ty_{G,H}) * YH_H - cpi * \sum_T SAM_{T,H} \\ - SADJ * mps_H * (1 - \sum_G ty_{G,HH}) * YH_H - YH_H * \sum_G ty_{G,H}$$

Household consumption demand:

$$Q_{H,C,H} = \lambda_{C,H} + \beta_{C,H} * (NY_{H,H} - \sum_{CC} \lambda_{CC,H} * (1 + t_{CC}) * PQ_{CC}) / ((1 + t_C) * PQ_C)$$

Investment demand equation:

$$Q_{INV,C} = IADJ * Q_{INV,O_C}$$

Institutional investment demand equation:

$$Q_{INV,HG} = Q_{INV,O_{HG}}$$

Federal government revenue:

$$\begin{aligned} Y_{FG} = & \sum_H \sum_{FG} ty_{FG,H} * Y_{H,H} + cpi * \sum_T \sum_{FG} SAM_{FG,T} + \sum_C \sum_{FG} PX_C * IMAKEQ_{FG,C} + \sum_{FG} \sum_{FF} Y_{FG,FF} \\ & + \sum_{FG} Q_{INV_{FG,INV}} + cpi * \sum_{FG} \sum_{FGG} SAM_{FG,FGG} + \sum_{FG} INDT_{FG} \end{aligned}$$

Federal government expenditures:

$$\begin{aligned} E_{FG} = & cpi * \sum_{FG} \sum_I SAM_{I,FG} + cpi * \sum_{FG} \sum_T SAM_{T,FG} + \sum_{FG} \sum_C PQ_C * q_{g_c,FG} - cpi * \sum_{FG} SAM_{INV,FG} \end{aligned}$$

State government revenue:

$$\begin{aligned} Y_{SG} = & \sum_H \sum_{SG} ty_{SG,H} * Y_{H,H} + cpi * \sum_T \sum_{SG} SAM_{SG,T} + \sum_C \sum_{SG} PX_C * IMAKEQ_{SG,C} + \sum_{SG} \sum_{FF} Y_{SG,FF} \\ & + \sum_{SG} Q_{INV_{SG}} + cpi * \sum_{SG} \sum_{SGG} SAM_{SG,SGG} + \sum_{SG} INDT_{SG} \\ & + CPI * \sum_{SG} \sum_{FG} SAM_{SG,FG} \\ & + \sum_C tq_c * (PM_c * Q_{M_c}(\text{if}(C \subset CM)) + PD_c * Q_{D_c}) \\ & + \sum_C tq_{sc} * PD_c * Q_{D_c} \\ & + \sum_H \sum_C tc_c * PQ_C * Q_{H,C,H} \end{aligned}$$

State government expenditures:

$$\begin{aligned} E_{SG} = & cpi * \sum_{SG} \sum_I SAM_{I,SG} + cpi * \sum_{SG} \sum_T SAM_{T,SG} \\ & + SGADJ * \sum_{SG} \sum_C PQ_C * q_{g_c,SG} - cpi * \sum_{SG} SAM_{INV,SG} - CPI * sgovbal \end{aligned}$$

State government budget balanced:

$$YSG = ESG + CPI * sgovbal$$

Factor market equation:

$$QFS_{FF} = \sum_A QF_{FF, A}$$

Composite commodity market equation:

$$QQ_C = \sum_A QINT_{C, A} + \sum_H QH_{C, H} + \sum_{FG} qg_{C, FG} + SGADJ * \sum_{SG} qg_{C, SG} + QINV_C$$

ROW current account balance:

$$\begin{aligned} & \sum_{\substack{CE \\ QERO_{CE, FT} \neq 0}} PER_{CE, 'FT} * QER_{CE, 'FT} + cpi * \sum_H SAM_{H, 'FT} + cpi * \sum_G SAM_{G, 'FT} \\ & + XR_{'FT} * FSAVX \\ = & \sum_{\substack{CM \\ QMRO_{FT, CM} \neq 0}} PMR_{'FT, CM} * QMR_{'FT, CM} + cpi * \sum_{FF} SAM_{'FT, FF} + cpi * \sum_{HG} SAM_{'FT, HG} \\ & + XR_{'FT} * FSAVM \end{aligned}$$

RUS current account balance:

$$\begin{aligned} & \sum_{\substack{CE \\ QERO_{CE, DT} \neq 0}} PER_{CE, 'DT} * QER_{CE, 'DT} + cpi * \sum_H SAM_{H, 'DT} + cpi * \sum_G SAM_{G, 'DT} \\ & + cpi * XR_{'DT} * DSAVX \\ = & \sum_{\substack{CM \\ QMRO_{DT, CM} \neq 0}} PMR_{'DT, CM} * QMR_{'DT, CM} + cpi * \sum_{FF} SAM_{'DT, FF} + cpi * \sum_{HG} SAM_{'DT, HG} \\ & + CPI * XR_{'DT} * DSAVM \end{aligned}$$

Savings investment balance:

$$\begin{aligned} & \sum_C PX_C * IMAKEQ_{INV, C} + SADJ * \sum_H (mps_H * (1 - \sum_G ty_{G, H}) * YH_H) + \sum_{FF} YF_{INV, FF} \\ & + (YFG - EFG) + XR_{'FT} * FSAVX + CPI * XR_{'DT} * DSAVX + CPI * sgovbal \\ = & \sum_C PQ_C * QINV_C + \sum_{HG} QIINV_{HG} + XR_{'FT} * FSAVM + CPI * XR_{'DT} * DSAVM \\ & + WALRAS \end{aligned}$$

Price normalization equation

$$\sum_C (1 + tc_C) * PQ_C * cwt_{sc} = CPI$$

Indirect taxes calculation:

$$\text{INDT}_G = \text{tbshr}_G * \sum_A \text{tb}_A * \text{PAA} * \text{QAA}$$

Factor supply equation:

$$\text{QFS}_{\text{FF}} = \text{SHIFTFF}_{\text{FF}} * \text{WF}_{\text{FF}}^{\text{facff}}$$

Closure:

The following closure options are available:

1. Capital closure (determined by setting the scalar CAPCLOS)

CAPCLOS = 1. Capital is mobile and supply is fixed.

CAPCLOS = 2. Capital is mobile and supply is variable

CAPCLOS = 3. Capital is activity specific and fixed.

2. Labor closure (determined by setting the scalar LABCLOS)

LABCLOS = 1. Labor is mobile and supply is fixed.

LABCLOS = 2. Labor is mobile and supply is variable.

LABCLOS = 3. Labor is mobile. Unemployment is possible.

3. Savings and investment closure (determined by setting the scalar SICLOS)

SICLOS = 1. Savings is investment driven.

SICLOS = 2. Investment is savings driven.

SICLOS = 3. CPI varies allowing prices to adjust to achieve equilibrium.

4. ROW current account closure (determined by setting the scalar ROWCLOS)

ROWCLOS = 1. Foreign exchange rate is variable.

ROWCLOS = 2. foreign savings (export - FSAVX) is variable.

ROWCLOS = 3. foreign savings (import - FSAVM) is variable.

5. RUS current account closure (determined by setting the scalar RUSCLOS)

RUSCLOS = 1. RUS exchange rate is variable.

RUSCLOS = 2. RUS savings (export - DSAVX) is variable.

RUSCLOS = 3. RUS savings (import - DSAVM) is variable.

CHAPTER THREE

Economic Analysis of Water Resource Use Efficiency in Golf

Introduction

According to figures released from the 2003 World Water Forum in Kyoto Japan, the United States is the most wasteful water user in the world and the nation's golf industry receives much of the blame (Sutherland 2003). In general, the golf industry and turf and landscape management have received a great deal of negative press over the past decade for their resource use and negative environmental impacts. The perception is that golf courses take up a great deal of land and habitat, pollute with turf chemicals, and use an inordinate amount of water, a particular concern in the western United States (Stix 1994). For example, it has been proposed that the amount of water used on the average golf course is enough to support the daily needs of 2,000 people and this number rises to 11,000 people in arid courses in California (Selcraig 1993).

According to the Colorado State Demographer's office, the population of Colorado is expected to grow to over 7 million by the year 2030, up from 4.5 million in 2002. This population growth trend is typical of the American West and has persisted over the past century (Hobbs and Stoops 2002). The West has seen a 14 fold increase in population, increasing from 4.3 million in 1900 to 60 million in 2000 (Beale 2000). This population increase has been spurred by many factors, not the least of which is the region's climate and high level of natural amenities (Power 1996). This population increase has had a profound effect on the demographic character of the West, transforming the region from an agrarian and extraction based economy to a diversified

economy with the majority of the population and economic activity centered around urban centers such as Colorado's Front Range (Power 1996, Shumway and Otterstrom 2001, Vias and Carruthers 2005).

The rise of the golfing industry has been directly related to population growth in Colorado (figure 1). In the face of increased population, and taking advantage of the state's natural amenities, favorable climate, and active lifestyle, the golf industry has grown along side the population. The correlation coefficient between population growth and the number of golf courses is 0.99 and shows a high degree of cointegration with population serving as the leading indicator and the number of golf courses lagging in response to population growth. This indicates that population growth and golf course development are inextricably tied to one another and the development of golf courses in Colorado can not be looked at separately from population growth. Population growth is directly correlated to golf course development and it is estimated that an additional population increase of 15,500 people in Colorado corresponds to a new golf course being built (figure 2). Given the population growth projections for Colorado and the close relationship between golf course development and population, the number of golf courses in the state is expected to continue to increase for the foreseeable future. Golf course development, while highly correlated with population growth, has been growing at a greater rate than the population as a whole (figure 3). There are considerably more golf courses in Colorado now than there were in 1898. In 1898 there were 3 courses and 500,000 people. The number of courses per million people has risen steadily since then and there are now over 55 courses per million people in Colorado.

In the face of increased water scarcity due to greater population pressures and chronic droughts in the Western United States, golf courses are feeling regulatory, economic, and broader public pressure to use water efficiently. Both theoretical and empirical models for economic water use efficiency under various conservation schemes have been applied in agricultural contexts (Huffaker and Whittlesey 2003, Huffaker and Whittlesey 2000, Wichelns 1999). The empirical models are most often solved using mathematical programming models which simulate effects of various water conservation schemes, such as water taxes or subsidies for improved irrigation efficiency, on the financial performance of agriculture. Similar studies have yet to be performed that focus on the golf industry. While there has been much research on technical efficiency of irrigation water use in golf (which is a relationship between water applied and plant matter produced), economic efficiency has largely been ignored (Bastug and Buyuktas 2003, Carrow et al. 2004). Yet, economic efficiency is an important measure of how well a natural resource is being used by a given industry as it measures economic returns to water use and takes into account all benefits and costs of irrigation.

Additionally, if policy makers across the United States continue to stress water conservation and threaten heightened water restrictions, then courses need to know how different water conservation policies will affect them. This study examines three potential policy tools that are often used in the United States to encourage water conservation. These are:

- 1) Enact volumetric based water costs
- 2) Enact hard quotas on the amount of water available to courses

This study examines the economic efficiency of golf course water use and determines the best policy tools for the adoption of water conservation practices and technologies. This information will be useful in informing policy makers and regulatory bodies when water restrictions are being proposed.

This research utilized a golf course survey related to water usage and the construction of a Positive Mathematical Programming Model (PMP). The PMP model is an economic computer model that will be constructed using the detailed course water use survey data collected in this study as well as data from a recent survey of Colorado's golf industry focused on its economic impacts. The model uses these real world numbers and determines what the results of different water conservation policies would be. The model will help determine which policy tools give incentives to adopt irrigation practices that lead course managers to conserve water while allowing courses to maximize profits under such policy regimes.

Mathematical Programming Models

Mathematical programming models have been widely used since the 1940's to optimize production processes and determine how resources and factors should best be allocated in various production regimes (Dantzig 1963). Kantorovich (1939) is credited with developing the first linear programming model which analyzed how machine tools could be employed to obtain the maximum output of completed goods (Johansen 1976). Since then linear programming models have been extended to a wide array of economic processes (Dorfman, Samuelson, and Solow 1958), including many in agricultural and natural resource economics (Found 1971, Johnson and Scheurman 1977). The US Forest

Service has a long history of using programming models to determine optimal timber harvests and management practices (Navon 1971, Hoekstra et al. 1987). Mathematical programming has also often been employed in the field of agricultural production and irrigation water allocation (Beneke and Winterboer 1973, Gibbons 1986).

Mathematical programming models utilize mathematical operations (i.e. simplex method) to solve simultaneous equations (Dantzig 1963). The tool allows the analysis of complex economic and production systems through the use of simultaneous interrelated equations. The general approach of mathematical programming models is to maximize or minimize an objective function subject to constraints. The objective function specifies how resources or inputs relate to returns or output. The constraints limit the model by not allowing solutions that are outside the bounds of the constraints. Constraints are often used to limit the solution to feasible solutions or to make sure the outcome of the model does not violate a mandated policy objective. The mathematical model finds a solution to the model by allocating resources or inputs between competing activities in order to find the optimal solution.

An example of mathematical programming might be for a farmer to choose how much land, fertilizer, and water to allocate to five potential crops in order to maximize their profits. In this case the objective function will be a profit function that is total revenue minus total costs. Constraints can be incorporated that will only allow for positive prices and quantities and to limit the total acreage of production to the total size of the farm. Other constraints that bind the solution to reality, such as downstream flow requirements for irrigation water and contracted acreage limits for specific crops, are often included in the model. The mathematical programming model will then solve out

for the allocation of the three inputs between the five possible crops that will maximize net returns to the farmer subject to all of the constraints. The solution will give the farmer the maximum net revenue that they can expect and the amount of land, fertilizer, and water they should allocate to the various crops to achieve this maximum.

Mathematical programming models, and especially linear programming models, have been criticized for not realistically representing real world situations. It is unlikely that even a thorough set of “reality” constraints that are based on physics and sound economic theory will be able to realistically represent real world conditions. Traditional mathematical programming models will not exactly reproduce real-world, observed base-period results without some form of a calibration process based on data collected from resource managers.

One modified type of programming, positive mathematical programming (PMP), is a non-linear programming model that optimizes an objective function, such as golf course profits, subject to constraints such as land and water availability or regulatory restrictions. The greatest advantage of PMP over other optimization models is that a PMP calibrates itself to actual collected data instead of using artificial assumptions and “reality” constraints to keep the model bounded in reality. This calibration phase is such that the true data collected from the golf courses will be recreated by the model in the absence of simulations. In other words, if you do not introduce any changes or shocks to the system, the model will calculate its parameters such that the original data and situation are recovered. PMP modeling was first formally described by Howitt (1995) and formal proofs of the model are presented in that paper. There have been numerous

calibration methods proposed (Hazell and Norton 1986, Bauer and Kasnacoglu 1990), however PMP has been the dominant method since the late 1990's (Heckelei 2001).

The process that PMP uses to determine optimal solution involves the common technique of assuming an objective function where individuals make rational decisions which optimize their utility. In the case of agricultural producers or golf course operators, these decisions would be to maximize profits. The profit function, then, is the difference between total revenue and total costs. Both revenues and costs are functions of the prices and levels of inputs and outputs. The PMP model takes this profit function and calibrates the parameters to yield a function which maximizes profits for the base year conditions at the observed base year values. It is assumed that if the researcher can derive the parameters that lead to the actual observed data, then the researcher has derived the parameters that were most likely used by the decision maker (Howitt 2005).

There are four main steps in the construction and analysis of the PMP model:

- 1) Construction of a constraint set that limits the resource usage in the unit modeled
- 2) Determination of a nonlinear economic function (maximize golf course profits in this case) that calibrates the model (is able to recreate the actual golf course water usage determined from actual data)
- 3) Changing the model to reflect institutional constraints by introducing different policy tools into the model
- 4) Analyzing the difference between the base case solutions and the policy implication models to estimate impacts of limiting policies

The data necessary for the construction of the PMP model of golf course operations and water use include golf course production activity levels (rounds of golf), inputs per round of golf, amount of water used from different sources, water charges, other costs, price of a round of golf, policy instruments that have been implemented, golf course responses, in water usage terms, to higher water prices, reduction of golf rounds that golf course superintendents credit to suboptimal course conditions, and reduction in hours of operation from watering restrictions.

Preliminary Findings

In 2003, Colorado State University and THK Associates conducted a study on the economic contributions of Colorado's golf industry (Davies et al. 2004). This study was primarily designed to evaluate the industry's size and scope but also provided some preliminary insights into golf water usage in the state. Colorado, along with much of the Western region, experienced a drought in 2002 and drought conditions are a common problem throughout the western United States. In response to the drought, Colorado's golf courses reduced their overall water consumption for 2002, although usage only dropped by 1.5%. This number, however, may be misleading due to the increased water use requirements caused by the 2002 drought. It was calculated that a typical Front Range golf course would have needed to increase their irrigation by about 25% in 2002 to offset the effects of the high temperatures and low precipitation. This, coupled with the actual overall reduction in water consumption, means that real net water savings in Colorado in 2002 is closer to 25%.

When asked in a separate question “what was the course’s percentage actual reduction in irrigation during drought in 2002”, the average response was a 19% reduction. So, the courses obviously perceive that they made a substantial reduction in their total irrigation usage and this figure is probably accurate given increased real water demand when adjusted for the increased evapotranspiration rate in 2002.

The courses also managed to shift some of their irrigation water from surface water to reclaimed wastewater. The use of reclaimed water has risen significantly from 2000 to 2002 (figures 7 and 8). In 2000, 61% of the irrigation water came from surface water while 10% was from reclaimed water. In 2001 the percentage of surface water declined to 59% and reclaimed water use increased to 16%. By 2002, surface water use had declined to 52% and reclaimed wastewater had increased to 20% (figures 7 and 8).

Comparison of Golf Water Use to Other Water Uses

According to the Golf Course Superintendents Association of America, golf courses in the United States use an average of 300,000 gallons of water per day. But, this number varies by region, with courses in Texas using under 197,000 gallons per course per day, on average, and courses in Florida using over 375,000 gallons per course per day (Hawes 1997). Florida’s roughly 1000 golf courses used a total of 173 billion gallons of water in 2000, almost half of which came from recycled water sources. Water use per acre in 2000 totaled 844,000 gallons.

These figures, however, do not provide any perspective on the complexity of water allocation and on the relative value of the water employed in respective uses for golf courses, to allow for comparisons to competing water uses such as residential lawns.

For example, over half of the 150 million gallons of water the average residential consumer uses is consumed in the form of landscape irrigation. In the arid west, turfgrass watering accounts for over 60% of urban water use (Fisher 2003). As one example, healthy bluegrass needs about 18 gallons of water per square foot per year to maintain healthy green lawns. The U.S. EPA has attempted to determine the total national lawn acreage data from the 1990 U.S. Census, Federal Housing Administration figures and the various available state surveys. They calculate the total U.S. home-lawn acreage to be between 14 and 26 million acres, with a conservative estimate of 17.7 million acres. The EPA then divided this by the number of single-family housing units with lawns (62.9 million, according to the 1990 U.S. Census) and obtained an average of 0.28 acres, or around 12,200 square feet, of lawn per home. Using national averages, lawns in the United States use 21,600 gallons of water per year per lawn. This translates into roughly 652,000 gallons of water per year per acre of lawn.

Based on an average golf course size of 160 acres and an average water use of 300,000 gallons per course per day, golf courses in the United States use 684,000 gallons of water per acre per year. This is 5% higher than the national average of water used per acre on residential lawns, yet the golf courses generate a great deal more use and economic activity.

However, Lisky (1997) cautions against applying these averages to specific situations. Clear regional differences are apparent in the figures. For example, four arid-climate states-Arizona, California, Nevada and New Mexico-averaged 0.12 acre (about 5,200 square feet) per home lawn, whereas the Northeastern states of Maine, New Hampshire and Vermont averaged 0.46 acre (about 20,000 square feet) per lawn.

Similarly, golf courses in arid regions will need to use more water per acre than average to compensate for high evapotranspiration rates and low levels of precipitation.

Colorado Water Use

It was found that Colorado golf courses use an average of 437,000 gallons of water per acre per year. On a per square foot basis, this works out to 10 gallons per square foot. When looking at just maintained acres, golf courses in Colorado use an average of 15 gallons per square foot.

By comparison, healthy bluegrass lawns require about 18 gallons per square foot per year. According to GreenCO, an association of Colorado's green industries, the average size of a lawn on Colorado's Front Range is around 5,000 square feet. On average, golf courses in Colorado occupy about 80 acres of irrigated turfgrass, which is about 3,484,800 square feet. This translates into about 700 average size lawns. If looking at total golf acreage, the average golf course occupies about 150 acres, which translates into 6,534,000 square feet. This represents about 1,300 average sized lawns. Well maintained lawns are appraised at 7% of a homes value. In terms of a cash flow for an average Front Range home, this translates into a value of a lawn to a homeowner of about \$6000 per year. On average each course in Colorado generates 31,000 rounds of golf per year. Based on survey data, an average round of golf generated \$42 per round in just greens fees and/or dues. This translates into \$8650 in direct revenue per acre per year from golf course fees and dues.

As a comparison, irrigated corn in Colorado uses approximately two acre-feet per acre a year to generate maximum yields. This is equivalent to 650,000 gallons of water per acre per year, almost 50% more water per acre than is used on golf courses.

2005 Follow-up Survey

In 2005 a follow-up to the Davies et al. (2004) study was conducted to further explore water use in Colorado's golf industry. The previous study involved surveying Colorado's golf courses on the general and financial aspects of operations. The initial investigation led to the realization that little formal research has been undertaken as to the economics of natural resource allocation in the golf industry.

The golf industry in Colorado was used as the case study in this research. A follow-up survey of Colorado's golf courses was developed that focused on water use, water conservation techniques, and adoption of water conservation technology. The water use survey was mailed to all of the golf courses in Colorado. This survey included specific questions on irrigation practices, the amount of water used for golf course operations, capital investments made on irrigation systems, water conservation techniques employed and the amount of money spent on these practices in 2003 and 2004. Questions were asked as to how differing prices of irrigation water, water quotas, and incentives to invest in water conserving irrigation technologies influenced the adoption of water conservation strategies. Past adoption and management behavior, along with survey responses on potential changes were then used to determine the economic efficiency of golf water use and incorporated into a PMP model. By entering golf specific data, available management options for several types of courses could be

analyzed and the profit maximizing optimal course plan (or policy instrument to encourage specific outcomes) could be identified. The PMP economic model determined what effects potential water conservation policies had on golf courses and which policies are likely to be most desirable from the golf industry’s perspective.

The direct information from the survey enabled the researchers to analyze the economic water use efficiency of Colorado’s golf courses and was then used to compare this to other industries and competing water uses.

PMP Model

PMP models have most commonly been used to estimate policy effects on strategies implemented by farmers. In this case, there is only one output that the golf course makes: golf rounds. Golf course operators are assumed to maximize profits by choosing the amount of inputs, such as water, to use. To make golf rounds we are assuming that the operators in Colorado need to use water. The golf courses themselves can only take a certain level of use and the amount of water applied increases the amount of rounds that can be played per day. The generalized form of the objective function, for each individual course would be as follows;

$$\begin{aligned} \max_{x_n \geq 0, y_n \geq 0, z_n \geq 0} \quad & \Pi(x_n, y_n, z_n) = r(x_n, y_n, z_n) - c(x_n, y_n, z_n) \\ \text{subject to:} \quad & x_n \leq A_n, y_n \leq B_n, z_n \leq E_n \end{aligned} \tag{0.1}$$

This is a standard profit maximizing problem for a firm where output is a function of inputs and profit is equal to total revenue minus total costs. The calibration step in PMP modeling uses observed data for prices and levels of inputs to ensure that the model will solve out for actual real world results. In order to accomplish this, either the revenue

function or the cost function can be made nonlinear. The revenue function in this study is already modeled as nonlinear; therefore the cost function will be used to calibrate the model. There are many possible nonlinear forms and the quadratic is often used due to its simplicity.

$$r(x_{ij}) = SP_1 \left[\beta_x x_1 + \beta_{var} (SP_2 (\beta_y x_2 + \beta_z x_3)) \right] \quad (0.2)$$

$$c(x_{ij}) = \sum_{ij} (\alpha_{ij} x_{ij} + 0.5 x_{ij}^2) \quad (0.3)$$

Where x_1 , x_2 , and x_3 are water, labor, and capital respectively, SP_1 and SP_2 are scale parameters, and the β s are share parameters.

Policy Analysis

The model described above will be used to determine how policy alternatives will simultaneously encourage water conservation while having a minimum impact on golf course financial performance. In addition to the three policy tools originally planned: increased water pricing, water quotas, and capital investment, a fourth policy option of subsidies for native grass adoption was included because of the finding of a high correlation between native grass roughs and lower water usage per acre among the sample of courses.

It is hypothesized that enacting strict quotas in water usage will be less economically efficient than tiered water prices due to the fact that a strict water quota will violate the equal marginal principal. The equal marginal principal states that a limited input, such as water, should be allocated among alternative uses in such a way that the

marginal value products of the last unit used on each alternative use are equal (equation 3.4).

The model will be run under all of these policy alternatives as well as a base case model with no policy simulations. The results of these policy tool simulations will be compared and analyzed.

Results

Surveys were received from 45 of the 250 courses, but due to nonresponse for some important questions, the number of useable surveys was reduced to 37. The courses that responded were generally considered to be representative of Colorado's golf course industry as a whole, with private, public, large, small courses from multiple regions in the state all reporting.

Overall water usage has remained fairly steady from 2000 through 2003, however, in 2004 the industry experienced a 17% reduction in overall water use (figure 3). Total water usage per irrigated acre also decreased in 2004, down 11% from 729,231 gallons per irrigated acre in 2003 to 651,295 gallons per irrigated acre in 2004 (figure 4).

The reason for this reduction is not obvious. There was an increase in precipitation in 2004 over 2002 and 2003, but the increase from 2003 to 2004 was not substantial. One possible explanation is that the drought of 2002 forced courses to invest in a great deal of water saving strategies which then carried over to 2003 and 2004. Water usage did not decrease in 2003 due to courses watering the turf heavily to help the grass recover from the drought. After a only slightly below normal water year in 2003,

courses were then able to fully realize the water savings of the capital investments in 2004, again a year with only slightly below normal precipitation (figure 5).

The source of water used by golf courses tends to be somewhat variable. From 2000 to 2003, the general trend saw a decrease in surface water use in favor of reclaimed water. In 2000, surface water accounted for 61% of total golf water use. That number declined to 59% in 2001, 52% in 2002 and 51% by 2003. Meanwhile, reclaimed water usage rose from 10% to 20% over the same time period. 2004 saw a departure from the trend with surface water usage increasing markedly to 60% of the total while reclaimed water decreased to 7%.

The price that golf operators face varies greatly from course to course. Water prices ranged from some city owned courses that do not face any volumetric water price, to courses that pay over \$2 per thousand gallons of water. The average amount paid per thousand gallons of water was \$0.51, but this had a standard deviation of 0.63. Of the courses that responded to the survey, 43% do not face any volumetric water price. For the remaining 57%, the average water price was \$0.91 per thousand gallons.

Potable water was the most expensive source for water, averaging \$1.25 per thousand gallons, followed by surface water at \$1.21, reclaimed at \$0.93, and well water at \$0.85 per thousand gallons. Most respondents who listed well water indicated that the only cost they accrued from this irrigation source was the pumping costs, and that was matched with no marginal cash cost for the water itself.

The majority of the water used by golf courses in Colorado comes from surface water rights owned either by the course themselves, owned by the municipality that owns the course, or leased. The price of this surface water varies greatly from course to course

with some paying as much as \$250 per thousand gallons and some paying as little as \$0.21 per thousand gallons (\$47 for a share of a ditch company water share which was equivalent to 0.7 of an acre foot).

It was determined that, on average, courses that faced a charge for water used 20% less water per irrigated acre of course than did courses that faced no per unit water charge. Courses that did not face water charges tended to be city owned public courses and the municipality provided the water to the course. The course managers did not see the water charge and therefore there was no marginal cost of using irrigation water. Additionally, many of these courses indicated in the comments section of the survey that water price was not an issue, however water availability was a problem. Instead of controlling water usage through price, cities tend to be using the command and control technique of water rationing during drought times. The courses, then, face the ever present risk that the water could be cut off at any time and, regardless of its relative value to golf course operators, they would not have access to irrigation water at any price.

Quotas are generally considered an economically inefficient policy tool. Economic efficiency is defined as the greatest level of benefit at the lowest possible cost so efficiency is realized when the marginal benefit of a unit of a resource equals the marginal cost of that resource for every potential user of the resource. We commonly assume that the first acre-foot of water generates more benefit than later units of water which is realistic in as much as the first acre-foot is likely to increase yields or allow more output than additional acre-feet. In the case of agriculture or turf grass management it is also common to assume that at some point too much water is a detriment and

decreases output by drowning the crops or turf. In order to insure that a socially optimal outcome is achieved, the equimarginal principal must be satisfied (equation 3.4).

$$\frac{MB_1}{P_1} = \frac{MB_2}{P_2}$$

The principal insures that producers will use water so that at the margin it generates the same benefit for all courses and will maximize total benefit of the water use to society. If equation 3.4 is not satisfied, then society could be made better off by allocating water from the activity with the lower marginal benefit to the activity with the higher marginal benefit. This is not the case under strict water quotas.

For example, if water is available to every potential user at \$10 per acre-foot and assuming water has decreasing marginal benefit (each additional unit of water does not increase yield or increase happiness as much as the preceding unit did), then users will consume water up the point where their marginal benefit of an additional unit of water equals the marginal cost, or \$10 in the example (figure 7). To use more would mean that the user is paying \$10 for the water and generating less than \$10 of output from it. Likewise, if the producer used less than that amount of water they could spend \$10 on an additional acre-foot of water and get more than a \$10 benefit from it. If \$10 is the market clearing price where total supply equals total demand for water, and there were no market failures, then this would yield an economically efficient outcome where the greatest benefit was achieved at the lowest cost. In contrast, a quota system where golf operators face no marginal cost but potentially face an across the board reduction in water availability introduces the opportunity for economically inefficient allocations of water.

The addition of marginal water costs to every course in the study is a policy tool that is examined in the PMP model. It is theorized that the addition of a marginal cost for

water will reduce golf course water usage while removing the threat of whole scale restriction on golf water usage. Different water prices will be examined to determine the expected water savings at different prices, how those prices will affect golf course operations, and how much revenue cities will generate from that water.

It was also found that for every one percent increase in native grass rough, water usage decreased by 0.83%. This averages out to an additional acre of native grass rough, reducing course water usage by just over 541,000 gallons a year. It is only reasonable that rough and out of bounds areas be considered for conversion to native grass, and since the average golf course in Colorado has 63 acres of rough, this means that conversion of an average course from turf roughs to native grass roughs will result in a total water savings of over 34 million gallons of water per year per course.

The upfront cost of installing native grass roughs can be considerable with some native grass seed or sod varieties costing considerably more than conventional turf varieties. Two species suited to Colorado, blue gramma and buffalo grass, can be planted from seed and either broadcast or drilled at rates of 20 pounds per acre. Both grasses, drilled in rows at 10 – 20 pounds per acre, form established stands within one growing season. Despite seed costs of \$10 - \$13 per pound, long run savings from diminished water and fertilizer requirements more than offset the initial cost of instillation. The greatest barrier to native grass rough adoption has been aesthetics (Voigt and Tallarico 2004). There is some reluctance to fully convert to native grass roughs because of the view that native grasses create an “unkempt” look. The results of this study indicate that there is a great deal of potential water savings from the conversion of rough acres to native grass. Overcoming this aversion to natural looking native grass areas, even if it is

a few acres of the most remote rough areas, can yield significant water conservation. This study serves to estimate the marginal economic benefit of converting even small areas of rough to unirrigated or partially irrigated native grass.

PMP Model Results

Simulation 1 – Uniform Marginal Water Cost

Instituting a uniform marginal cost to golf course water users reduced the amount of water that was used in golf, increased the amount of native grass acreage, and increased the total investments in irrigation capital. This result is consistent with economic theory and, due to the high percentage of courses that face no marginal cost for water, it is intuitive that moving from no marginal cash cost for water to having courses pay a volumetric based water cost will reduce water use. If demand for water is anything less than totally inelastic, an increase in the price will reduce water use.

Connecting this with data collected from representative courses, public golf courses that do not incur marginal water prices tend to report between 20% and 25% more water use per irrigated course acre than do courses that do face a marginal cost of water. It is estimated that if every course paid the mean price for water already paid by the courses that did have a marginal water cost, which was \$0.93 per 1000 gallons, the estimated annual savings of water would be 3 million gallons.

This savings, however, would come at a cost to golf courses. It is estimated that imposing the uniform water costs would increase the total water expenditures for the golf industry by 40%. This results in an estimated increase in total expenditures of \$6.8 million. The water expenditure, however, is such a small portion of the total golf course

operational expenditures that this increase in the water expenditures would, on average, result in only a 2% increase in the total golf course expenditures.

The financial impacts on courses, however, vary greatly from course to course depending on whether the course currently faces a volumetric water charge. There are some courses that would pay less than they are currently paying for water and some which would pay more. On average, the addition of the uniform volumetric price would result in courses devoting roughly 6% of their total expenditures to water, up from the current level of just over 3%. However, with the addition of the uniform water charge, some courses would pay as much as 14% of their total operational budget for water and some would pay as little as 2.3%. This is up from the 0% to 11.6% they currently pay, but this range may tighten once courses responded to the changed input price through water-saving technology, improved water management practices or course redesign.

Simulation 2 –Water Availability Quotas

The fact that the implementation of a water price (cash cost) reduces water use is not remarkable, however, the estimated effect of the increased water price on golf course operations can now be compared to other water conservation policy options such as quotas. The possibility of a hard water quota is a very real perceived threat on the minds of many golf course operators. The most common comment given on the survey was that the price of water is not the problem, it is the availability.

The threat of a shutdown in water deliveries looms over the golf course operator. It was estimated by respondents that most could incur a 25% reduction in water availability before they would need to reduce the number of rounds played to preserve the

integrity of the course. The responses to this question were highly variable, however, with some operators believing that they could incur an 80% reduction before course use would need to be reduced and some feeling that they could not reduce irrigation at all without restricting the number of rounds played.

Golf course operators were also asked how much of a reduction in water usage they could sustain before they would need to shut the course down for one day a week to limit damage to the turf. On average it was estimated that the courses could sustain a 50% reduction in water usage before partial shutdowns were needed. To analyze the effects of a water quota, a simulation was constructed that limited water use to 75% of the current water use, or a 25% reduction as a second scenario. This simulation mimics the water savings of the first simulation so that the effects on golf course revenues and costs can be directly compared.

In this simulation, golf course rounds were decreased 25% to account for the reduction in capacity from the water quota. This reduction in rounds played created a \$166 million dollar reduction in total golf revenues. This level of reduction put the entire golf course industry in jeopardy, causing the revenues to fall to just 2% over total expenditures since costs would not fall to a similar degree because of fixed costs and the inability to make partwise reductions in some variable costs.

Simultaneous Simulations

Another way to look at the effects of water price changes and water availability on golf course operations is to look at simultaneously changing both the prices and the availability of water to look at the response of the courses (through the simulation

model). This allows for interaction effects among both policies. A total of 15 simulations were undertaken which analyzed the pair wise combination of a 25% reduction, 25% increase, and no change to the price of water incurred by all courses against a 50% reduction, 25% reduction, 25% increase, 50% increase, and no change in the available water supply to each course. For the purposes of these simulations, the base price of water incurred by all courses was set to the mean price of water, \$0.93 per 1000 gallons.

Figure 8 shows the simultaneous effects of varying both water price and water availability on the aggregate net revenues of the courses in this study. The golf course respondents indicated that a 25% reduction in the availability of water would not seriously impede operations in a normal water year. After that point, however, the slope of the net revenues with respect to water availability is steeper than the slope of the net revenues with respect to water price, indicating that increasing the water price instead of the water availability would be the optimal choice.

Figure 9 shows the relationship between water use and water availability and price. Again, water usage is not significantly affected by changes in availability until the availability drops below 75% of normal usage. After that point a limit on the supply of water greatly decreases usage. Water usage with respect to price increases slightly as price decreases and decreases steadily as water price increases. After the water supply goes below the 75% threshold, water usage falls off much more quickly with the water quota than it does when water prices fall below the original level. The policy implications here indicate that water usage can be more quickly altered with pricing increases, but after reaching a threshold, water usage drops off drastically.

Conclusion

From the PMP model it was determined that instituting a marginal price to water is a more economically efficient solution than instituting an absolute quota on the amount of water that can be used by any given course. The data obtained from the survey of golf course operators indicated that over 40% of courses do not face any type of volumetric based water cost. This fact severely limits the ability of policy makers to control golf course water usage by increasing the water price.

Currently golf course water use is regulated by perceived threats and realized water quotas. In 2002, a very serious drought year, many courses were forced to shut down for certain days of the week, increase tee intervals, or shut down for the off-season. This had a serious negative effect on golf course operations and awakened managers to the threat of water reductions on profitability. Because the imposition of hard water use quotas for all courses violates the equimarginal principal, it would be more desirable to have the ability to use price as a water control, rather than depending on quotas. Golf course operators intuitively know this and a common remark garnered from the survey was that the price of water was not what the courses were concerned with, it was the availability. This study set out to verify that instinctual response with expected outcomes of several water management policy instruments.

In order to examine the use of both water quotas and water price on golf operations, a uniform water price was imposed on courses to simulate how they would respond. It was found that the imposition of water prices had less of an impact on course profitability for the same level of water reduction than did water quotas.

When examining the simultaneous alteration of both water price and water availability, it was found that increasing the price gradually reduced water consumption while imposing water quotas has little effect on water usage until water availability decreases to 75% of normal. After that point, water usage decreases sharply. Similar effects are observed for water policy on course profitability. Increasing the price of water has an immediate but minor effect on course profits. Limiting the availability of water has little effect on course profits until water availability decreases to 75% of normal. After this point golf course operations are negatively affected and expected golf course profits fall off sharply. Golf courses seem to be quite resilient to limitations in water availability up to a threshold. After reaching that threshold limitations in water availability begin to severely constrain course operations. Increases in water prices are expected to decrease water usage immediately and decrease use moderately as water prices increase.

An additional, possibly under explored, avenue for water savings on Colorado's golf courses is the use of native grass roughs and out-of-bounds areas. It was found that a 1% increase in native grass roughs decreases water usage by 0.83%. Additionally, native grasses can use less than half of the water of conventional turf grasses and remain healthy, thus mitigating the effects of water quotas. The up front costs associated with establishing native grass areas can be considerably higher than conventional turf, however, the savings on water and fertilizer will make them less expensive to maintain over time.

The potential for native grass adoption to reduce water use on Colorado's golf courses is a fertile topic for future research, especially with respect to consumer demand

and marketing aspects of a changed golf experience. It is unsure, for example, how Colorado golfers would respond to native grass roughs and out-of-bounds areas, either negatively because of perceived loss in aesthetics or positively if golfers appreciated a course's attempts to be more environmentally sound. If public courses were to adopt native grasses at a rate higher than private courses, it is currently unknown if golfers would change their current preferences for the respective course type. A survey of golfer preferences and a more detailed exploration of the reasons why courses do or do not incorporate native grass roughs would need to be undertaken to explore this issue further.

Number of Golf Courses and Population in Colorado From 1898 to 2004

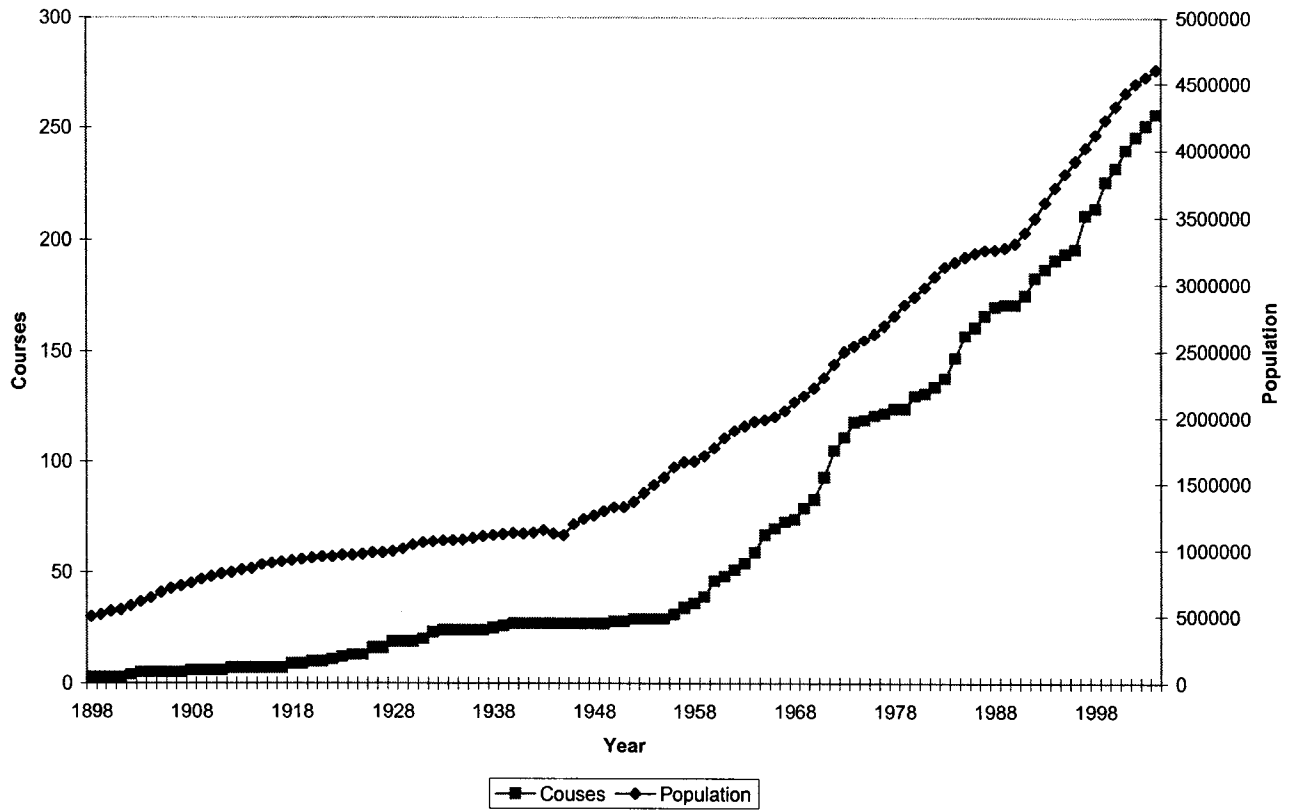


Figure 1 - Relationship between population and number of golf courses in Colorado from 1898 to 2004

Colorado Population vs. Number of Golf Courses in Colorado

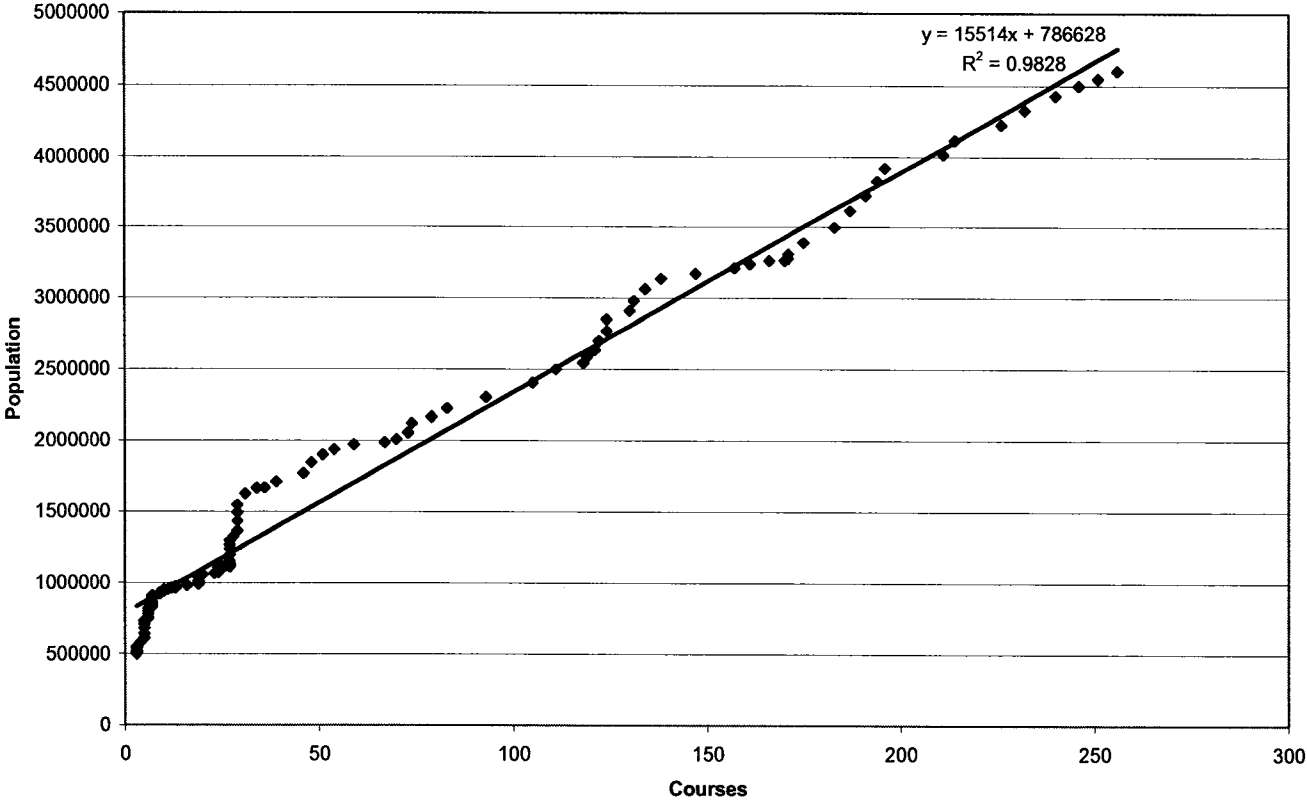


Figure 2 - Regression of the number of golf courses in Colorado on the Population of Colorado

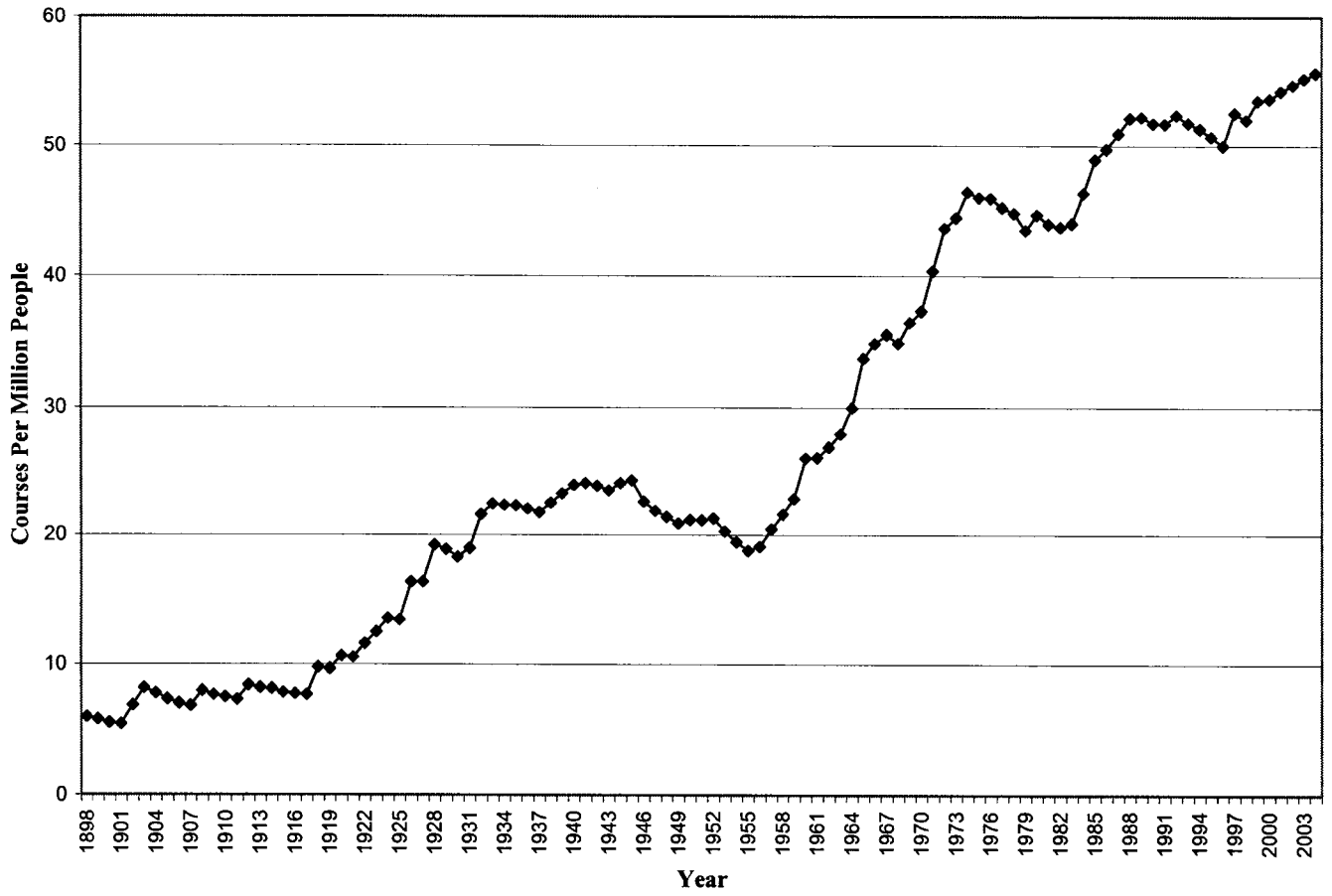


Figure 3 - Per Capita Increase in the Number of Colorado Golf Courses, 1898 to 2004

Total Water Use Estimate for Colorado's Golf Industry by Year

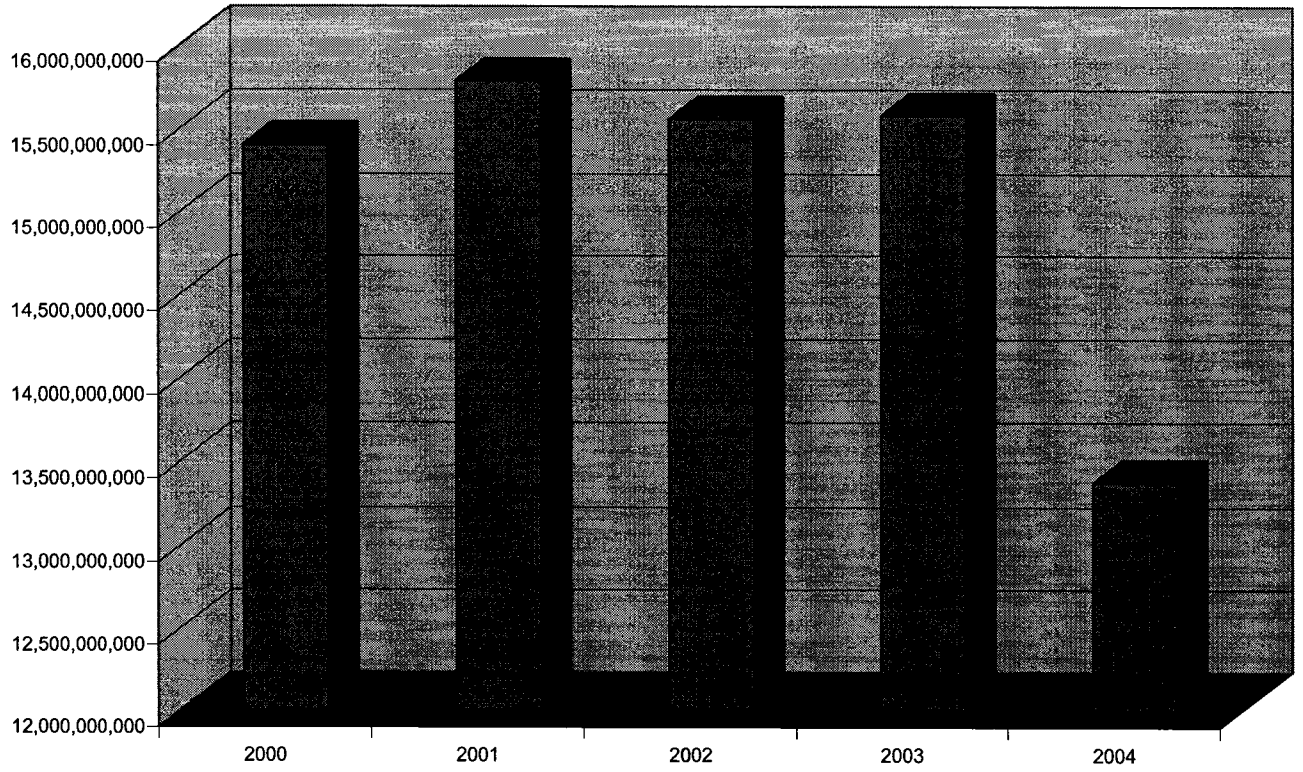


Figure 4 - Total Colorado golf course water use, 2000 - 2004

Gallons of Water Used per Irrigated Acre of Turfgrass by Colorado's Golf Industry by Year

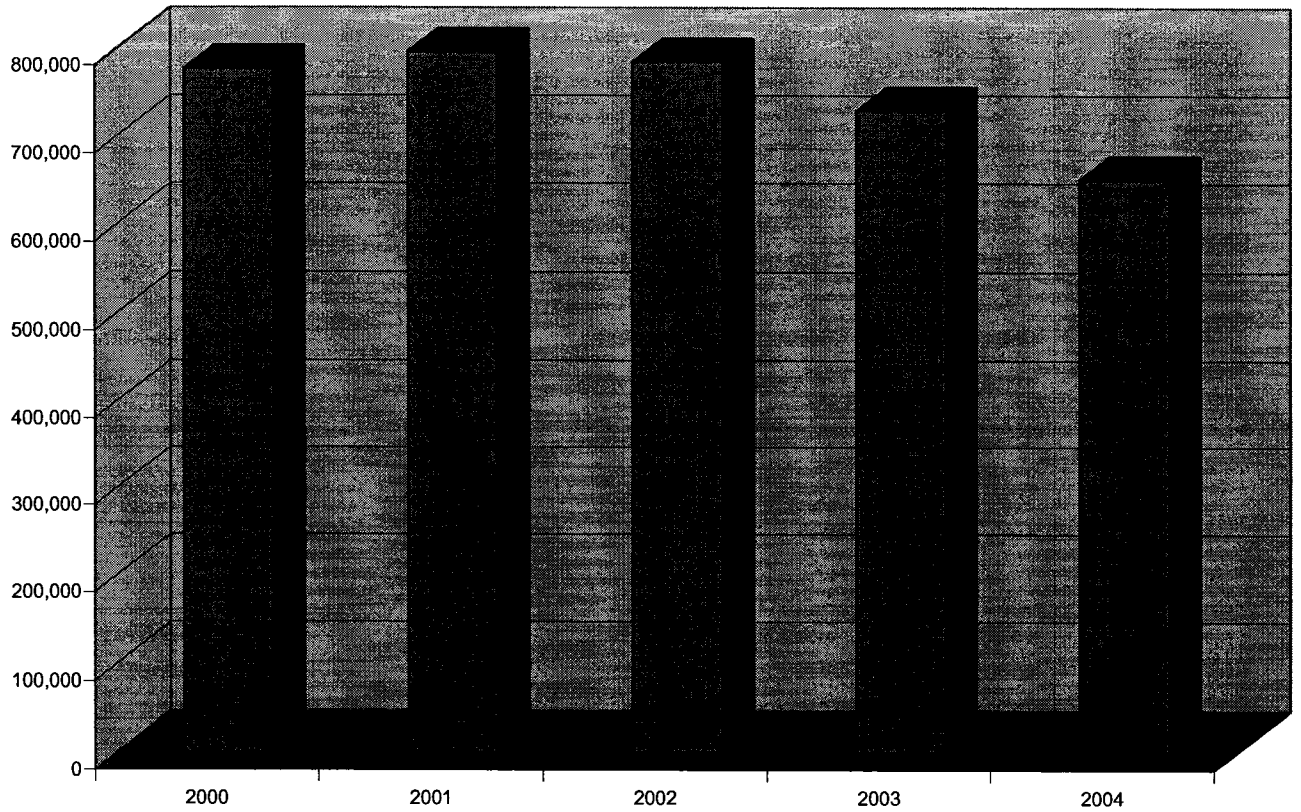


Figure 5 - Total Colorado golf course water use per irrigated acre, 2000 - 2004

Annual Precipitation for Dever, CO

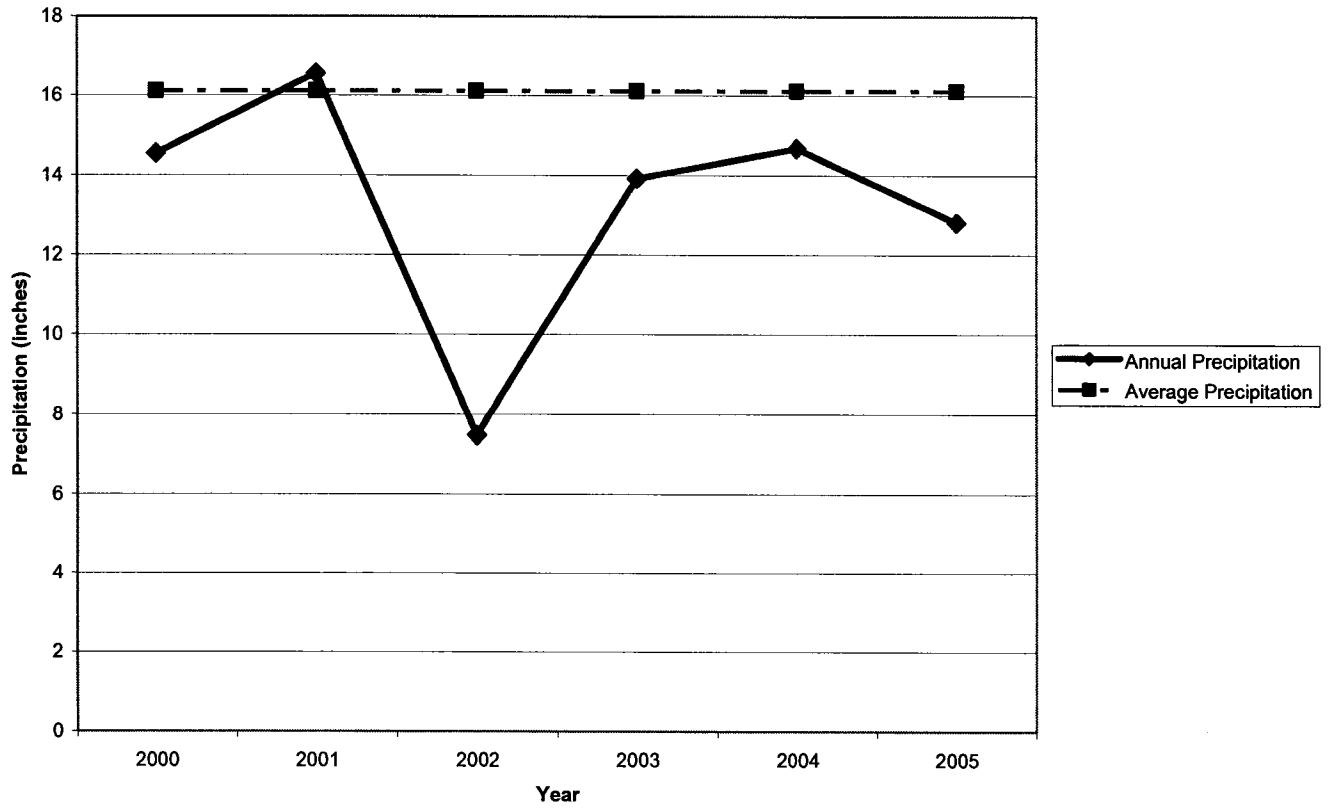


Figure 6 - Annual precipitation for Denver Colorado, 2000 - 2005

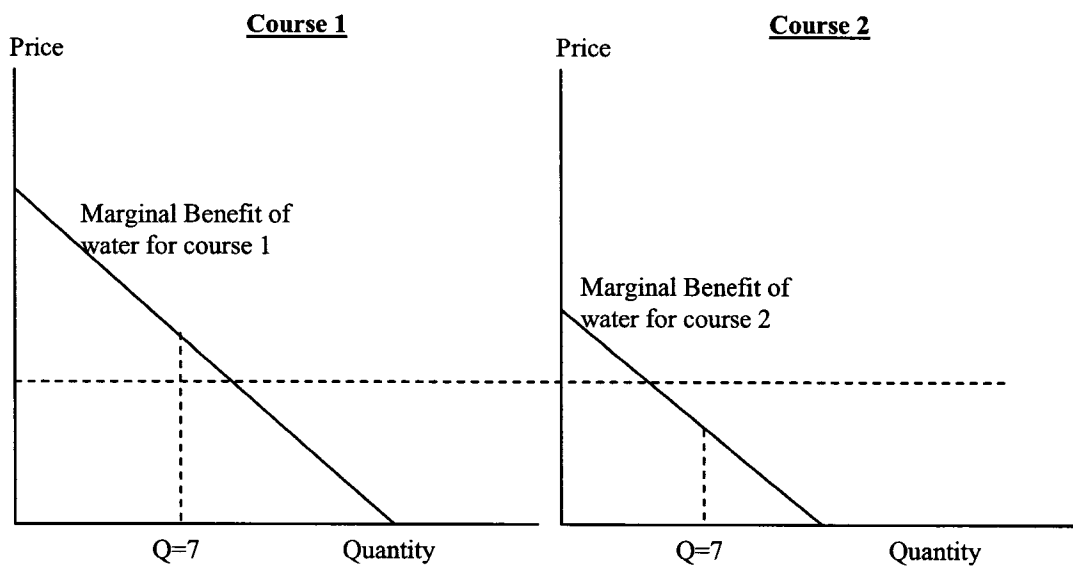
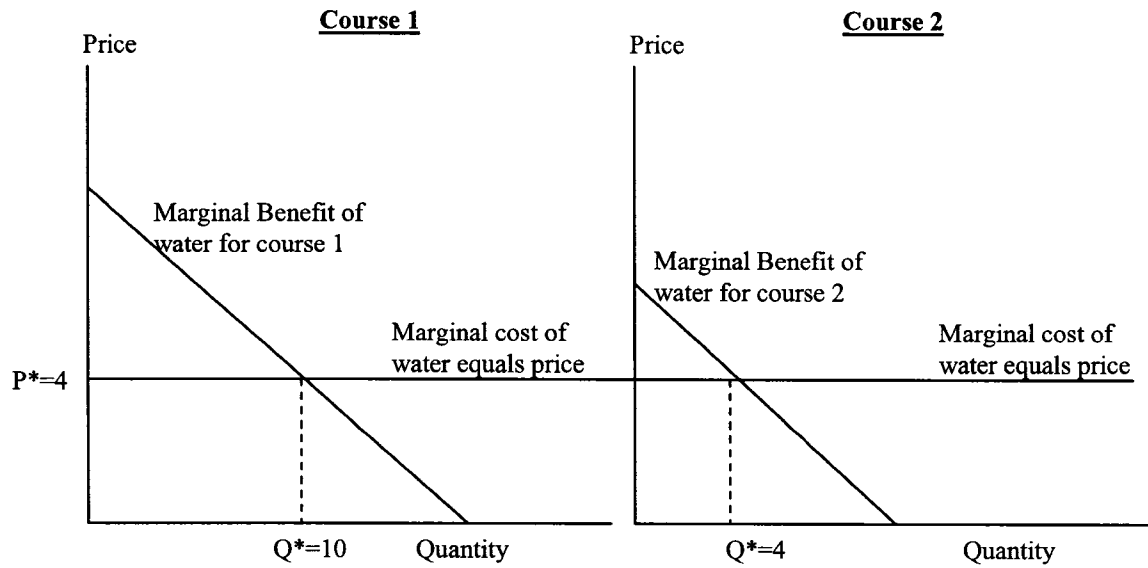


Figure 7 - Policy differences between pricing and quotas

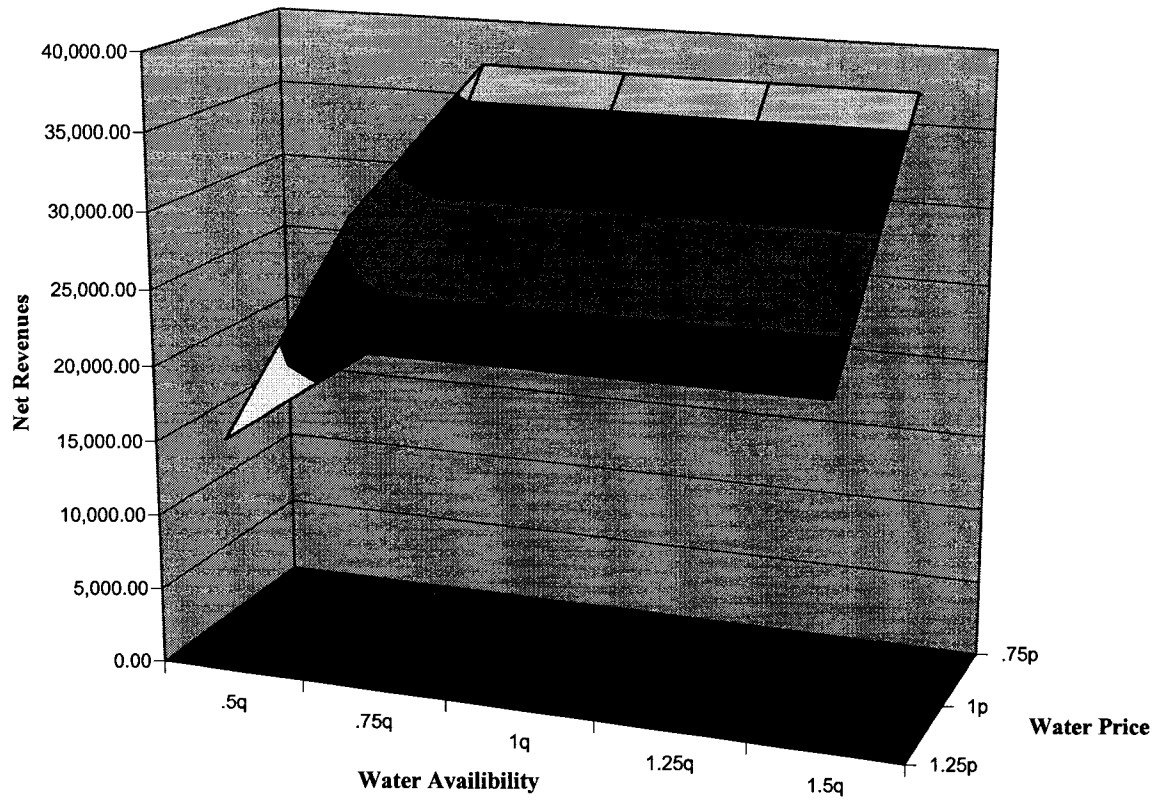


Figure 8 - Course net revenues by water price and availability

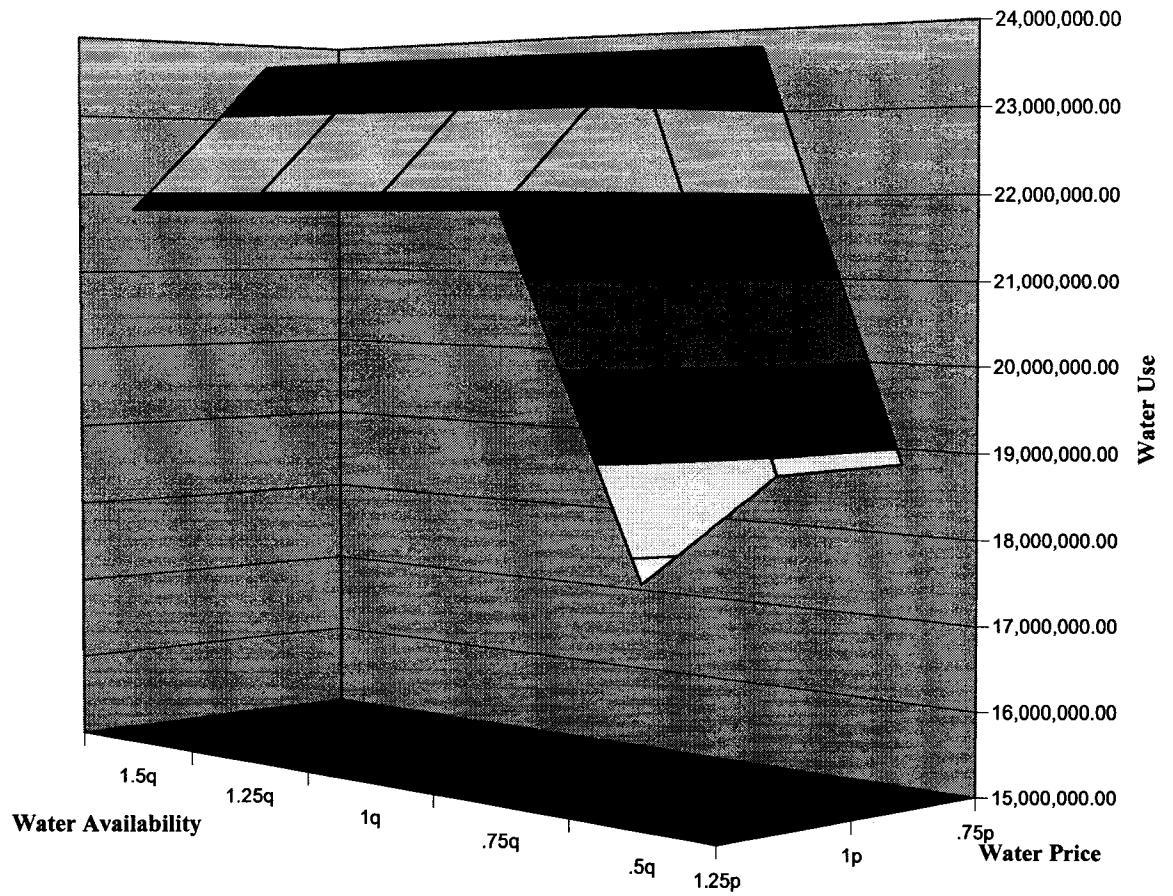


Figure 9 - Course water use by water availability and price

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CHAPTER FOUR

Concluding Remarks

The irrigated use sector contains a large reservoir of water for agricultural production, conserved open space, and infra-structure that has long-lasting value to Colorado. To what extent that resource should support the increasing urbanization of the state will be determined by voluntary market transfers and regulatory choices. Under Colorado law, conditional water rights and water storage rights will continue to function as an essential element in use of the state's allocated share of interstate waters. The needs and values of twenty-first century citizens will shape and reshape a water law which is well-grounded in the history and heritage of this magnificent land.

JUSTICE GREGORY J. HOBBS, JR.
COLORADO WATER LAW: AN HISTORICAL OVERVIEW (1997)

The issues surrounding agriculture, growth, land and water in the Western United States is obviously multifaceted and goes beyond the scope of this study. The quote above summarizes well many of the issues facing water and growth in Colorado and the West. The purpose of this study was to provide insight into the relationships between agricultural viability, population growth, and natural resources use through the use of three distinct economic modeling tools focused at three different levels of the Colorado and Western economy. Modern agriculture is a complicated business with the multifaceted objectives of wealth accumulation, long-run natural resource management and farm household utility maximization. For these reasons, Blank and others have argued persuasively that there are numerous factors that will contribute to a gradual decline in the relative importance of agriculture in the American economy, primarily the competition for resources with other, more profitable (at least in the short run), industries.

There are, however, factors that will contribute to continued strong agricultural sector performance. The first chapter of this study contributes an empirical estimation of that factors that currently affect financial performance, with predictions on which are likely to exacerbate or mitigate the decline of agriculture in the 413 counties of the Western Contiguous United States. Consistent with a theoretical gravitational model, it is found that counties with a low natural amenity index but high mean temperatures in January currently exhibit, and are expected to have, the highest net farm incomes per value of land and buildings. Remote counties with low population pressures will also continue to perform well with respect to net farm income per value of land and building.

Not surprisingly, the results indicate that climate is an important factor in the ability to generate high net farm income per acre. The theoretical model also predicts that, as urban centers grow and bid up land prices, net farm income per value of land and buildings decreases substantially. As the opportunity cost of land and water in proximity to urban development increases, it is transferred to higher value agricultural production or out of agricultural production. So, after controlling for climate, natural amenities are negatively associated with higher net farm income per acre likely due to their contribution to upward pressure on residential development. The relationship between climate and natural amenities is examined more closely and it is found that the residuals from the regression of natural amenities on average temperature in January are a very good predictor of net farm income per value of land.

After controlling for land value, field crops are again shown to contribute favorably to farm financial performance, indicating that in areas where land costs are low because of fewer alternative opportunities for investment, field crops still enjoy a

comparative advantage. Moreover, agriculture still controls the majority of the land and water in much of the West, including Colorado. If other sectors in the economy are to obtain these primary factors of production, they are going to need to procure these resources from agriculture. This fact, along with the continued strong performance of the agricultural sector in limited areas, insures that agriculture will remain an important sector to the regional economy for the foreseeable future.

The second chapter focuses more specifically on the economics of resource transfers from agriculture to more urban development enterprises. An equilibrium model of the Colorado economy shows that, in order to sustain a 10% increase in the population of the South Platte River Basin of Colorado, and the corresponding increases in high growth industries, agriculture loses an estimated 1.5% of its land and 5% of its water. What is masked in this result is that land and water use in intensive agriculture and livestock agriculture is likely to increase as extensive crop agriculture loses land and water, due to its declining comparative advantage. It was found that a larger percentage of agriculture's water was transferred to other sectors than was its land. This resulted in a great deal of land transferred out of relatively water intensive extensive crop agriculture to relatively land intensive livestock agriculture.

Under this scenario, the total output of the agricultural sector is expected to decrease by between 1.5% and 3.5% in real terms, while the non-agricultural sector is expected to increase by between 16% and 17%. The gross regional product (GRP) is expected to increase by an estimated 15% to 16% in real terms in all simulations. The real losses to agricultural output total an estimated \$30 to \$70 million while the real output increases to other sectors total an estimated \$23.4 to \$25.5 billion. As urban

centers, which in the West are generally located in high natural amenity areas, grow, agriculture will add some higher intensity production as land and water are transferred out of agriculture.

Finally, the golf industry, an industry which is both highly related to urban population growth and a significant user of municipal water, was analyzed to determine how the increased water demand resulting from the anticipated growth of the industry can be mitigated by policy tools. It was found that enacting a unit based marginal cost for water created a more efficient solution than does enacting hard water quotas. It was also found that significant water gains can be obtained from encouraging courses to increase water conservation practices, specifically for this modeling exercise, native grass use in rough and out-of-bounds areas. It is clear, however, that compared to other agricultural uses, golf generates a great deal more economic activity per unit of water than do field crop production. The growth in the population will result in the growth of the golf industry and it is likely that the water needed for the growth of this sector will need to be obtained from both conservation and the transfer of water from agriculture.

The agricultural sector will develop along side the larger economy. The high rates of population growth in the West will present both a challenge and an opportunity to the agricultural sector. As Justice Hobbs is quoted above, resources will move from sector to sector in order to meet the needs of future generations. This has measurable estimated impacts on the historically dominant economic sectors, such as agriculture, that have driven the economy of this region over the past couple centuries. Most experts would agree that agriculture will continue to be important well into the future, even if there is a transition to considerations of natural resource management rather than food

production among agricultural producers and policymakers, as the most recent Farm Bills would suggest. The results presented here serve to partially inform how resources are managed and to meet the needs of future generations of residents “in this magnificent land,” in hopes of motivating future research on how to most effectively plan for, manage within and create policy instruments to influence what appear to be unstoppable forces drawing water and land from agriculture to urban areas.