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Examining Impacts on Water Demand Resulting from Population and Employment Growth Using a Regional Adjustment Model

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I am submitting herewith a thesis written by Steven Blake Thomas entitled "Examining Impacts on Water Demand Resulting from Population and Employment Growth Using a Regional Adjustment Model." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Economics.

Christopher D. Clark, Major Professor

We have read this thesis and recommend its acceptance:

Dayton M. Lambert, William M. Park

Accepted for the Council:
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(Original signatures are on file with official student records.)

Examining Impacts on Water Demand Resulting from Population and Employment Growth Using a Regional Adjustment Model

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Steven Blake Thomas
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Abstract

This thesis examines the currently available water use data and its limitation for use in scientific research. The first chapter offers a description of the current nationwide water data including descriptions of collection methods and trends found within the data. The varying collection methods used result in inconsistencies within the datasets and between the years. These inconsistencies have resulted in the data being used more as a point of reference than in nationwide empirical analysis of water use. There has been a calling for systematic improvements to the data, which could contribute to greater empirical analysis taking place at the national level. Chapter 2 acts as a caveat to Chapter 3 which employs the nationwide data to examine the impacts of population and employment growth on water demand. The growth dynamic of population and employment has been shown to impact resources utilized by households and firms such as land absorption rates. This thesis applies a regional adjustment model to model the impacts of population and employment growth on water demand. Furthermore, the thesis projects whether water use per person and water use per employee is adjusting towards a future steady state equilibrium. By doing so, this work looks to further the calls for improvements to the Nation's water use data.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

Part 1: Introduction

Better understanding of the use of water resources in the United States is becoming increasingly important as population and economic growth continue. Water is a critical element to human well being, and a primary input to the production of goods and services (Guan and Hubacek, 2008). The role of water in economic activity is not confined to agricultural uses, but rather, is critical for all industries from power production to food manufacturing. Additionally, population growth and migration will continue to change how much water is needed and where. Migration is not necessarily deterred by the absence of available water resource as demonstrated by the increasing growth in the west (Reisner 1986).

Complicating the challenge of managing water resources are the impacts of climate change and human impacts on water supplies. The debate continues as to the true effects of climate change and its impact on the Nation's water resources, but understanding the potential risks of such a change is being given considerable attention and resource managers will need to plan accordingly. Projections include increases in frequency and intensity of floods and droughts (Kundzewicz et. al 2008). Human activities provide additional stress to hydrological systems through mechanisms such as relocation and pollution. One of the reasons population flows are not deterred by the absence of water resources is because of human resourcefulness in storing and distributing water supplies. This has taken place through the construction of dams and aqueducts, or by the mining of deep aquifers (Gleik 2000). While an aquifer may be considered part of an area's available water resources, human use of some to these waters is referred to as mining because the water is not replenished at a rate equal to withdrawal (Kim, Moore, and Hanchar, 1987).

Human impacts on water resources as a result of pollution are a global issues and one which has been given considerable attention in the scientific community. The use of water resources in a particular way which makes those resources unavailable for further use is the equivalent of the consumption of those resources. Return flows from industrial activity and agricultural runoff have resulted in numerous negative ecological impacts. These ecological impacts result in higher treatment cost.

Despite the concerns over the future of water resources, scientific based assessment has been limited by lack of funding and access to reliable data. The National Research Council published a report in 2001 calling for the need for a cohesive research vision for water resources in the twenty-first century (NRC 2001). The research areas were applied broadly to three categories: 1) water availability, 2) water use, and 3) water institutions (Vaux 2005). This thesis examines the second of these three categories of water use, and how the lack of nationwide data has made this area of research difficult.

The United States Geological Survey (USGS) is currently the leader in collecting and distributing water use data for the nation. The USGS has produced a report on the Nation's water use every five years which documents the water use of the country by category of use. While this report is a valuable asset for understanding where the country uses water, its use in scientific study is limited due to the inconsistencies in collection methods for the data. While these collection methods may be the best available assessment of use, they do not necessarily reflect the actual withdrawals taking place. Data collection methods include the use of per capita coefficients along with actual surveying of use.

The employment of per capita use coeffients in the collection of the nations water use is understandable when considering the scope of work needed to collect such a vast amount of data. In 2005 it was estimated that the United States was withdrawing over four billion gallons of water per day (Kenney et al. 2009). The resources needed to account for this magnitude of data are considerably large, and suggesting that further resources should be applied to improve the data is debatable. But understanding that systematic improvements to the Nation’s water use could provide researchers the resources needed to better prepare for the future challenges of managing the Country’s hydrological systems.

One area of emphasis should be on understanding the flows of population and economic activity across the country, and the impact on resources consumed by the two. The investigation of population and employment growth, and the effects of the two on one another has been underway as early as the 1970’s with Steins and Fisher’s (1974) examination of population employment dynamics. Recently this analysis has blossomed into a further investigation of how the two impact the resources they consume such as land (Carruthers and Mulligan, 2005). This research applies this framework to water use in an attempt to better understand the population employment growth dynamics and the impact on water use.

In doing so, an example of how a nationwide water data set could be applied to an economic analysis will be presented along with an examination of the limitation of the currently available data, highlighting what aspects of the Nation’s current water use data could be improved upon to benefit the research community. The goal of this research is to highlight the impacts of this growth dynamic between population and employment as well as highlight a potential use for an enhanced database.

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Part 2: Water Data

Abstract

This Chapter aims to outline the currently available water use data including concerns around collection methods and trends found over time. The United States Geological Survey is at this time the major collector and distributor of the Nation's water use data. The difficulty in collecting such a vast amount of data and waters ubiquitous use across the nation has contributed to the use of per-capita coefficients. The use of per capita coefficients combined with actual surveyed data creates issues with consistency within the data which has resulted in the national water use survey being used in few empirical analyses. While meta-data is not provided on the specifics of where the coefficients are used, a suggestion for identifying where these methods are taking place is provided, which is done by examining the levels of instate variability of per capita domestic use. The Chapter goes on to outline how researchers have relied more on micro data sets from sources such as as municipal utilities, which limits analysis in terms of geographical scope. Trends in the data are then explored as a lead-in to the next portion of the thesis. These trends include an observation of the decrease in total water use since 1985 in the face of population and employment growth suggesting increases in efficiency. Additionally, the population served data in the surveys, in terms of source of domestic supply either from a public supply utility or a self supplied well, is explored. Finally publicly-supplied waters are examined over increasing population densities to highlight the impacts of increases in population levels on per capita water demand.

Introduction

When it comes to conducting economic analysis of water use in the United States, one of the major constraints is access to adequate water data, such as household consumption and prices. Available and reliable water data is far less accessible to researchers than data on other commodities for several reasons. Mainly, the number of water users is quite large and use is not always reported, and possibly for reasons of privacy, and when it is available, its accuracy is difficult to verify. Despite the sparse data availability, important studies have been conducted to examine water's role in socio-economic development as well as the impacts that price, incomes, and other factors have on water use.

A major frontier in the future of water use analysis will be the sharpening of the available water use data on both a local and national scale, by improving the consistency of collection methods and distributing the meta-data on said methods. The United States Geological Survey (USGS) is, at this time (2012), the major collector and distributor of data on the Nation's water use. The USGS has been producing a report on the Nation's water use for over 50 years. While this service is valuable to water researchers, the challenges associated with collection results in data inconsistencies. This lack of consistency is a result of different collection methods used between jurisdictions. It is not fully known what impacts data inconsistencies have had or will have on previous or future research. At the very least, predictions using nationwide water use data will have to be made with less confidence until the data collection is improved, collection methods are standardized across jurisdictions, or the problematic areas within the data are indicated and can be avoided.

Alternatives to the USGS water use data have been used on regional and municipal levels, allowing more precise estimates of price and income elasticity of water. While it would be beneficial to have a broader understanding of the Nation’s water demand with similar precision to the regional or municipal studies, the cost of creating a macro level data set needed to do so would be large. An intermediary step would be to identify holes in the current data, such as jurisdictions using per capita coefficients versus actual measurements, and allow researchers to filter data which lacks the accuracy needed for various analyses. Thus, what is needed is clarity on how current data is collected and a plan on how to systematically improve and standardize this process. This could be done by producing supplemental materials (i.e., metadata) to go along with the nationwide data sets which describe and identify which collection methods were used and where. Thus, the objectives of this chapter and the subsequent chapter are to explain the current water data availability, including the USGS data set and other data used in the current literature, explore concerns with this data and how improvements in the data could foster a better understanding of water demand use across the country.

Review of Literature

The geographic size of the United States and high volume of water users makes nationwide assessments of water demand difficult. First, there is the difficulty associated with collecting water data due to its low relative value and its ubiquitous and heterogeneous use. Second, the varying climates across the country and socio-economic settings impact regional demand, making a nationwide assessments of demand less accurate. These challenges have pushed research efforts towards more micro assessments of water use. The obstacles to understanding our Nation’s water needs have been recognized from an early stage in the literature (e.g. Wong, 1972). Wong (1972) used data from the City of Chicago and the Cook County survey of water rates to estimate municipal water demand. Wong was quick to point out concerns with the data including aggregation, 'guestimates' as opposed to measurements, and lack of identification of source, either ground or surface water.

Early water demand analyses dealt mostly with price elasticity and demand forecasting in an effort to contribute to municipal planning (Howe and Linaweaver, 1967). Using city or multi-city data, primarily from urban areas where data from local utilities was more readily available, researchers compiled data sets that combined individual household water use with other indicator variables to estimate demand. These indicator variables included dwelling characteristics, climate data, and price. The methods for collecting this data included surveying of households and combining local utility data with proxies for household characteristics[1].

A number of different household characteristics have served as a compliment to demand determinants. Size of household, i.e., the number of residents in the home, has been found to significantly impact water demand (e.g. Nieswiadomy, 1992; Renwick and Archibald, 1998; Cavanaugh et al., 2002; Piper 2003). For example, Cavanagh et al. (2002) found that for each additional person in a household, demand rose by 22%. Home age has also been shown to have a significant impact on demand as newer homes tend to have more efficient water using utilities and are less susceptible to leaks than homes with older piping (Mayer et al., 1999; Caanagh et al., 2002). In a study by Cochran and Cotton (1985) the number of single family versus multi-family homes in an area was shown to be significant indicator of per capita demand, where a higher ratio of single family homes equates to higher per capita demand.

Climate data has been included in some analyses with varying degrees of success. For example, rainfall and daily temperature have been shown to have a statistically significant effect

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[1] For example, home value multiplied by a coefficient to create a proxy for income.

on per capita use (e.g. Kenny et al., 2004; Hewitt and Hannemann, 1995; Neiswiadomy, 1992). A difficulty with including climate data is the uncertainty of weather combined with the limited scope of research, in terms of the length of study. Weather patterns are subject to trends or abnormal periods, such as droughts or times of intense rain. If a study takes place in a time of abnormal weather, the impact of weather-related variables could be skewed. For example, Michelson et al. (1999) described how pre- and post- test analysis of the effectiveness of water conservation methods did not take into account weather patterns such as drought.

While the effects of dwelling characteristics and climate on water demand have been investigated, the objective of most of the empirical research on water use has been to estimate the price elasticity of demand for water. To do so, water use and price must be available and measured accurately, as well as correctly applied to one another which is made difficult by the block rate pricing structure employed by many water supplying utilities, where price per gallon depends on consumption level. Nieswiadomy and Molina (1989) investigated the problems with water demand estimations under block rate pricing using 101 individual customers in Denton, Texas. They identified a problem of simultaneity, in which the price of water both determines, and is determined by, consumption. This problem raises the question of whether the price variable in the demand equation should be average price or marginal price, and a debate over whether water consumers observe price at the margin or the overall average price (Hewitt and Hanemann, 1995; Mckean et al., 2004). Howe and Linaweaver (1967) provided a convincing argument for the use of marginal price, yet the use of average price persisted in the literature (Neiswiadomy and Cobb, 1993; Michelsen et al., 1999). In a meta-analysis by Espey et al. (1997), the use of average price was shown to result in higher price elasticities.

Furthering the challenge of price specification is how to apply pricing data to the appropriate use of data, specifically dis-aggregated data. Hewitt and Hanemann (1995) described how fewer than half of the studies they surveyed used disaggregated household level data to model individual behavior. The problem with using aggregated data is that if data does not actually describe the individual household, but rather a typical household. This problem has been acknowledged from an early stage but has simply been ignored because the use of a correct specification would require information beyond what is commonly available to researchers (Martinez-Espineira, 2003).

While the debate continues with respect to appropriate model formulation and use of data, a rich literature currently exists which examines water demand using a myriad of different data sets and estimation techniques. The areas of study found in the literature range from single city settings to multiple cities or municipalities to state level estimations. Early studies examining demand at the municipal level include Cassuto and Ryan's (1979) use of water data from the Oakland, California area to forecast residential elasticity of water demand and Maidment et al.'s (1985) multivariate time series analysis of daily municipal water demand in Austin, Texas. More recent examinations of single city demand include Billings and Agthe (1997) and Fullerton and Elias (2004) in Tucson, Arizona and El Paso, Texas respectively. The use of multi-city data is prevalent throughout the water demand literature and was seen early on with Howe and Linaweaver's (1967) multi-city cross-sectional regression analysis of residential water demand and later Maidment et al.'s (1986) use of daily water consumption data from nine cities in Florida, Pennsylvania and Texas. Few studies have examined state-level data, with exceptions including Gottlieb (1963), who examined water demand in Kansas, and Franczyk and Chang's (2008) analysis of water use in Oregon. The water demand literature covers many types of analyses using a multitude of estimation techniques. For a more detailed review of this literature see Martinez-Espineinra et al. (2002) and Qi and Chang (2010).

Other studies have employed national water data bases similar to the USGS data set for other countries. Portnov and Meir (2008) examined convergence patterns of per-capita water demand in Israel using the Mekorot[2] data set. They examined a pattern of convergence in Israel’s domestic water sector, finding that areas with low per capita water use experienced larger growth rates in per capita use than areas with higher per capita water use. This observation was associated with water saturation in affluent areas that began with high per capita use of water, and a rising standard of living in areas with the low per capita use. Guan and Hubacek (2008) addressed the water needs of China using input-output models using water consumption data. Andreu et al. (2007) suggested an integration of an economic-hydrologic model into the discussion of the European Water Framework Directive.[3]

Another emerging trend in the literature is examination of water footprints. This literature is based on the argument that while traditional data sets will show water withdrawals for various sectors of the economy, such as agriculture and domestic uses, it does not fully capture total water demand as many of the products consumed within a country are produced abroad (Hoekstra and Chapagain, 2005). Schutte and Pretorius (1997) describe the ‘full water demand’ of an individual as all water necessary for consumer goods, transport, housing and job-creation. The notion of a water footprint was first introduced in the early 1990’s as an analogy to ecological footprints (Rees, 1992; Wackernagel and Rees, 1996; Wackernagel et al., 1997) and

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[2] Mekorot is an Israeli water utility company which supplies water to the whole of Israel, providing 90% of Israel driknking water.

[3] The European Water Framework Directive is an initiative by the European Union to have all member nations commit to achieving water quality in all marine bodies.

was closely linked to the concept of virtual water (Allan 1993). Virtual water is the volume of water required to produce a commodity or service. Hoekstra and Hung (2005) quantified the virtual water flows of international trade of crop products and similar studies have been conducted for livestock and livestock products (Chapagain and Hoekstra, 2003).

History and General Structure of the USGS Water Use Survey

Similar studies to those of Portnov and Meir (2008), and Guan and Hubacek (2008) have not been conducted for the United States. Empirical analysis of nationwide water data in the United States has been somewhat limited. The database in the United States with the most comprehensive report of nationwide water use is the USGS National Water Use Survey. While empirical analyses using USGS's water data have been limited (an exception is Franczyk and Chang's (2008) examination of water use in Oregon) the data has been used as a point of reference. Researchers will typically cite the data, or trends in the data, to support conceptual ideas, but appear less willing to use the data in empirical analyses, most likely due to concerns with the data, as will be discussed in the next section.

The USGS National Water Use Survey has been published every 5 years since 1950 (Kenny et al., 2009). Data sets from 1985 onward have been digitized and are available for public use. As described in the survey, water use is the total number of gallons withdrawn per day separated by category of use. Withdrawals are defined as water removed from the ground or diverted from a surface water source for a specific human use (Kenny et al., 2009).

Water use is reported for separate categories representing different types of human use. In the 2005 data there are eight use categories: Public Supply, Domestic, Irrigation, Livestock, Aquaculture, Industrial, Mining, and Thermoelectric. Previous surveys such as the years 1985 and 1995 included all of these categories except for Aquaculture[4] in addition to Commercial, Hydroelectric, Sewage Treatment, and Reservoir Evaporation. For a full listing of the data provided in the 1985, 1995, and 2005 surveys see Tables 1 and 2. It is interesting to note that the Commercial category was dropped, starting with the 2000 survey, given that commercial withdrawals, those for commercial facilities such as restaurants and hotels, could seemingly account for a significant percentage of demand in urban areas.

Within each category, water use is reported for fresh water withdrawals for both ground and surface waters individually down to the county level, as well as saline waters where they apply. The categories for which saline withdrawals do not apply include domestic and irrigation uses where only fresh water is consumed. The categories included in the surveys vary from year to year for the digitized data sets. However this variation does not preclude the categories from being used in combination because they gauge the Nation’s water use as a whole. For the most part, this means providing a comprehensive picture of the water use of every category for every county, but one exception is the 2000 survey where only quality estimates were reported at the expense of data comprehension.

The same categories exist in the 2000 and 2005 survey. However, the 2000 survey does not provide a complete survey when compared to the others conducted since 1985. This incompleteness is the result of change in focus from a comprehensive collection of the Nation’s water use to reporting only quality estimates of use (Hutson et al., 2004). This resulted in an absence of a large amount of data from specific states for specific categories where estimates of sufficient quality in terms of measurements could not be collected. In States such as Texas,

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[4] First introduced in the 2000 survey

Tennessee, Kentucky, Maine, Oregon, Pennsylvania, Utah, and West Virginia, total water use was not reported for any county.

In addition to the standard provision of water withdrawals, supplemental information has been included in the data sets to provide a broader picture of the Nation's water use. This provision of additional information is where the surveys diverge most from year to year in terms of consistency. Examples of additional information include the thermoelectric category, where energy source was provided in the 1985 and 1995 surveys but not in the 2005 survey, and where withdrawals were subdivided into once-through and recirculation waters. For public supply and domestic use, the populations served are provided on a per county basis in all of the digitized surveys. Additional information that is included in the surveys for the years 1985, 1995, and 2005 is presented in Table 2.

Concerns with USGS Data

The National Research Council (NRC) conducted an analysis of the USGS National Water Use Survey to make recommendations for its improvement (Vaux, 2005). The NRC suggested a separate publication be prepared, documenting the collection methods used by individual states. They point out that domestic water supply is usually determined by applying per capita coefficients rather than actual measured amounts. Few studies have been conducted that directly determine how much error is embedded in published water use maps and aggregated estimates. The report concludes that the consequences of continuing the present policy of neglect associated with water resources monitoring will be very serious and will significantly constrain the Nation's ability to carry out water resources research needed in the future (Vaux, 2005).

The authors of the USGS water use surveys state that various collection methods were used, but do not specify which methods were used or where they were used. While one state may have data from local utilities to provide public supply and domestic use values, another may not and as a result it may use per capita use coefficients. The major caveat to using the USGS water use data is the fact that the data is a compilation of available data and surveys, supplemented by indirect estimation methods where survey data are absent (Vaux, 2005). These indirect estimation methods pose perhaps the greatest difficulty for empirical use. For example, if the domestic use values are reported based on per-capita coefficients, a researcher examining effects on per capita use may simply be reverse engineering the data to show the coefficient used rather than a true estimate of demand. The National Research Council highlighted the importance of metadata for defining the uncertainty in the numbers given the widespread political and economic implications of water use compilations, such as preserving the quality of drinking water supplies and finding sufficient water to support both economic growth and the environment (Vaux, 2005). For now, this source may be considered the greatest compilation of the Nation's water use data, but due to the lack of certainty with reporting methods and aggregation of the data, analysis must be conducted with these caveats in mind.

It is difficult to make confident estimates of water demand using the actual water use data for domestic use because many of these numbers are generated using population coefficients (Hutson, 2007). In some jurisdictions, using population served estimates, derived from various sources such as State agencies, the USEPA SDWIS[5] database, and census data, per capita coefficients are employed to calculate total water use. While in other regions, surveys of public-supply sales information are conducted (Kenny et al., 2009). This situation exists for the other

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[5] The USEPA SDWIS is the United States Enivironmental Protection Agencies Safe Drinking Water Information System which provides information about public water systems.

categories as well, where different accounting methods vary between different jurisdictions. The only category which claims to have close to complete data is the thermo-electric sector which is collected through individual facilities, state agencies, or the USDOE EIA (Kenny et al., 2009).

Domestic use is especially difficult to measure due to the high volume of users. While most utilities collect use data for billing purposes, the data is not always made publicly available. The other portion of domestic water withdrawals, self supplied users, adds to the difficulty because data is often not collected on withdrawal amounts for these types of users. These difficulties have pushed the USGS data collectors towards employing population coefficients. Despite the lack of meta-data it may be possible to identify the use of these coefficients by examining the extent to which per capita use varies from one county to another within a state (Figure 1). A lack of county-level per capita use variation within a particular state could suggest the use of coefficients. In any of the three years, certain states stand out as being quite different from their geographic neighbors, in that they exhibit very low if not zero levels of spatial variation in per capita use. Examples of this are New Jersey and South Carolina in 1985, Indiana and Maine in 1995, and Oklahoma and South Carolina in 2005. These observations are highlighted in Table 3 which shows the standard deviations of the ten states with the lowest variation for 1985, 1995, and 2005.

It is unlikely that this lack of variation would occur naturally as it is quite reasonable to expect variation between counties within a state due to such factors as differences in water price, household income, or water availabilities. While water prices show some spatial correlation with one another, meaning that neighboring counties tend to reflect close rates, variation in price is expected to have an impact on demand (Eskaf and Hughes, 2008). Disparities in income would also appear to have an effect on water demand as more affluent communities may have larger lot sizes or more homes with swimming pools impacting demand for that area. Lastly, supply will have an effect on demand, as municipalities experiencing shortages of water will look to lower demand through education, rationing, or pricing. With these factors impacting demand, lack of variation within a state should raise concern with any researcher using the USGS data for empirical analysis.

Concern over the use of coefficients is exacerbated to the extent that state level coefficients, as opposed to more accurate county level estimates, are used. The previous paragraphs explored the observation that certain states lack variation for per capita domestic demand at the county level. If county-level coefficients are used it makes the analysis of county level-socio economic influence on water demand more appropriate than if state-level coefficients are used.

One thing to note is the states exhibiting low levels of water use variation have not been consistent over the years. Table 3 shows the top 10 states with low variations in 1985, 1995, and 2005. Only two states have made the top ten all three years, New Hampshire and Connecticut. South Carolina and Oklahoma both made the list in 1985 and disappeared in 1995 only to re-emerge in 2005. It is unknown what explains these trends in the data, whether data was available in 1995 that was unavailable in the other years. It can also be seen that none of the low variation states are in the western portion of the country. Visually, the western states appear to lack variation, but that is simply because water demand is much higher in those areas as most western counties fall in the upper category of water use. It is also possible that because water use in the western states is higher than the east coast, more detailed reporting is used on water use. Figure 2 presents a map of per capita domestic water use for the western portion of the United States.

Exploration of Data

While the collection methods may not allow certain types of analysis using the USGS water data, an exploration of the data exposes some interesting trends which could act as a conceptual framework for future research projects. In 2005, 410 billion gallons of water were used per day which was slightly less than 2000 and 5% less than the peak year of 1980 (Kenny et al., 2009). In the face of population and economic growth, the decline in water use suggests increases in efficiency. Withdrawals for the Irrigation and Industrial sectors declined from 2000 to 2005, while acres irrigated and industrial output both increased. Table 4 shows how these numbers vary between Census regions. Total water use per capita has been falling in the west and north, but rising in the south and mid west. Per capita domestic use has been fluctuating in most regions aside from the north, where it has been steadily declining. Figure 1 and Table 4 show that water use in western states has traditionally been higher than in the eastern states. This has generally been attributed to drier conditions and large irrigation projects.

Households generally withdraw water from one of two sources, self-supplied wells or public utilities. The USGS water use survey provides data on the populations receiving their domestic water from either a self-supplied or publicly-supplied source. This data could provide an opportunity for researchers to investigate which factors contribute to household water supply being self- or publicly-supplied. While this outcome is most likely linked to the available water infrastructure, an examination of which regional characteristics contribute to the expansion of such infrastructure and the possible benefits of such an expansion presents a future research opportunity. Table 5 presents data on self supplied users over the years 1985, 1995, and 2005. As a whole, the country has experienced a reduction in the percentage of households that use self-supplied wells. In every region the percentage of the population which uses self supplied domestic water has been declining. Lacking the appropriate meta data, it is unclear at this time what portion of this is due to new households using publicly supplied water as opposed to self supplied, and what portion can be attributed to self supplied households switching to publicly supplied sources. This opens up a potential line of research in water demand analysis in observing the supply side of the argument. It is possible that certain county characteristics, such as age and median income, may influence the rise or fall of the self supplied population, and further what impacts that rise or fall may have on county level health and economic viability.

The public supply category of the water use survey reveals much about the demand of any particular county. Publicly supplied water is responsible for everything from supplying households, local businesses, and such things as fire prevention and local amenities such as fountains. In this respect, the public supply water captures much of the water demand of the individuals within a county.

The data appears to shows a consistent convergence of publicly supplied water per capita to a narrower range as population density increases (Figure 3). The volatility in per capita use in the low density areas could be explained by the presence or absence of particular types of businesses in a sparsely populated county. Some counties may have businesses that produce products for people in other counties and water use by these businesses increase per capita water use estimates. While other counties are likely to have lower estimates if they lack these businesses. These differences disappear as population grows both because the denominator grows and because economies become more robust or similar in terms of water use.

As population density increases it becomes more and more likely that a particular location will have attracted the types of businesses the residents demand or simply a variety of businesses so that the mean water intensity of these business start to even out. Or it could be that domestic (household) use grows relative to other users of publicly-supplied water so that differences in industrial and commercial use start to wash out. This could be a potential future research direction in investigating the potential reasons for convergence of per capita water demand in the public supply sector. As density increases, per capita public supply converges to a range that could provide a more accurate representation of the publicly-supplied water demand for water per capita. This opens the discussion of whether there exists a theoretical equilibrium of water demand as communities reach a certain size and all demand by firms and people is satisfied in the best possible way. Perhaps the presence of a greater number of individuals allows a more accurate representation of the equilibrium demand for water, as opposed to over- or under-inflated portrayal of per capita use, through the abundance or lack of particular firms within a given geographic area. Examining these trends in the data suggest that demand patterns may exist which may provide a plausible explanation for how and why people use water the way they do.

Conclusion

The USGS provides a valuable service to the Nation by collecting and providing water use information to the public. This data is a valuable asset, but the difficulty of collecting accurate measurements of water use has resulted in the use per capita coefficients rather than actual measurements of withdrawals, resulting in many scholars being forced to rely on micro data sets when conducting economic analysis. These micro data sets focus mainly on state or municipal level data and therefore do not provide a picture of the nation’s water in its entirety.

As a result, numerous studies have been conducted estimating such things as price elasticity and demand schedules, but due to the variety of data and methods used the findings have a wide range of results.

The nationwide data currently provided by the USGS National Water Use Survey provides a broader outlook on the Nation’s overall water demand, but lack the consistency needed in collection methods to be used in many types of economic analysis. While it may not be appropriate for use in many types of analysis it provides a good overall picture of the Nation’s water use as a whole, and lays the ground work for further analysis. Some findings highlighted in this Chapter are the contraction of the self supplied population and the convergence of per capita public supply water over population density. These findings highlight potential for future research using USGS data. Also noted, although less explored, was the general decline in total water use. It will be important for us as a Nation to continue increasing water use efficiency into the future, and it is encouraging to see it taking place already. Further potential research exists in an exploration in which sectors or geographic areas are experiencing the greatest growth in efficiency in terms of water use.

The resources needed to create a nationwide inventory of water use with the accuracy of surveys or municipal level data are infeasible at this time. However, given the potential for further research it seems beneficial to continue investing in the collection of our Nation’s water use data. A first step could the introduction of meta data which highlights the collection methods used for the different sectors in different localities. If this data could be included at the county level, researchers could filter the data as to provide only the robust estimates they desire for their analysis. A combination of both of these steps will open up a great potential for water researchers in the future.

Despite the concerns with the nationwide water use data-set, an important frontier for scientific based assessment of water use is analysis at a national level which will require the use of the currently available data. In the next chapter this type of analysis will be conducted using a regional adjustment model examining population and employment growth over a twenty year span and the resultant impact on water use. The USGS Water Use Survey will be used, and this Chapter is meant to act as the caveat to the data used in the analysis.

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Appendix

Table 1 USGS Water Use Categories by Year

Category	1985	1995	2005
Public Supply	✓	✓	✓
Commercial	✓	✓	-
Domestic	✓	✓	✓
Industrial	✓	✓	✓
Thermoelectric	✓	✓	✓
Mining	✓	✓	✓
Livestock	✓	✓	✓
Aquaculture	-	-	✓
Hydro-Electric[6]	✓	✓	-
Sewage Treatment	✓	✓	-
Reservoir Evaporation	✓	✓	-

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[6] Hydro-Electric, Sewage Treatment, and Reservoir Evaporation are not included in the calculation for total water withdrawals.

Table 2 Additional Information Provided in USGS Water Use Surveys

1985	1995	2005
Public Supply • Population served • Number of public utility facilities	Public Supply • Population served (by both groundwater and surface water) • Number of public utility facilities • Deliveries to domestic, Commercial, Industrial, and Thermoelectric • Reclaimed waste water	Public Supply • Population served
Commercial • Deliveries from public supply utilities • Consumptive use	Commercial • Deliveries from public supply utilities • Consumptive use • Reclaimed waste water	-
Domestic • Self supplied and publicly supplied population • Consumptive use	Domestic • Self supplied and publicly supplied population • Consumptive use	Domestic • Self-supplied and publicly-supplied population
Industrial • Deliveries from public supply • Consumptive use • Number of facilities	Industrial • Deliveries from public supply • Consumptive use • Number of facilities	Industrial • No additional information
Thermoelectric • Data for each energy source (fossil fuels, geothermal, or nuclear) • Deliveries from public supply • Consumptive use • Power generation • Number of Facilities	Thermoelectric • Data for each energy source (fossil fuels, geothermal, or nuclear) • Deliveries from public Supply • Consumptive use • Power generation • Number of Facilities	Thermoelectric • Power generated and withdrawals provided for once-through and recirculation plants
Mining • Consumptive use	Mining • Consumptive use • Reclaimed waste water	Mining • No additional information
Livestock • Withdrawals for stock and specialty animals • Consumptive use	Livestock • Withdrawals for stock and specialty animals • Consumptive use	Livestock/ Aquaculture • No additional information

Table 2 Continued

Irrigation • Irrigated land by spray and flood irrigation type • Conveyance losses • Consumptive use	Irrigation • Conveyance losses • Consumptive use • Irrigated acres for sprinkler, and surface irrigation • Reclaimed waste water	Irrigation • Withdrawals and acres irrigated given for both crop and golf course irrigation • Acres irrigated provided for sprinkler, micro-irrigation, and flood irrigation
Hydro-Electric • Power generation • Number of facilities	Hydro-Electric • Power generation • Number of facilities (in-stream and off-stream)	-
Sewage Treatment • Number of facilities, both public and industrial • Returns from municipal systems • Reclaimed waste water	Waste Water Treatment • Number of facilities, both public and industrial • Returns from municipal systems • Reclaimed waste water	-
Reservoir Evaporation • Amount evaporated • Surface area	Reservoir Evaporation • Amount evaporated • Surface area	-

Table 3 States with Low Variation in Per-Capita Domestic Use, Their Average, and the Average of All States

1985				1995				2005		
State	Mean	STD		State	Mean	STD		State	Mean	STD
NJ	74.97	0.08		CT	74.99	0.03		CT	75.01	0.03
SC	74.98	0.12		ME	65.03	0.15		NH	74.99	0.07
OK	56.49	2.14		IN	76.02	0.20		SC	99.99	0.09
VA	77.40	2.64		IL	90.00	0.38		IN	75.99	0.21
NH	84.48	3.88		RI	64.74	0.51		IL	90.03	0.28
NY	94.40	4.60		VI	28.72	1.34		VA	75.06	0.74
WI	49.22	6.29		VT	75.53	1.53		OK	84.83	1.78
VT	82.20	6.54		MA	65.06	1.66		ND	91.80	2.19
KY	58.04	10.48		NH	77.01	1.92		VT	64.44	3.39
MO	72.14	10.77		KY	66.33	3.84		IA	64.64	3.93
Average	72.43	4.75		Average	68.34	1.16		Averages	79.68	1.27
All States	103.49	33.30		All States	100.07	44.33		All States	105.23	31.70

Table 4 Per Capita Domestic and Total Water Use by Census Region for 1985, 1995, and 2005

Census Region	Per Capita Domestic	Per Capita Total
1985		
South	92.14	2709.42
West	171.71	16903.98
North	79.59	1182.5
Midwest	88.83	3443.68
1995		
South	100.89	3076.52
West	154.13	15379.41
North	77.69	1044.5
Midwest	82.58	3806.44
2005		
South	100.47	3183.18
West	165.04	15231.88
North	72.66	1001.56
Midwest	87.3	3965.18

Table 5 Self Supplied Population Percentages by Census Region

Region	Self Supplied Percent	Absolute Change From Previous Period
1985		
South	18.68	.
West	11.4	.
North	16.84	.
Mid West	21.83	.
1995		
South	16.32	-2.37
West	9.76	-1.64
North	16.64	-0.20
Mid West	20.77	-1.04
2005		
South	14.65	-1.67
West	9.44	-0.32
North	14.89	-1.74
Mid West	18.92	-1.86

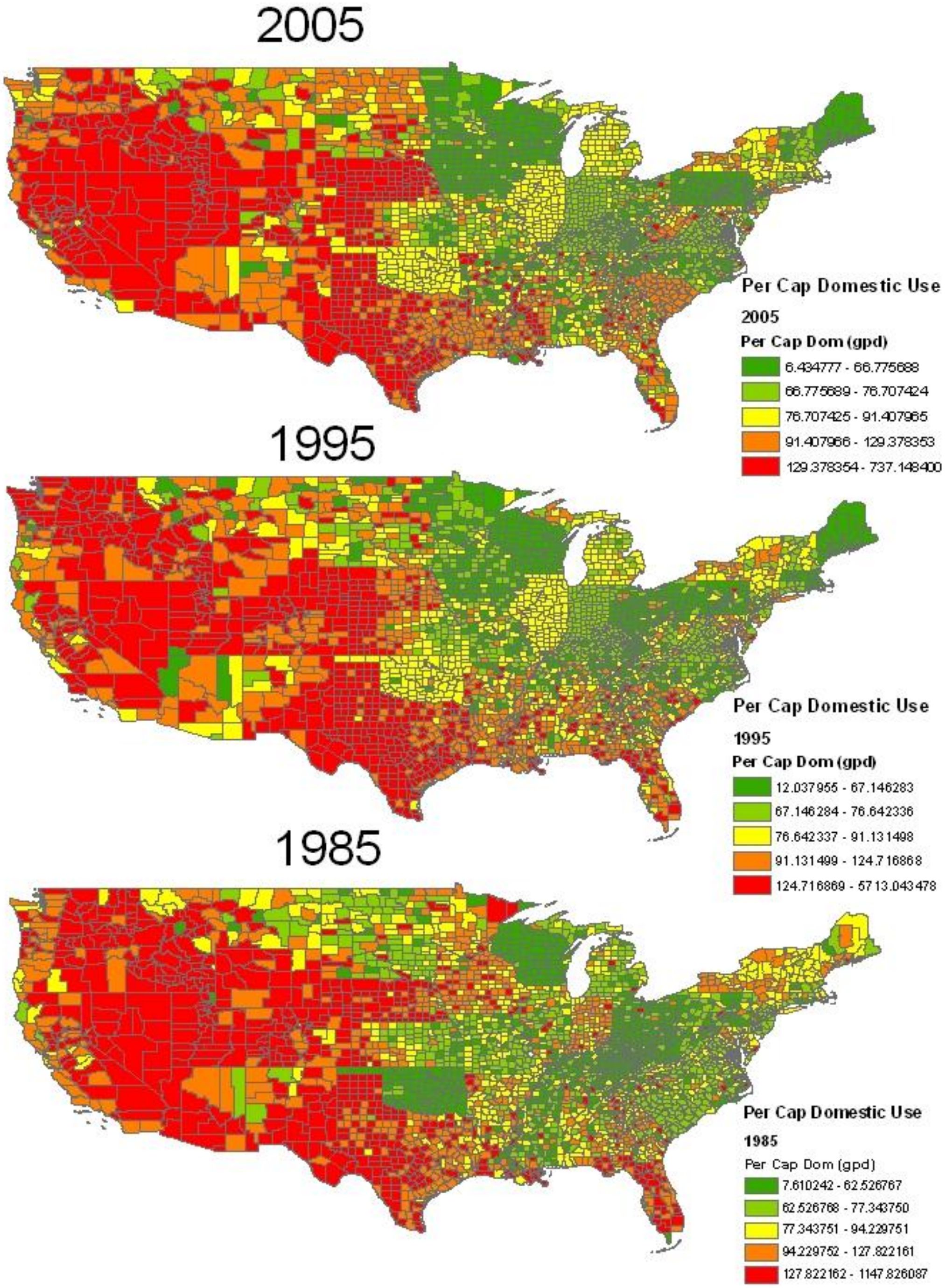

Figure 1 County Level Per-Capita Domestic Use Over Time

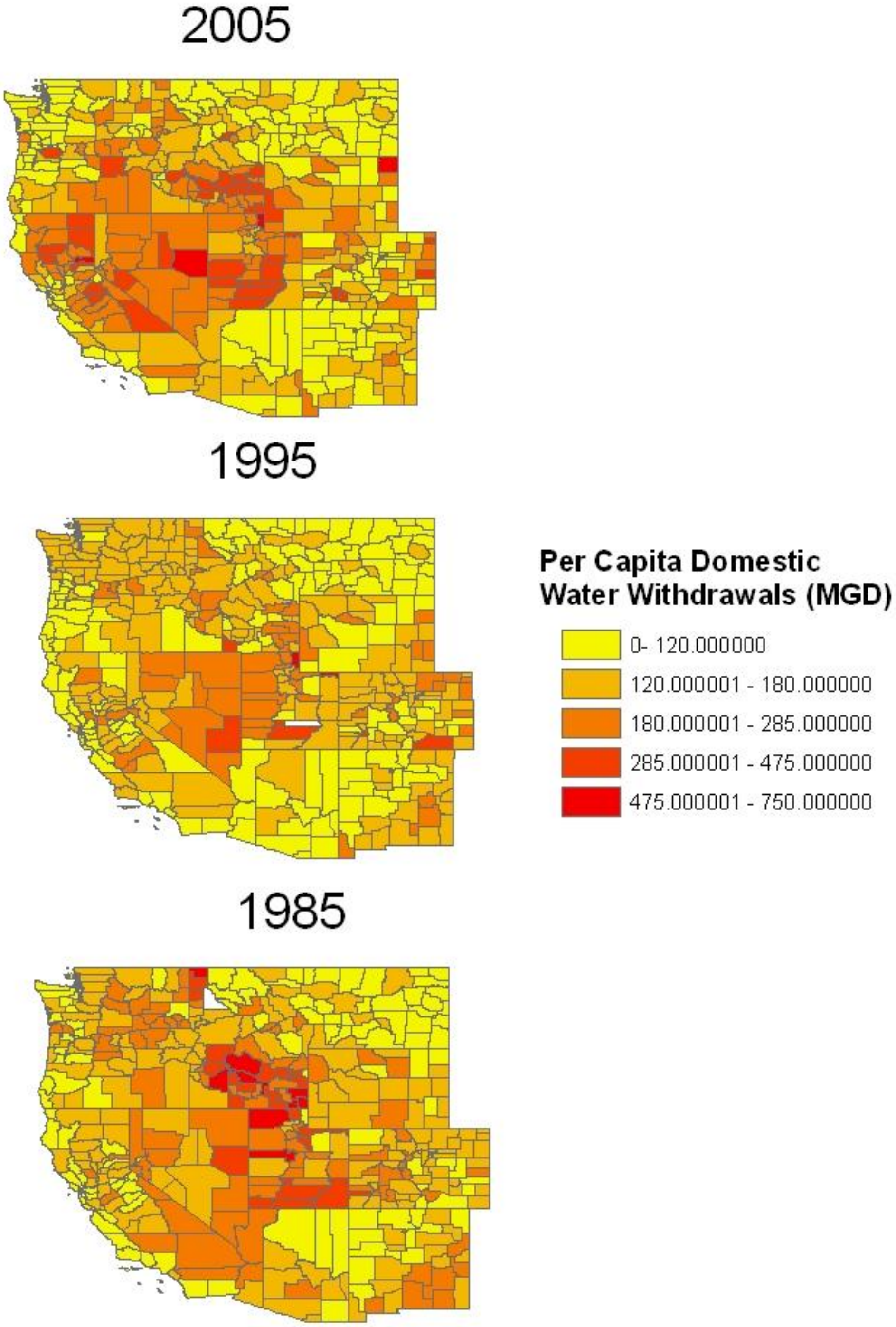

Figure 2 County Level Per-Capita Domestic Use Over Time for the Western united States

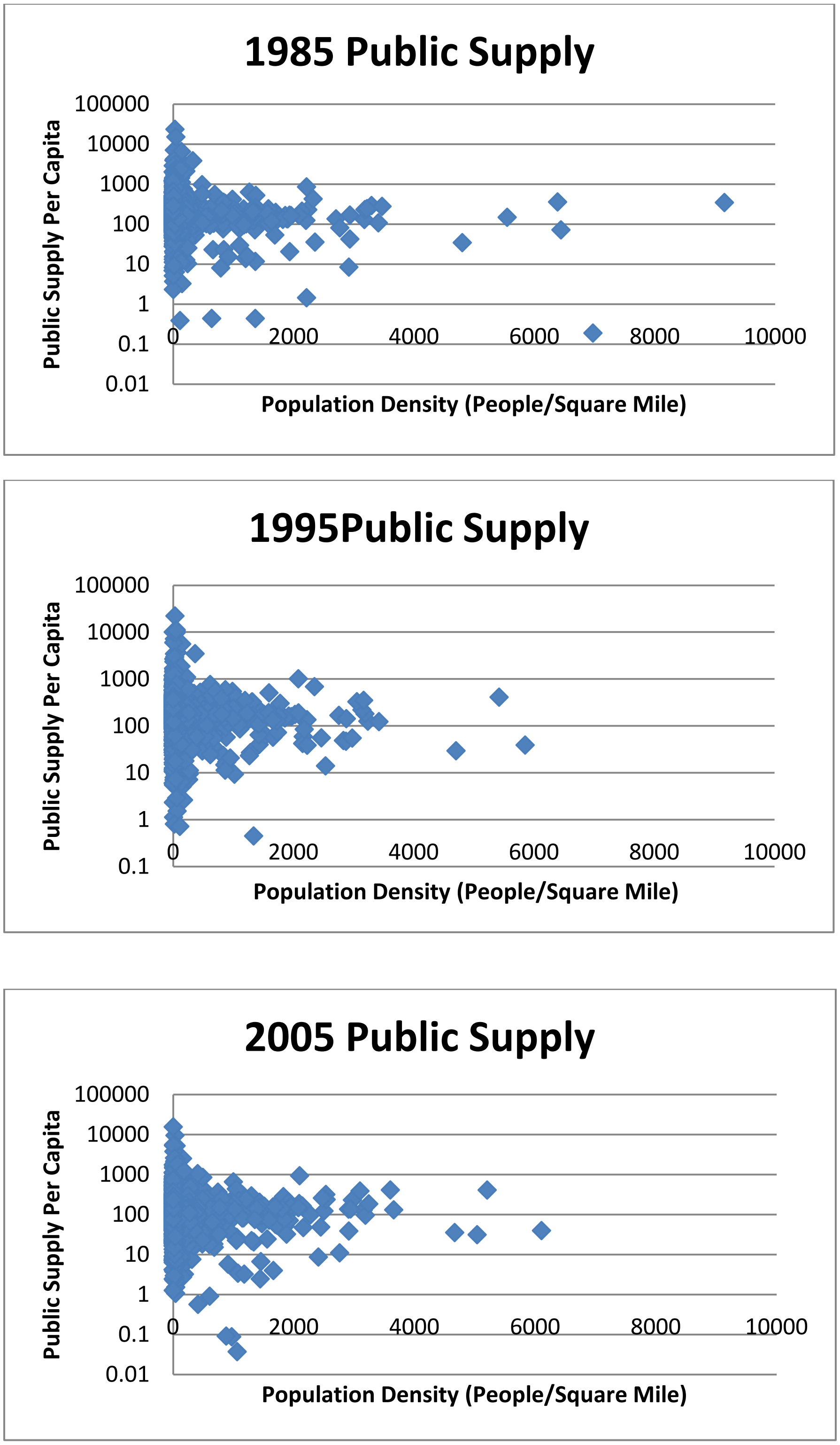

Figure 3 Per-Capita Public Supply Use Over an Increasing Population Density

Part 3: Examining Water Use with a Regional Adjustment Model

Abstract

This portion of the thesis uses a regional adjustment model to examine the impacts of population and employment growth on water use. Population and employment growth has been shown to be a dynamic process, with employment availability impacting population migration and access to labor markets impacting firm location. This process has been modeled with regional adjustment models. Furthermore, this adjustment process can be modeled in a way that highlights the impacts of population and employment growth on resources utilized by people and firms. Using the previous section as a caveat, the USGS water use survey data is used. Adjustment parameters were estimated using a three stage least regression to account for the endogeniety of the independent variables and to model the equations as a system to account for the dynamic growth process taking place between population and employment growth. A third equation was used in the system to provide additional information in terms of impacts on water use growth rates by water uses per person and per employee. The stability of the system was then estimated using the SURE method which employs reduced form equations. The system estimated was shown to converge to a steady stable state. Furthermore the steady stable state ratios on predicted, and were all shown to be close to .13 units of water use per employee to 1 unit of water use per person. Visual representations of this adjustment process were presented using reduced form equations and Maple’s *phaseportrate* routine.

Introduction

Water is a resource commonly used by both households and firms. In that respect there is some level of competition between the two, as the resource must be distributed in order to meet respective demands. Water availability has shaped where people settle and firms locate. Throughout history, access to water resources has been critical for the growth and development of communities. Water has been mostly overlooked in traditional economic analysis, but in reality water is a primary input to all goods and services either directly or indirectly (Guan and Hubacek 2008). Water resource availability is therefore affected by, but also a contributor to the location of people and jobs.

Population and employment growth is a dynamic process, with employment opportunities impacting migration and firm location. This growth dynamic has been commonly referred to as a regional adjustment process, as employment and population adjust towards theoretical equilibrium (e.g. Carlinao and Mills, 1987; Carruthers and Vias, 2005; Carruthers and Mulligan 2007). Research using regional adjustment models have expanded to explore how the population-employment growth dynamic affects resource availability. The primary example was the incorporation of land absorption into the employment-population growth dynamics by Carruthers and Mulligan (2007). They analyzed how population and employment growth dynamics impacted land absorption rates, using their model to predict regional convergence towards to a steady state equilibrium in terms of land per person and land per employee.

This chapter extends Carruther's and Mulligan framework, substituting water for land to examine the impact employment and population growth have on county-level water use. A regional adjustment model is used to examine the population employment dynamic, along with the dual effects on water use.

In the locations in which people live and work, available resources are distributed between two types of users, households, or what we might call people, and firms, or what we might think of as jobs. The dynamic of population and employment has been explored through the use of regional adjustment models, which model the growth process of the two as a dynamic process with population growth influencing employment growth and vice-versa. This literature has been further expanded to examine how this growth dynamic influences the resources used by people and jobs, such as the Carruthers and Mulligan (2007) analysis of land absorption in metropolitan counties. Water is similar to land, a resource demanded by households as well as by firms. Therefore, the growth dynamic of population and employment should impact water use. While population and employment growth affect one another they also influence the use of land and water resources. The importance of understanding this dynamic is the influence the movement towards equilibrium has on water use. Assuming that households and the workplace use water differently, this analysis will enhance the ability to plan for future water needs. Policy makers and water resource managers alike stand to benefit from further understanding how water use and economic growth are simultaneously determined.

Literature Review

Regional adjustment models explain the growth dynamic as an adjustment process between population and employment through a series of equations. The empirical equations model population (employment) as a function of employment (population) in addition to previous population (employment) and a set of exogenous explanatory variables (Carruthers and Vias, 2005; Carlino and Mills, 1987). The theoretical framework behind this model is that population and employment are simultaneously determined. In this framework, population growth (or migration) is typically explained by growth in jobs, in addition to changes in employment being induced by different rates of in-migration. In theory, the adjustment is taking place towards some state of spatial equilibrium where population and employment are distributed in a way that satisfies the demands of both people and firms. These models assume that there is a spatial equilibrium that regions are moving towards, but never reach because the equilibrium level is always changing.

Population migration is a product of labor availability, but it is also determined by local amenities and provision of services which contribute to an individual's utility (e.g. Roback 1982; Henderson 1982; Clark and Cosgrove, 1991; Clark and Hunter, 2006).These amenities include climate and access to environmental attractions, while services could include proximity to workplace, wage availability or lower rents. Profit maximizing firms, and eventually jobs, will locate where labor is available but will also look for comparative advantages one region may have over another. Comparative advantages include access to product markets, agglomeration economies, labor attributes, infrastructure, fiscal characteristics, and social capital (Lambert, McNamara, and Beeler 2007). While both firms and people will locate to maximize profit or utility, respectively, access to the other, either employment for people or human capital for firms, is a consideration.

The adjustment process models a theoretical equilibrium where the tradeoffs between the utility individuals is balanced with the distribution of profit maximizing firms. The focus is centered on the tradeoffs people are willing to incur when deciding where to locate, such as between job and wage availability and the natural amenities of an area. The natural benefits of a region, such as a temperate climate and recreation opportunities, may be offset by such costs as lower wages or higher rents (Porell, 1982; Greenwood and Hunt, 1989; Cragg and Kahn, 1997; Roback, 1982).

The population employment dynamic has a rich history of analysis, being introduced by Borts and Stein (1964) and Muth (1971). Borts and Stein's (1964) seminal research explored the idea that population and employment drive one another, and Muth (1971) continued the discussion with the eventual development of a regional adjustment model. Muth's findings supported the Borts and Stein hypothesis, demonstrating that population and employment growth were simultaneously determined.

Steinnes and Fisher (1974) introduced an intra-urban model, which allows for the growth of people and jobs to be simultaneous. This early analysis was restricted to a relatively small geographic area (e.g. Steinnes, 1977; Mills, 1983; Mills and Price, 1984). Carlino and Mills expanded the Steinnes-fisher framework to analyze jobs and migration at the national level (Carlino and Mills, 1987; Carruthers and Mulligan, 2007).

The introduction of regional adjustment models to the literature has allowed for the exploration of the affects two endogenous variables, population and employment, have on one another (Carlino and Mills, 1987; Carruthers and Vias, 2005). This research has expanded to analyze the effects of two endogenous variables on a third outcome variable (Carruthers and Mulligan 2007). The economic agents in this process, people and employees, consume resources as they locate across space. These resources could include anything demanded by people or employees such as land, water, or energy. Carruthers and Mulligan (2007) explored the impact the adjustment process had on land absorption rates. Their results indicated that population and employment growth jointly determined the outcome of land development in the largest metropolitan areas of the country. Furthermore, their analysis found that the system dynamics converged to a steady state, as expressed by a constant ratio between land per person and land per employee.

Population and employment impact water demand in direct and indirect ways. Population growth impacts water demand through increased demand by households, but also indirectly through uses in maintaining particular lifestyles (Schutte and Pretorious, 1997). Indirect water demands include food and energy production, as well as water sewage and treatment. Water demand associated with employment growth includes water needed to manufacture goods and services, which may include processing, washing, cooling or transporting. Indirect factors of demand through job growth could include the water needed for sustaining the needs of the employees such as air-conditioning and general plumbing demands.

Conceptual framework

Early adjustment models were based on a single equation that represented movement towards an unknown equilibrium level. More recent adjustment models have improved on the single equation (Equation 1) adjustment models, by describing variables in a constant state of partial equilibrium. The single equation partial adjustment model that represents movement toward an unknown equilibrium (*) at time *t* is as follows:

$$y^{*} = \mathbf{X}_{t}\beta + \mu_{t} \tag{1}$$

where y represents the variable of interest moving towards equilibrium, ***X*** is a vector of covariates, β is a vector of parameters which influence the equilibrium point, and μ_t is the error term. In one given time period only a fraction (λ) of the movement toward equilibrium is attainable:

$$\Delta y_{t} = (y_{t} - y_{t-1}) = \lambda(y^{*} - y_{t-1}) \tag{2}$$

where y_t and y_{t-1} represent the variable of interest in the current and previous time period, λ is the adjustment parameter bound between zero and one, describing the rate of movement toward. Moving y_{t-1} to the right hand side of the equation yields the following:

$$y_t = \lambda y_t^* + (1-\lambda) y_{t-1} \tag{3}$$

As shown in Equation 2 the current level of y will lie at some point between the equilibrium level and y_{t-1}. Substituting Equation 1 into Equation 3 allows for an estimatable model:

$$y_t = \lambda X_t \beta + (1-\lambda) y_{t-1} + \mu_t \tag{4}$$

where y_t is as stated above and μ_t is a stochastic error term.

Regional adjustment models use this framework to describe two or more codependent variables adjusting towards some unknown spatial equilibrium. The prevailing example in the literature is that of the population and employment dynamic. Carlino and Mills (1987) used this framework to expand on the adjustment model first introduced by Steinnes and Fisher (1974):

$$E^* = \alpha_0 P + \alpha_1 X_e \tag{5}$$

and

$$P^* = \beta_0 E + \beta_1 X_p \tag{6}$$

where P and E are population and employment, P^* and E^* are equilibrium levels, X_e and X_p are vectors of exogenous variables influencing E^* and P^* respectively, and α_0, α_1, β_0, and β_1 are estimatable parameters.

Substituting the equilibrium values of employment and population from Equations 5 and 6 into Equation 3 produces a simultaneous system of equations with endogenous variables, a set of exogenous covariates, and a lagged value of the dependent variable:

$$E_t = \lambda\alpha P_t + \lambda\alpha X_e + (1-\lambda)E_{t-1} + \alpha\mu_t \qquad (7)$$

$$P_t = \lambda\beta E_t + \lambda\beta X_p + (1-\lambda)P_{t-1} + \beta\mu_t \qquad (8)$$

The empirical version of this system is:

$$P_t = \beta_0 + \beta_1 P_{t-1} + \beta_2 E_t + \beta_3 X_p + \varepsilon_{et} \qquad (9)$$

$$E_t = \alpha_0 + \alpha_1 P_t + \alpha_2 E_{t-1} + \alpha_3 X_e + \varepsilon_{pt} \qquad (10)$$

Where E_t and P_t represent employment and population observed at time t, E_{t-1} and P_{t-1} are employment and population for the previous time period (t-1), α and β represent estimable parameters, and ε_{pt} and ε_{et} are the stochastic error terms, where $E(\varepsilon)=0$.

Carruthers and Mulligan (2007) used a modified form of the dependent variable in their analysis to portray a multiplicative growth process. This was done with the introduction and use of a third variable, land use. Ratios of land use to employment and population were used with natural logs to measure multiplicative growth rates. This analysis modifies their model by substituting water use in the place of land use to examine the impact on county level water use of the population and employment adjustment process. The natural logarithms of the ratios are defined as follows:

$$\ln\Delta WP_{it} = \ln(WP_{it}/WP_{it-1}) \qquad (11)$$

$$\ln\Delta WE_{it} = \ln(WE_{it}/WE_{it-1}) \qquad (12)$$

$$\ln \Delta W_{it} = \ln(W_{it}/W_{it-1}) \tag{13}$$

Where WP_{it} is per capita water use in county i at time t, WE_{it} is water use in gallons per job in county i at time t, and W_{it} is total water use in county i at time t in million gallons per day. These three variables are then modeled in multiplicative form as in Equations 9 and 10:

$$\ln\Delta WP_{it} = \alpha_0 + \alpha_1 \ln(WE_{it}) + \alpha_2 \ln(WP_{it-10}) + \alpha_3 \ln \mathbf{X}_{it-10} + e_{pit} \tag{14}$$

$$\ln\Delta WE_{it} = \beta_0 + \beta_1 \ln(WE_{it-10}) + \beta_2 \ln(WP_{it-10}) + \beta_3 \ln \mathbf{X}_{it-10} + e_{eit} \tag{15}$$

$$\ln\Delta W_{it} = \gamma_0 + \gamma_1 \ln(\Delta WP_{it-10}) + \gamma_2 \ln(\Delta WE_{it-10}) + \gamma_3 \ln \mathbf{X}_{it-10} + \varepsilon_{wit} \tag{16}$$

Where α_0, β_0, and γ_0 are intercepts, α_1, β_1, and γ_1 are estimable parameters, and α_2, β_2, and γ_2 are vectors of estimable parameters, $\boldsymbol{X}_{it}$ represents a vector of exogenous covariates including state based fixed effects, metropolitan indicator variables, and base year indicators. As noted by Carruthers and Mulligan's analysis of land use, the third equation (Equation 16) does not contain endogenous variables because the total water use depends on the change in water use per person and per employee not the other way around. Changes, instead of levels, are used to examine the individual impacts of population and employment on the rate of change in water use.

Data

Water use in the United States is dominated by two main uses, agriculture and thermoelectric power, which accounted for roughly 80% of water use in 2005 (Kenny et al., 2007). While agriculture has been a major competitor with municipalities in terms of water use, especially in the western portion of the United States where water supplies are more limited, agriculture may be considered apart from the population employment dynamic of water use, and is therefore excluded in this analysis. Including agricultural water use might distort the results, given the large water use related to employment, without shedding much light on the dynamic between population and employment and the resultant impacts on water use. While thermoelectric power is a large user of water, it is also an almost equally large recycler of water, and the respective employment sector is relatively low compared to water use. This creates a similar concern to agricultural water use where the large water use relative to employment may distort the analysis. With these factors taken into consideration, the metric for water use in this analysis is total water use less thermo-electric and irrigation water use at the county level.

The regional adjustment model was estimated over a 20 year time period using 10 year periods from 3 points in time, 1985, 1995, and 2005, and USGS data for water use. Although the water use data set has been digitally distributed every 5 years since 1985, the data for the year 2000 was incomplete and was therefore excluded from this analysis. To maintain uniform periods and cover the greatest scope of time, the best available option was to use the three time periods previously mentioned.

The counties used in this analysis included those in the lower 48 states, with the exception of Virginia. Virginia was excluded due to difficulties with merging data between the USGS water use data set and other data sets. Washington D.C was also excluded from the analysis. The total number of observations came to 5924, which is 2962 counties measured over two time periods, 1985 to 1995 and 1995 to 2005.

County level employment and population data was extracted from the Bureau of Economic Analysis’s (BEA) Regional Economic Information System (REIS) and combined with the USGS water use data. These variables were measured as ratios, water use per person and water use per employee, to portray a multiplicative growth process as identified in Equations 11, 12, and 13.

Additional data for the indicator variables and initial conditions came from the United States Department of Agriculture's (USDA) Rural Atlas Database and the BEA REIS. County level data for the indicator variable METRO came from the USDA Rural Atlas Database, which defines a metropolitan county as a county containing one or more urbanized areas, or high-density areas containing 50,000 people or more. This variable was used to account for the different growth processes that may describe differences between urban and rural areas. The base year dummy was used in order to identify trends in water use per person and per employee over time. State dummy variables were included to capture the state-based effects, resulting from different reporting methods used between states for the USGS water use data set and other unobservable state-based effects. Data for the initial condition of economic composition was compiled using the BEA REIS data. The variables corresponding with initial conditions are the percent of income concentrated in various sectors at the county level. This data was meant to represent the economic structure of a county and show how the various sectors affect water use. Descriptions and means of the variables used in the model are shown in Table 6.

Empirical Model

Following Carruthers and Mulligan (2007), the series of equations (Equations 13, 14, and 15) were estimated using a three stage least squares (3SLS). The equations were estimated in Stata using the *reg3* command. As previously discussed, population and employment growth is a dynamic process, with population growth impacting employment growth and vice versa. Is it under this context that we adopt a modeling form (3SLS) that estimates the equation parameters as a system of simultaneous equations as opposed to one which estimates the equation separately such as ordinary least squares.

Again, following Carruthers and Mulligan (2007), four models were run in which different sets of initial conditions were used to gain further insight into the adjustment process, such as the effects of size and previous water use on the adjustment process. The first initial condition, size, was run with additional variables of *LNemppop10*, *LNemp10*, and *LNpop10* (Table 7) where a negative parameter on the variables would suggest a pattern of convergence, where a larger county, either in terms of population, employment, or the sum of both, would undergo less of an increase in water use. *LNemppop10* was applied to Equation 16, *LNemp10* to Equation 15, and *LNpop10* to Equation 14. The second initial condition, previous water use, used the additional variable *lnw10* (Table 7) and applied it to equations 14,15, and 16 . Similar to the initial condition of size, a negative parameter on the *lnw10* variable would suggest convergence, where larger users of water in the previous period would be expect to experience smaller rates of growth in water use. The third and final initial condition was economic structure, which applied variables equal to the percent of total income concentrated in various economic sectors (Table 7). This condition was included in order to portray how concentration of county level income in any particular sector impacted growth rates of water use.

Results

The results of these estimations are presented in Table 7, with the adjustment parameters, λ_p and λ_e, represented by $-\alpha_2$ and $-\beta_1$ or the estimated parameter for the own lagged variable in each equation. While all of the adjustment variables showed high levels of significance ($p<.001$) some fell out of the theoretical range of $0<\lambda<1$. The four cases repeated from above are as follows: (1) no initial conditions, (2) size, (3) initial water use, and (4) economic structure. The adjustment speeds were found to be $\lambda_p = .97$ and $\lambda_e=.96$ for Case 1; $\lambda_p = .95$ and $\lambda_e= 1.004$ for Case 2; $\lambda_p = 1.091$ and $\lambda_e=.88$ for Case 3; $\lambda_p = .98$ and $\lambda_e=.98$ for Case 4. The parameters in cases 2 and 3 violate the theoretical range as they are greater than 1.

The results from the Equations 15for the 4 cases showed that the majority of the explanation of the rate of growth of water use comes from the rate of growth of water use per person and is less affected by the change in water use per employee. This equation estimates the rate of change of total water use based on the rate of change in water use occurring in the population and employment sectors. In all four cases the variable change in water per employee (*LNDeltWE*) was near zero and was insignificant in three of the four cases with the one exception (Case 2). The variable change in water per person (*LNDeltWP*) was highly significant in all 4 cases ($p<.001$) and was extremely close to one. In other words, these results suggest that an X% increase in the rate of water use per person would result in a (1*X)% increase in total water use, while an X% increase in the rate of water use per employee is expected to have no impact on the rate of total water use, or (0*X)%.

The results of implementing the initial conditions provide additional insights into the affects of previous water use, county size, and economic structure on the system of equations. The initial condition of size did not show the same consistent trend of convergence as the land use equations in the Carruthers and Mulligan (2007) analysis. Only in the water per employee equation was the coefficient negative, suggesting that counties that began the period with a large employment sector results in smaller gains in water use per employee. In the other cases, water per person and total water use, the parameters suggest divergence, where a larger population or combination of population and employment results in greater increases in water use per person and overall water use.

Similar to previous equations with the initial condition of size, an apparent trend of divergence was noticed in the water per person equation and convergence for the water per employee equation. For the third equation, total water use, the variable was insignificant and therefore convergence or divergence cannot be stated with confidence. The initial conditions in Case 4 were implemented to show the impacts of the presence of different economic sectors have on water use. The effects can be seen in Table 9, but one trend worth noting is opposite signs on the parameters for the water per person and water per employee equations, where a positive sign in one equation is paired with a negative sign in the other, and vice versa. All parameters but one, percent of income in agriculture, are positive in the water use equation suggesting that increased presence of any sector will ultimately result in increased water use regardless of the sector[7].

One potential explanation of the divergence witnessed in cases 2 and 3 could be the different supply structure of water compared to other resources such as land. The supply of land is much more fixed than that of water, which can be transferable over large distances if demand is high enough which eliminates the supply constraint. The diminishing spatial impacts of population growth are not paralleled with water use as the demand for water does not appear to diminish but rather increase with the presence of a larger population base. It appears that land absorption can be reduced at the margin much more so than water, possibly because of people's inherent need for water being more fixed than the need for land. Explanations for the divergence are unclear, and should be considered in future research efforts.

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[7] The exclusion of irrigation waters from the water use metric could explain this deviation.

The metro indicator variable showed a lack of consistency for the adjustment models, but a consistent positive effect for the water use equations. In Case 1, the parameter was positive for the water per person equation indicating a greater changes of water use per person in metro counties, and negative for the water per employee equation indicating less changes in water use per employee. However this result was flipped for the other cases where the initial conditions were employed, the metro parameter on the water per person equations became negative and positive for the water per employee equations. The base year indicators were significant for all models, and, similar to the metro variable, showed a lack of consistency between the four cases in respect to the signs of the parameters.

Concerns with the findings of these models include the large adjustment parameters, especially those greater than one and outside the theoretical range. As discussed in the conceptual framework section, the adjustment parameter should be between zero and one as the variable on interest, in this case water per person or water per employee, moves toward equilibrium from the previous period's position but never fully reaches that point. Therefore the adjustment parameters which are greater than one violate the assumptions of the model and suggest the variables actually over shoot the equilibrium level in the adjustment process. The explanation for this is not fully known, one hypothesis is the long periods used in the model could be contributing to the large numbers. In the span of the 10 year periods used in the model, the adjustment speeds would be expectedly higher than a model using shorter periods as the variables under examination have a greater amount of time to adjust.

Given concerns over the findings, this analysis continues with an examination of the stability of the solutions. The process and findings of this analysis will be discussed further in the next section, but this examination will look to examine if the system is stable and converging towards a steady state that is empirically plausible.

Stability of the Solutions

As previously mentioned it is important to examine the stability of the models. The stability of the solutions are an indication as to whether or not a future steady state is plausible given current growth patterns, and whether or not the adjustment process is converging towards or diverging from this steady state. Divergence would suggest that counties don't seem to be trending towards an equilibrium ratio, this is especially troubling given the findings in the previous section which saw adjustment parameters greater than one.

The standard approach to estimate the stability as suggested by Carlino and Mills (1987) is the seemingly unrelated regression equation (SURE) approach. This method employs reduced form equations in order to attain a characteristic root which leads to a projection of the steady state ratio between the two variables. The reduced form equations are as follows:

$$\ln(\Delta WP_{it}) = \eta_0 + \eta_1 \ln(WE_{it-10}) + \eta_2 \ln(WP_{it-10}) + \eta_3 \ln\mathbf{X}_{it-10} + \varepsilon_{it-10} \qquad (17)$$

$$\ln(\Delta WE_{it}) = \varphi_0 + \varphi_1 \ln(WE_{it-10}) + \varphi_2 \ln(WP_{it-10}) + \varphi_3 \ln\mathbf{X}_{it-10} + \varepsilon_{it-10} \qquad (18)$$

$$\ln(\Delta W_{it}) = \kappa_0 + \kappa_1 \ln(\Delta WE_{it-10}) + \kappa_2 \ln(\Delta WP_{it-10}) + \kappa_3 \ln\mathbf{X}_{it-10} + \varepsilon_{it-10} \qquad (19)$$

where the variables are the same as the previous equations with different parameters (η_0, η_1, η_2, η_3, φ_0 φ_1, φ_2, $\varphi_{3)}$ for distinguishing reasons.

The parameters from these equations are estimated and then placed in a two by two matrix in order to solve the determinational equation for the characteristic root. The absolute value of the two by two matrix less the product of *p*, the characteristic root, and an identity matrix is set equal to zero yielding the following:

$$|A - pI| = 0 \qquad (20)$$

Where ***A*** is a two-by-two matrix with the parameters from equations 16 and 17, *p* is a product scalar, and ***I*** is an identity matrix. Written as:

(21)

Which can be written as:

(22)

Subtracting the second matrix from the first yields:

(23)

Through matrix manipulation this matrix yields the following equation which allows *p* to be solved:

$$(\eta_1 - p)*(\theta_2 - p) - \eta_2*\theta_1 = 0 \qquad (24)$$

This equation can be solved for the two possible solutions for the characteristic root, *p*. In all cases the roots are real and within the unit interval, suggesting that water per person and water per employment rates converge to a stable steady state. The results are shown in Table 8. The larger root is then used to identify a column vector which indicates the ratio between water per person and per employee at equilibrium. The regression estimates are in natural logarithmic form, therefore the ratio should be transformed through exponentiation where the value on the right-hand side is equal to e^1=2.73. The resulting ratios after exponentiation were all close to .13:1, suggesting that .13 units of water are consumed by the employment sector to every one unit consumed by the general population, or 7.69 gallons are consumed by people for every gallon consumed by jobs. These findings seem consistent with the previous estimates which showed water use per person dominating the overall water use equations from the previous section. It seems theoretically reasonable that water and land differ in their consumption patterns by either people or jobs. While an employee may have a different consumption pattern of land, considering the differences between a work space and dwelling, one could safely assume the consumption of water is not all that different for an employee or a member of the general population and the empirical result tends to support that hypothesis.

As previously mentioned, the characteristic roots from the reduced form coefficients (Table 8) are real and within the unit interval, suggesting that water per person and per employee converge to a stable steady state. We can therefore analyze the trajectories of the adjustment process by applying first-order differential equations (FODEs) which also allows a visual representation of the adjustment process. These trajectories can be portrayed using Maple 15.0’s phaseportrait routine, which uses a series of arrows with different slopes representing the adjustment path at various points other than equilibrium. Furthermore, starting points can be set and allowed to move towards equilibrium through a set number of cycles which creates a visual path as seen in Figure 3. To avoid having the models converge to the origin a forcing term must be employed. The forcing term is equivalent to the intercept of the reduced form equations plus the summation of the covariate parameters times their mean values excluding the predicted values for water per person and water per employee. The FODEs with the forcing terms are as follows:

$$\overline{} = \ln WP_t - \ln WP_{t-10} = {}_1 \qquad + \quad {}_2\text{-}1) \qquad +({}_0 + \quad {}_{WP} \quad {}_{t-1}) \quad (25)$$

$$\overline{} = \ln WE_t - \ln WE_{t-10} = \quad {}_1\text{-}1) \qquad + \quad {}_2 \qquad +({}_0 + \quad {}_{WE} \quad {}_{t-1}) \quad (26)$$

where and are the means of the natural log of water per person and water per employee in the previous period, and $_{t-1}$ are the means of the covariates from the intial period.

Four starting points were chosen to highlight the different trajectory paths towards equilibrium (Figure 4). The points were set to the four corners of the quadrant in which the adjustment process was set in order to portray four different paths towards equilibrium, with either variable being greater than or less than its theoretical equilibrium. In all four cases the solutions converged to their respective steady states with similar trajectories in any of the four cases. When both variables are either greater than or less than their respective equilibrium the path towards equilibrium exhibits a constant slope or linear path, while if one is above the equilibrium level and the other under the equilibrium level, or vice-versa, the path towards equilibrium is parabolic.

Conclusion

The idea of water being both an economic good and an element vital to sustaining life was the conceptual framework behind incorporating water use in a RAM, which examines the dynamic growth process of populations and employment. Both of these elements, people and employees, are in a perpetual state of adjustment, people following jobs and jobs following people, which will impact the resources demanded by people and jobs, such as water. It was demonstrated by Carruthers and Mulligan (2007) that the regional adjustment analysis could be expanded to analyze the impact the adjustment process has on resources utilized by both people and employees in their analysis of land absorption rates. This framework was applied to an examination of county level water demand where available water resources must be distributed between the general population as well as the demands of economic activity.

The results from this study are consistent with the evidence that population and employment are jointly determined and the two converge towards a theoretical steady state equilibrium. In addition to predicting steady state equilibrium, potentially useful observations were made on the indicator variables as well as the initial conditions impact on the adjustment parameters and overall water use growth. A potentially troubling observation of divergence was noticed in two of the initial conditions, where large users of water were shown to have larger growth rates of per capita use then lighter users and larger counties in terms of population , were also shown to have larger growth rates of per capita water use.

Perhaps the greatest limitation to this analysis is the water use data employed in the analysis. There is an inherent difficulty in creating a nationwide water use data set do the magnitude of use and the difficulty of data collection. However understanding that our water resources are constrained, and therefore increased use will cause more and more stress to the hydrologic system, we should look towards understanding the impact population and employment growth have on this limited resource. Having a better understanding of the impact of the population employment growth dynamic has on water use will allow us to better prepare for maintaining the sustainability of our water resources.

This chapter looks to contribute to the discussion of the importance of improving our Nation’s water use data by demonstrating a potential use for such a data set. It therefore opens the door for further exploration of our Nation’s water use data, and what restrictions to scientific analysis of water use exist due to data constraints. Other future research options which should be explored are more precise estimates of the population employment dynamic impact on water at a strictly municipal level. Currently the best available water use data for the nation as a whole is at the county level, however a data set of just municipal water use throughout the country may provide more accurate estimates of the adjustment parameters and provide more realistic estimations of the adjustment parameters.

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Appendix

Table 6 Descriptive Statistics

Variable	Definition	Mean	Source
Popt	Population in current period	90594.85	REIS
Popt10[8]	Population in previous period	81362.37	REIS
Empt	(Non –Farm)Employment in current period	50464.55	REIS
Empt10	(Non –Farm)Employment in previous period	42538.90	REIS
Watert	Water withdrawals in MGD[9] in current period	25.57	USGS
Watert10	Water withdrawals in MGD in previous period	24.79	USGS
Metro	1 if metro county, 0 otherwise	0.3376	USDA RAD
Base1995	1 if current period is 2005, 0 otherwise	0.50	N/A
WEmpt	Water withdrawals per employee in current period	1219.86[10]	USGS and REIS
WEmpt10	Water withdrawals per employee in previous period	1181.36	USGS and REIS
WPt	Water withdrawals per person in current period	547.85[11]	USGS and REIS
WPt10	Water withdrawals per person in previous period	467.66	USGS and REIS
LNEmpt10	ln(Empt10)	9.3841	REIS
LNPopt10	ln(Pop10)	10.1668	REIS
LNEmppop10	ln(Empt10+Pop10)	10.514	REIS
NWt	ln(Watert)	1.98	USGS
LNWt10	ln(Watert10)	1.907	USGS
LNWEt	ln(WEt)	6.377	USGS
LNWEt10	ln(WEt10)	6.4699	USGS and REIS
LNWPt	ln(WPt)	5.5756	USGS and REIS
LNWPt10	ln(WPt10)	5.5579	USGS and REIS
LNDeltW	ln(LNWt/LNWt10)	0.0719	USGS and REIS
LNDeltWP	ln(LNWPt/LNWPt10)	0.0186	USGS and REIS
LNDeltWE	ln(LNWEt/LNWEt10)	-0.0917	USGS and REIS
Agperct10	% of income from agricultural sector in previous period	1.18	REIS
Conperct10	% of income from Construction sector in previous period	6.52	REIS
Fireperct10	% of income from F.I.R.E. sector in previous period	3.66	REIS
Manperct10	% of income from Manufacturing in previous period	20.62	REIS
Tradeperct10	% of income from Trade sector in previous period	15.09	REIS
Servperct10	% of income from Service sector in previous period	16.76	REIS
Transperct10	% of income from Transportation in previous period	6.46	REIS
Farmperct10	% of income from farming sector in previous	6.98	REIS
Govperct10	% of income from government sector in previous period	21.89	REIS

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[8] Observations were made in 10 year increments, thus the t10 is represents the period 10 years previous.

[9] Million Gallons per Day

[10] Gallons per day per employee

[11] Gallons per day per person

Table 7 Adjustment Model Results Using Initial Conditions

	Case 1. No Initial Conditions						Case 2. Size					
	LNDeltWP		LNDeltWE		LNDeltW		LNDeltWP		LNDeltWE		LNDeltW	
	α	t	β	T	γ	T	α	t	β	t	γ	t
Intercept	-0.3432	-7.49	0.315	6.70	-0.012	*-.77*[12]	-1.851	-33.40	1.773	35.13	-0.182	-8.53
LNWEt	0.9453	221.06	-	-	-	-	0.974	240.73	-	-	-	-
LNWEt10	-	-	-0.961	-209.49	-	-	-	-	-1.004	-247.10	-	-
LNWPt	-	-	0.992	221.22	-	-	-	-	0.9907	266.53	-	-
LNWPt10	-0.9713	-211.00	-	-	-	-	-0.959	-221.70	-	-	-	-
LNDeltWP	-	-	-	-	0.9750	84.80	-	-	-	-	1.0184	88.8
LNDeltWE	-	-	-	-	0.0157	*1.38*	-	-	-	-	-0.024	2.14
Metro	0.0362	5.03	-0.042	-5.84	0.0982	31.00	-0.126	-16.33	0.1193	16.87	0.0764	20.88
Base1995	0.0687	10.73	-0.074	-11.31	-0.0104	-3.56	0.0635	10.66	-0.055	-10.07	-0.009	-3.11
LNEmpt10	-	-	-	-	-	-	-	-	-0.129	-47.50	-	-
LNPopt10	-	-	-	-	-	-	0.130	42.31	-	-	-	-
LNemppop10	-	-	-	-	-	-	-	-	-	-	0.0166	11.76
N	5924	-	5924	-	5924	-	5924	-	5924	-	5924	-
R^2	.8295	-	.8267	-	.9699	-	.8556	-	.8781	-	.9705	-

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[12] Italicized font indicates a lack of significance

Table 7 Continued

	Case 3. Previous Water Use						Case4. Economic Conditions					
	LNDeltWP		LNDeltWE		LNDeltW		LNDeltWP		LNDeltWE		LNDeltW	
	α	t	B	t	y	T	A	t	B	t	y	t
Intercept	-0.047	*-0.89*	-0.005	*-0.13*	-0.0147	*-0.89*[13]	-0.507	-7.51	0.498	7.38	-0.3305	-12.85
LNWEt	0.973	240.14	-	-	-	-	0.9836	225.77	-	-	-	-
LNWEt5	-	-	-0.879	-228.80	-	-	-	-	-0.982	-218.5	-	-
LNWPt	-	-	0.992	269.29	-	-	-	-	0.9847	227.72	-	-
LNWPt5	-1.091	-213.30	-	-	-	-	-0.984	-245.40	-	-	-	-
LNDeltWP	-	-	-	-	0.9995	86.14	-	-	-	-	1.0015	75.14
LNDeltWE	-	-	-	-	-0.008	-.075	-	-	-	-	-.0099	-.*75*
Metro	-0.133	-17.26	0.124	17.84	0.0994	28.66	-0.012	*-1.63*	0..010	*1.36*	0.0687	20.42
Base1995	0.063	10.55	-0.051	-9.45	-0.0087	-2.96	0.0259	3.83	-0.027	-4.05	-0.0215	-6.66
LNWt10	0.136	44.21	-0.128	-50.13	-0.00087	*-0.68*	-	-	-	-	-	-
agperct5	-	-	-	-	-	-	-2.782	-9.95	2.8012	10.03	-0.0521	*-0.41*
conperct5	-	-	-	-	-	-	-0.9367	-9.2	0.9507	9.35	1.2155	26.18
fireperct5	-	-	-	-	-	-	2.652	14.23	-2.689	-14.46	0.2475	2.96
manperct5	-	-	-	-	-	-	0.2832	5.44	-0.293	-5.63	0.3132	13.22
tradeperct5	-	-	-	-	-	-	-0.0644	*-0.66*	0.0625	*0.64*	0.3332	7.48
servperct5	-	-	-	-	-	-	0.8283	10.33	-0.843	-10.54	0.4099	11.28
transperct5	-	-	-	-	-	-	0.0472	*0.05*	0.0183	0.*19*	0..0592	*1.36*
farmperct5	-	-	-	-	-	-	-0.4079	-6.94	0.404	6.87	0.1571	5.81
govperct5	-	-	-	-	-	-	-0.2915	-5.07	0.2853	4.97	0.294	11.29
N	5924	-	5924	-	5924	-	4576	-	4576	-	4576	-
R2	.8555	-	.8806	-	.9699	-	.8736	-	.8758	-	.9760	-

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[13] Italicized font indicates a lack of significance.

Table 8 S.U.R.E. Estimations with Initial Conditions

	Initial Condition			
	No Initial Conditions	Size	Previous Water Use	Economic Make up
Coefficients				
η_1	-0.012	-0.149	-0.165	-0.148
η_2	0.769	0.889	0.994	0.872
φ_1	0.862	0.648	0.708	0.728
φ_1	-0.108	0.089	0.117	-0.012
Characteristic Roots				
p1	0.756	0.738	0.826	0.72
p2	-0.876	-0.798	-0.875	-0.88
Ratio of water per employee to water per person				
Log Format	-1.0013	-1.0023	-1.00303	-1.00461
Transformed	0.135159	0.13503	0.134926	0.134713

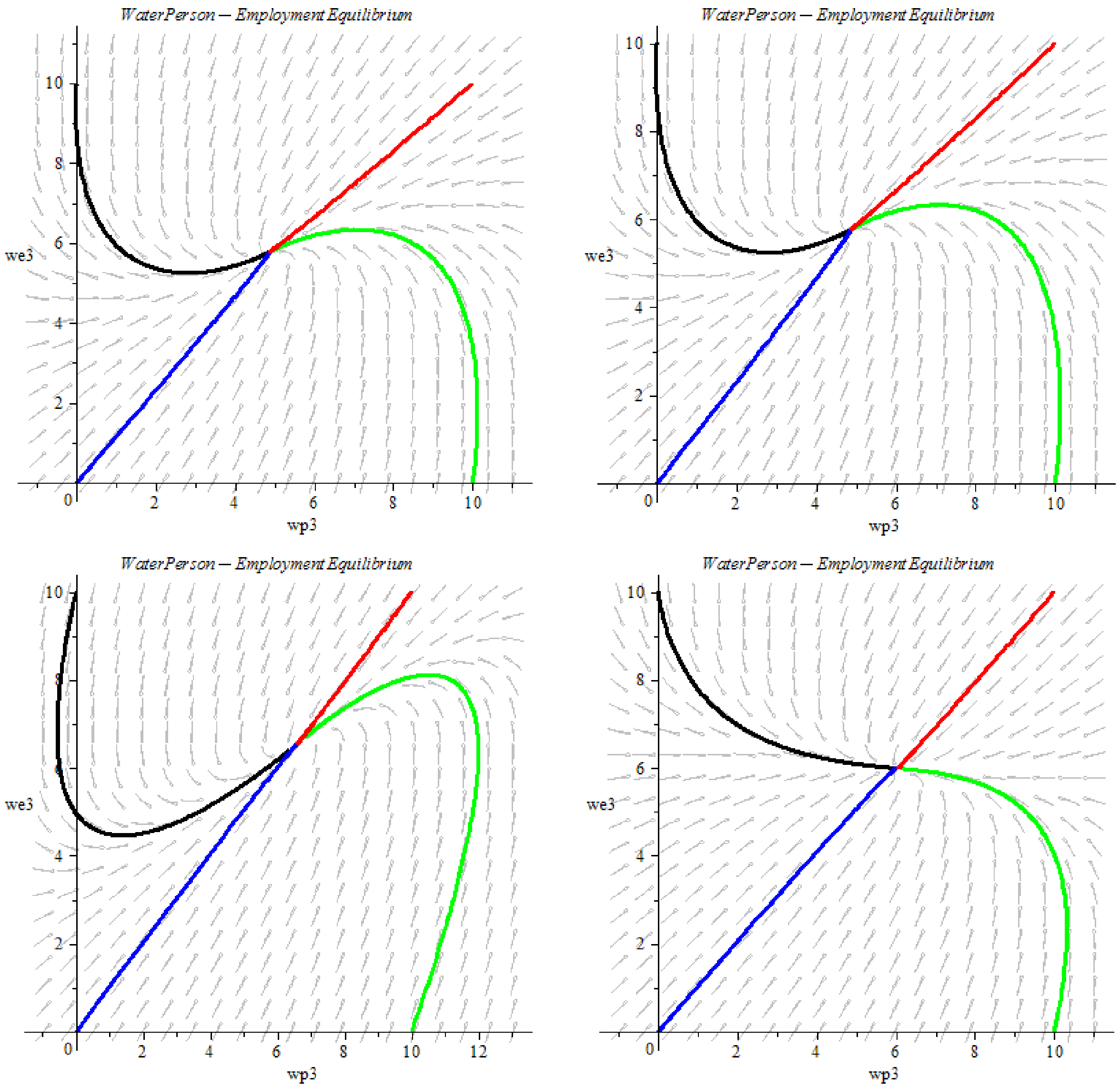

Figure 4 Trajectory Paths Using Phaseportrait Routine in Maple

Part 4: Summary and Conclusions

Summary

Economic and population growth have been shown to impact demand on water resources. The growth of jobs and population has been shown to be a dynamic process, with job availability influencing population migrations and labor availability impacting firm location. This dynamic growth process has been studied through the use of regional adjustment models. This thesis extends this type of analysis by applying a third variable, water use, to the adjustment model in order to model the impacts of population and employment growth on water use.

Empirical analysis of water demand has been limited at the national level partly as a result of the scanty water use data on a national scale. Currently the national leader in collecting and distributing water use data is the United States Geological Survey (USGS) with their National Water Use Survey. The USGS has been producing these surveys since 1950 and the surveys since 1985 have been digitized and are available for public use. While the service the USGS provides is valuable, the difficulty in collecting water use data for the entire Nation has contributed to the use of per-capita use coefficients. These coefficients are used with actual survey data which creates issues with consistency within the data sets.

Water use as defined in the survey is water diverted from a surface water source or withdrawn from a ground water source for a specific human use. The surveys are broken down by category of use, and within each category water use is provided for both ground and surface water for fresh and salt water sources down to the county level. Since the beginning of the digitized surveys began, 1985, the categories provided within each year have varied, but each survey attempts to capture the water use of the nation as a whole. It is under this context that the survey can be combined to examine water use changes over time.

Examining the data illuminated certain trends with water use that both open up potential routes for future research and provide a conceptual foundation for the latter part of the thesis. Total water use has seen a general decline in the face of population and economic growth suggesting that water use efficiency has been increasing. Examining which sectors have seen increases in efficiency, in terms of water use per person or economic output per unit of water, is open for future research. Domestic water supply source, either through a public-supply utility of self-supplied well, was also examined. As a whole the country has seen a decrease in the amount of self supplied users as a percent of the total population. Understanding what influences this shift in supply could benefit resources managers in preparing future water infrastructure systems.

The trend of convergence in public supply water use per capita was used as a conceptual framework for the second part of the thesis. As population density increases, there is an apparent convergence in the range of public supply water use per capita. Hypothesis for this apparent convergence include the presence or absence of particular firms within the low density areas. As density increases, areas appear more likely to attract firms to meet the demand of the individual within that community or possibly that domestic demand begins to dominate the demand for publicly supplied water.

Using this as a theoretical framework, the next portion of the thesis adopts a regional adjustment model to analyze the impacts of population and employment growth on water demand, and project whether the systems are adjusting towards a steady state equilibrium. The first portion of this analysis used a system of three equations to estimate the adjustment parameters on population and employment. This was done using four different initial conditions, outlined within the thesis. The results of this portion of the analysis produced concerns as some of the adjustment parameters were estimated to be greater than one which is outside the theoretical range of $0<\lambda<1$. The third equation in this system was included to provide additional information about the system, specifically the impacts of the rates of increase of water per person and water per employment growth on total water growth. This equation showed that the rate of total water use closely mirrored the growth in water person, and was marginally impacted by the rate of increase in water per employee.

The next portion of the analysis examined the stability of the system using the SURE method. This method applies the use of reduce form equation and estimates a steady state ration of water use per employee to water use per person. The systems showed convergence to a steady state equilibrium for all four initial conditions. The steady state rations were shown to be .13 to 1, or .13 units of water per employee used for every 1 unit of water used per capita.

A visual representation of this adjustment process was presented using first order differential equations and Maple's *phaseportraite* routine. This methodology produced four images of the adjustment process taking place from four points away from equilibrium for each of the four initial conditions. The images use arrows of various slopes to portray the path towards equilibrium from any given point.

This thesis highlighted the concerns of the currently available water use data, but using that as a caveat, employed said data to highlight a potential use for the data. The objectives of this thesis were to further the calling for a systematic improvement of the nations water use data. Improving the national data set could improve analyses similar to the one conducted here, as well as open up future potential research efforts.

Vita

Blake Thomas was born in Austin, Texas on July 26, 1986 to Steven and Cindy Rich. He currently holds a B.A. in Economics from the University of Texas, in Austin, TX and a M.S. in Agricultural Economics in May 2012.