

Final Report

Integrating Marginal Cost Water Pricing and Best Management Practices

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Prepared for Metropolitan Water District of Southern California

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Project Description

In May of 2005 the student team from California State University, Long Beach was awarded a \$9,000 grant to complete a comprehensive study on marginal cost rate design and best management practices. In January of 2006, the contract was signed and CSULB received \$8,100 (the balance due after the project is complete). The study focuses on a two part integrated approach to efficient water allocation through economically efficient rate design.

Part one of the study is an examination of current rate structures in Southern California and research on historical implementation of marginal cost pricing to evaluate alternative methods for estimating marginal cost. We collected and analyzed data from the Metropolitan Water District of Southern California and other sources in order to estimate marginal cost. Economic theory of cost functions provides the variables measured by the data to use in regression models to estimate long run total costs. The functional form of total costs allows for projection of long run costs into the future to increase the scope of the estimates and analyze future cost trends. Differentiation of the long run total cost function yields long run marginal cost which is used as another projection of marginal cost.

An important adjunct to implementation of a marginal cost rate design is to simultaneously provide water customers with information about water conservation opportunities. Best Management Practices (BMPs) are a key part in achieving optimal water conservation in California. We surveyed local water agencies to examine bill formats, existing BMPs, and the investment in a High-Efficiency (HE) clothes washer.

We surveyed one hundred single family homes in Long Beach. We designed three alternative bill formats to compare participant response to a change from current pricing structures to a two tiered, marginal cost rate structure. The alternative rate structure has a low initial block rate providing basic amounts of water at an affordable price, with a higher, marginal cost water rate that applies to additional water use and encourages water conservation. We designed a bill insert to compare participant response to the investment of a HE clothes washer when a \$100 rebate is available and when a \$200 rebate is available. The questionnaire contains queries regarding current conservation methods and rebates available to water customers in order to test customer resource knowledge. The questionnaire is designed with objectives to gauge participant responses to marginal cost water pricing, determine the role a resident's water bill has on their water conservation decisions, determine the effect of rebates on customer purchasing decisions and whether there is an impact on consumer's decisions to buy a HE clothes washer caused by a difference in rebate amounts. The survey provides insight into what participants currently own, their current awareness and participation in public conservation programs available to them at this time, the effectiveness of the bill designs and bill insert, and demographics of the participants.

The results of our research offer valuable information to regional and global water agencies when analyzing their rate designs, bill formats, and public conservation programs.

I. MARGINAL COST ESTIMATION

Philosophy

The philosophy behind marginal cost rate design is a unique and highly cost-effective method of providing the incentive to conserve. In addition, there is an essential fairness issue: if the long run marginal cost is higher than the historic average cost, then a two-tiered rate design for residential customers can provide an essential amount of water at a low, affordable rate, while water consumption beyond that amount will be priced at the cost to the utility of obtaining additional water.

Typically, engineering solutions to water scarcity in Southern California focus on capital intensive measures. While these are worthy pursuits, the ability to maximize economic efficiency relies on an economically sound pricing strategy. Economic theory tells us that this efficient pricing strategy hinges on pricing that captures and conveys the marginal cost of water to consumers, allowing them to adjust usage habits accordingly. This process will increase the stability of rising water rates, increase economic efficiency in allocation of water, and provide a net economic benefit to society.

The theory of marginal cost pricing hinges on the economic concept that goods are allocated efficiently when price is set equal to marginal cost. Marginal cost refers to the incremental change in cost resulting from an incremental change in output. Put another way, when the incremental change in cost due to adding an additional unit is what the consumer of that good is made to pay, the good is allocated efficiently. Under this allocation no one consumer can be made better off without making another worse off.

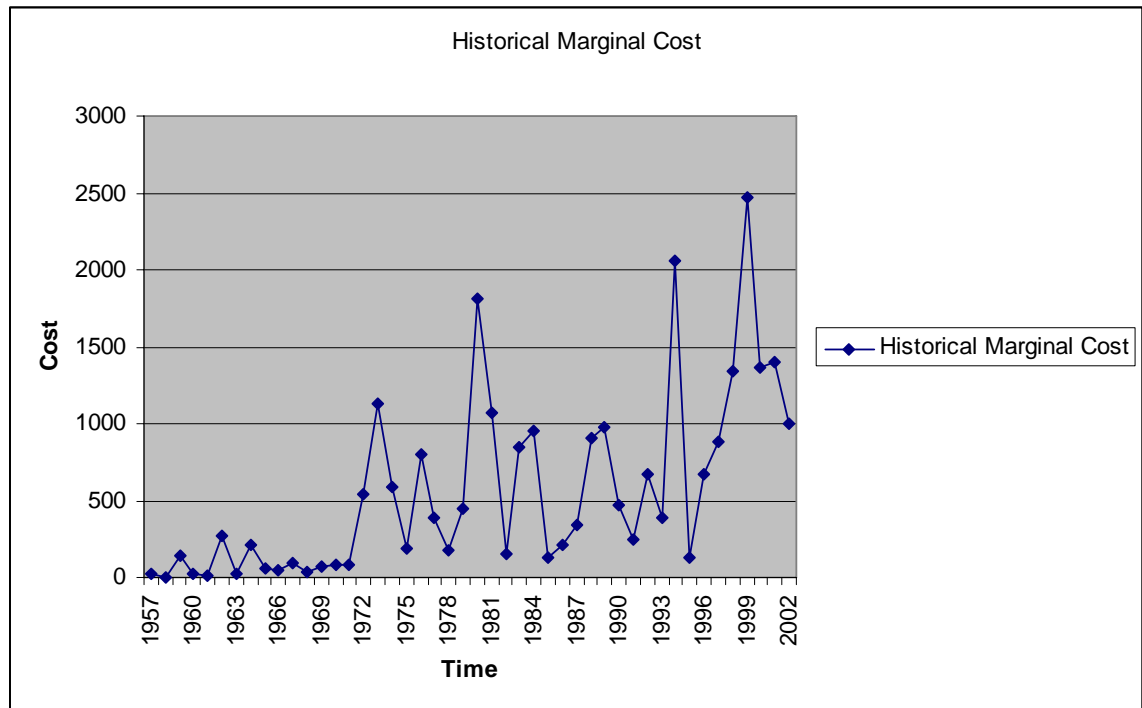
The goal of marginal cost pricing is to allocate goods in an economically efficient manner. This efficiency serves to alert society about the cost of producing (or not producing) another unit so that usage can be adjusted accordingly. A long-run marginal cost rate design is structured to cause consumers to realize the long term cost of water and adjust usage habits accordingly. Given that marginal cost pricing is in the best interest of the public, it is a plausible rate design goal from an economic perspective. Municipal water utilities exist to provide the public with safe water now, and into the future, and pricing at marginal cost can serve as a means to this end.

The hypothesis about the current rate design for most water utilities is that the presence of fixed charges indicates that water is under priced and, as such, being allocated inefficiently. Marginal costs are rising over time, as shown in the graph of historical marginal costs below. The presence of fixed charges in bills indicates that consumers are not able to fully adjust their usage habits, meaning that price is not allowed to regulate demand. Over 1.1 billion people worldwide do not have access to clean drinking water, while the United States uses over 135 billion gallons of water on irrigation alone per day. If consumers were able to realize the true cost of water, it is possible that more serious conservation measures would be implemented, thus reducing water usage.

Marginal cost pricing is a proven theory but there are some problems with practical implementation. One issue raised against implementation of marginal cost rates is that of revenue stability. It is argued that fixed charges help the utility collect a certain amount of revenue, and without fixed charges revenue would vary, requiring frequent and

costly changes in the rate design. This problem can be easily solved with a two-tier rate design where the first block rate is automatically adjusted each quarter to meet a stable revenue target determined by the total costs that the utility must pay and financial ratios necessary to maintain a good bond rating. Another issue is that marginal cost rates would make water too expensive, and would be unfair. A two-tiered rate design can address the issue of fair prices by carefully selecting the amount of water available at the lower first block rate so that an essential amount is available at an affordable price. The second rate would be set equal to the long run marginal cost so that customers have the incentive to invest in water conservation if such investment is less expensive than the marginal cost to the water agency of providing additional water.

Metropolitan Water District



History

Marginal Cost pricing was first implemented during the late 1970's in the electric utility industry in response to increasing costs. During the prime of the Army Corps of Engineers and the Bureau of Reclamation, hundreds of dams were built across the United States and many were built to generate electricity to defray costs. For a while there was surplus electricity and it was consequently sold cheaply on the market. However as urban areas developed in the 1970's into the 1980's, increasing demand for electricity strained the existing system. The electric utility response was to develop rate structures that captured and conveyed forward looking costs to consumers, thus allowing consumers to adjust usage habits and reduce overall demand.

Marginal cost was simply a theoretical approach until researchers began to develop algorithms to calculate marginal cost. An influx of economic literature on the practical applications of this pricing method resulted during this time. NERA developed

an algorithm applicable to electric utilities that focused on the actual operating costs of existing systems. Ernst & Ernst developed an algorithm and computer program that estimated a cost function utilizing roots of economic theory. It is most common that a combined approach is used to double check numbers and eliminate subtle problems inherent in an individual method. Many of the previously developed algorithms are directly applicable to the water industry with minimal modification.

Marginal Cost Estimation Methodology

Our first task was to develop an understanding of current rate designs and supply plans among member agencies. We analyzed several agencies to determine the marginal source of supply in the event of supply shortage or sudden increase in demand. We determined that many agencies within the Metropolitan service area are built out and running at full capacity, thus the least expensive additional source of water comes from increasing supply from MWD. Therefore, it is reasonable to base a marginal cost rate structure on the marginal cost to Metropolitan.

One economically and statistically valid method for estimating marginal cost is a direct application of neo-classical economic theory through the estimation of a total cost function. The cost function to be estimated should be long run total costs in order to capture the long run capital investment flexibility of developing alternative water sources and providing customers with the appropriate incentive when they decide to invest in water conservation, such as a high efficiency clothes washer. We derive two functional forms of long run total costs in order to provide a comparison of results and to check for computational error.

Duality theory in economics allows for the derivation of the long run total cost function from the production function. We specify a factor in the production function called Ricardian Scarcity in order to capture the fact that the least costly sources of water are depleted first, and over time costs are increasing as new sources are more expensive, expensive water storage becomes more critical, and as water treatment costs rise. From a Cobb-Douglas production function with parameters α and β , Ricardian Scarcity parameter θ , and scale factor γ , we can derive the associated long run total cost function given by:

$$LRTC = \left[\left(\frac{\alpha}{\beta} \right)^{\frac{\beta}{\alpha+\beta}} + \left(\frac{\beta}{\alpha} \right)^{\frac{\alpha}{\alpha+\beta}} \right] q^{\frac{1}{\alpha+\beta}} (\gamma e^{\theta t})^{-\frac{1}{\alpha+\beta}} v^{\frac{\alpha}{\alpha+\beta}} w^{\frac{\beta}{\alpha+\beta}} + \varepsilon$$

where q is output, v is the price of fixed inputs, and w is the price of variable inputs. See Appendix A1 for complete derivation and explanation of parameter interpretations.

In addition to the Cobb-Douglas, the Constant Elasticity of Substitution (CES) production function, a more flexible form, was estimated. With parameters γ and σ , Ricardian Scarcity parameter θ , and scale factor δ the associated long run total cost function is given by:

$$LRTC = (\delta e^{\theta t})^{-\frac{1}{\gamma}} q^{\frac{1}{\gamma}} (v^{1-\sigma} + w^{1-\sigma})^{\frac{\sigma}{1-\sigma}} [v^{1-\sigma} + w^{1-\sigma}] + \varepsilon$$

Where q is output, v is price of fixed inputs, and w is price of variable inputs. See Appendix A2 for a complete derivation and explanation of parameter interpretations.

The model can best be estimated by classifying all inputs as either fixed or variable. Fixed inputs are defined as capital investments such as the physical infrastructure and buildings that can't be moved like dams, pipes, and plants. Variable inputs are defined as all other inputs that are variable on a day to day basis such as employee labor and other human input. The generalization of having two production inputs makes economic sense in the context of the model. Fixed and variable input prices have remained relatively steady over the last fifty years, consequently, the main variation in cost over time is modeled using the concept of the Ricardian Scarcity. The escalating cost of water is captured by the Ricardian Scarcity parameter.

Data Collection

Both of the long run total cost equations are functions of the prices of variable and fixed inputs, time, and quantity of water produced. A common problem with estimating a long run total cost function is collecting data on price of inputs, and defining the units of these inputs. This problem was circumvented by collecting estimates of these prices from sources outside of the water industry, as well as MWD.

We obtained variable input prices from the Bureau of Labor Statistics. The average yearly salary of a municipal water employee serves as an appropriate approximation to price of variable inputs. We converted average hourly wage data into average yearly wage for easier implementation in the regression and to maintain uniform units.

We obtained fixed inputs prices from the Economic Report of the President. The annual rate of return on municipal bonds is an accurate estimate for price of capital. Another way to look at annual bond return is the cost of one unit of capital for one year. We used the rate of return on bonds to calculate the value of \$10,000 of capital for one year to create units of capital comparable to units of labor for the regression.

All cost and output data are from the MWD Annual Financial Reports and Budgets. Cost data are also annual, giving total cost per year. Output data are measured in acre feet per year.

We converted all data into 2004 dollars using the Implicit Price Deflator of Gross Domestic Product. We collected data for the years 1949-2004. The data are summarized below. The raw data are available in appendix A3.

Variable	Source	Units
Time (t)	-	Years (1949=1)
Total Cost (LRTC)	MWD Financial Reports	Total Operating Costs
Fixed Input Price (v)	Municipal Bond Yield	Price of \$10,000 of capital per year
Variable Input Price (l)	Bureau of Labor Statistics	Yearly Wage per employee
Quantity Produced (q)	MWD Financial Reports	Acre-feet per year

Summary of Cobb-Douglas Estimation Results

We estimate the parameters of the Cobb-Douglas technology by nonlinear unconstrained estimation. (This functional form is estimable by Ordinary Least Squares regression but the OLS functional form requires a log transformation of variables and the result has substantial multicollinearity with corresponding large standard deviations of the estimated parameters.) We used the software package SAS to estimate the coefficients with PROC NLIN. Due to the high correlation among input prices, we use the Marquardt method of nonlinear estimation. A full printout of statistical results and residual analysis is presented in appendix A4.

The estimated coefficients are as follows:

Cobb-Douglas		
Parameter	Estimate	Std Error
Gamma	29.94	64.79
Alpha	0.3947	0.6646
Beta	3.1389	1.777
Theta	-0.1509	0.1028

The results are consistent with economic theory; alpha, and beta are both positive. Economic theory holds that increasing the cost of inputs will increase total costs. The results of the regression agree and indicate that costs rise with input prices. The estimate of theta, the time parameter, is negative and the estimate of gamma is positive, indicating increasing costs over time (see the function above) which is again consistent with economic theory. These parameters account for Ricardian Scarcity, the cheapest sources of water are used first and over time additional water is more expensive. Both economic theory and Ricardian Scarcity predict increasing costs over time, which the parameter estimates support. The estimated functional form of the Cobb-Douglas total cost function is as follows:

$$LRTC = \left[\left(\frac{.394}{3.13} \right)^{\frac{3.13}{.394+3.13}} + \left(\frac{3.13}{.394} \right)^{\frac{.394}{.394+3.13}} \right] q^{\frac{1}{.394+3.13}} (29.94e^{-.1509t})^{\frac{-1}{.394+3.13}} v^{\frac{.394}{.394+3.13}} w^{\frac{3.13}{.394+3.13}}$$

F-Value = 421.8

Extremely high multicollinearity among parameters is present in the model; for reference the correlation matrix is given in appendix A4. As such, confidence intervals for the estimated parameters are extremely large. However, it should be noted that the F-value of 421.8 indicates that there is strong predictive power with the overall model, and the signs of all parameter estimates satisfy the prerequisites of economic theory.

Summary of CES Estimation Results

We estimate the CES total cost function with nonlinear, unconstrained regression. The CES function is not a linear function, thus the nonlinear estimation is the only option. We specified the NLIN procedure in SAS with the Newton method of nonlinear estimation. The Newton method provides the fastest convergence of the parameter estimates given the functional form. A full printout of the statistical results and residual analysis can be referenced in appendix A5.

The estimated coefficients are as follows:

CES		
Parameter	Estimate	Std Error
gamma	4.7866	4.349
delta	54561.9	.
sigma	1.1034	0.0402
theta	-0.2475	0.2451

The estimated coefficients are consistent with economic theory. Theta is negative and delta is positive, indicating increasing costs over time, supporting the Ricardian Scarcity hypothesis. Gamma is positive indicating that costs rise with output, also in support of economic theory. Sigma is a parameter called the elasticity of substitution, which essentially measures substitutability among input mixes. The CES model and economic theory specifies that this parameter is greater than one, which the model satisfies. The estimated form of the CES long run total cost function is:

$$LRTC = \left(54,561.9e^{-0.2475t}\right)^{\frac{-1}{4.78}} q^{\frac{1}{4.78}} \left(v^{1-1.103} + w^{1-1.103}\right)^{\frac{1.103}{1-1.103}} \left[v^{1-1.103} + w^{1-1.103}\right]$$

F-value = 520.26

High correlation among parameters is present; the full correlation matrix is presented in appendix A5. Due to the high correlation the confidence intervals for parameter estimates are large. However, the statistically significant F-value of 520.26 indicates the model has high predictive power overall.

Marginal Cost Projection

Upon estimation of the Long Run Total Cost functions outlined in the preceding sections, we project marginal cost for ten years into the future. For the purposes of the forecast, we assumed that the prices of fixed and variable inputs will remain constant. The reasons this is an acceptable assumption is that 1) it is safe to assume that prices will not fall thus the only possible error is underestimation of marginal cost, and 2) historic input prices have been constant in real terms. All the predicted increase in cost over time results from the Ricardian Scarcity parameter. The detailed outlines of calculations are presented in appendix A6.

The Cobb-Douglas technology cost function projects marginal cost with the following inputs:

Year - time	Price of Fixed Inputs	Price of Variable Inputs	A/ft per Year	time
2005	4630	36160	2340000	57
2006	4630	36160	1900000	58
2007	4630	36160	2000000	59
2008	4630	36160	2100000	60
2009	4630	36160	2200000	61
2010	4630	36160	2450000	62
2011	4630	36160	2500000	63
2012	4630	36160	2550000	64
2016	4630	36160	2650000	68

Prices of fixed and variable inputs are held constant. Time varies over the range of the estimation from 2005 to 2016. Acre-feet of production per year vary in accordance with MWD's estimated future production outlined in MWD's Annual Budget.

Substituting these inputs into the Cobb-Douglas function, total cost is projected out ten years into the future. From this forecast of total cost, incremental cost is

estimated by applying the definition of marginal cost: $MC = \frac{\Delta TC}{\Delta Q}$. The results are

outlined in the table below:

Year	Projected Total Cost	Incremental Marginal Cost
2005	\$442,720,352.77	.
2006	\$446,361,186.59	\$287.51
2007	\$475,112,361.47	\$303.39
2008	\$505,451,074.79	\$320.21
2009	\$537,472,124.82	\$165.57
2010	\$578,865,164.61	\$665.94
2011	\$612,162,091.29	\$703.16
2012	\$647,320,184.41	\$1,773.24
2016	\$802,478,195.31	\$1,551.58

The CES technology cost function projects marginal cost with the following inputs:

Year	Price of Fixed Inputs	Price of Variable Inputs	A/ft per Year	time
2005	4630	36160	2340000	57
2006	4630	36160	1900000	58
2007	4630	36160	2000000	59
2008	4630	36160	2100000	60
2009	4630	36160	2200000	61
2010	4630	36160	2450000	62
2011	4630	36160	2500000	63
2012	4630	36160	2550000	64
2016	4630	36160	2650000	68

Analogous to the Cobb-Douglas forecast, the prices of fixed and variable inputs are held constant. Time varies over the range of the estimation from 2005 to 2016. Acre-feet of production per year vary in accordance with MWD estimated future production outlined in MWD's Annual Budget.

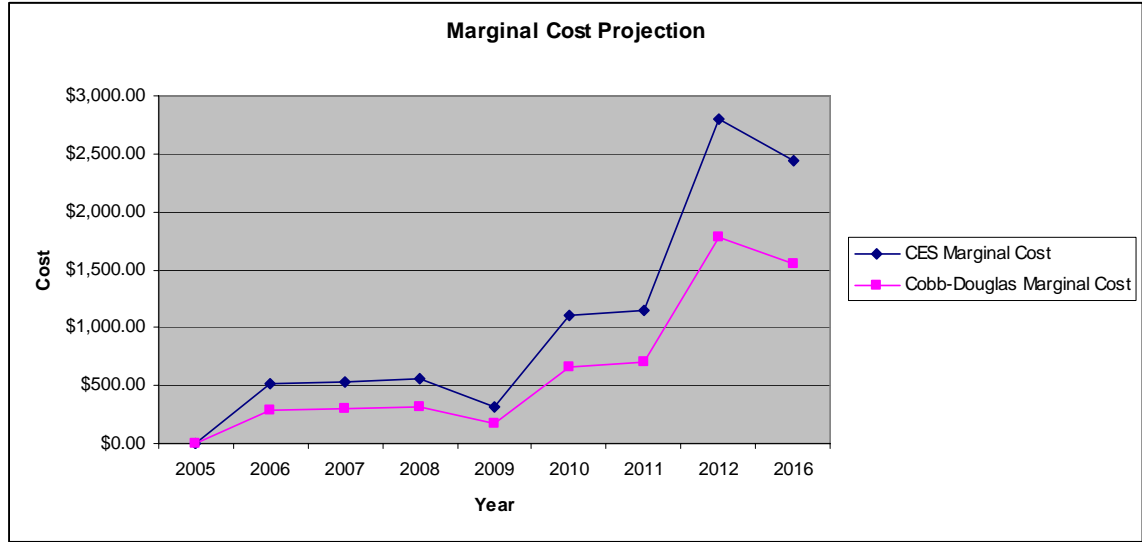
Substituting these inputs into the CES function, total cost is projected out ten years into the future. From this forecast of total cost, incremental cost is estimated by applying the definition of marginal cost: $MC = \frac{\Delta TC}{\Delta Q}$. The results are outlined in the table below:

Year	Projected Total Cost	Incremental Marginal Cost
2005	\$883,907,900.39	.
2006	\$869,666,366.96	\$512.14
2007	\$920,880,106.83	\$535.39
2008	\$974,419,266.82	\$559.90
2009	\$1,030,408,951.33	\$312.86
2010	\$1,108,623,657.43	\$1,100.05
2011	\$1,163,625,937.07	\$1,151.86
2012	\$1,221,218,775.22	\$2,805.09
2016	\$1,464,556,570.87	\$2,433.36

It should be noted that both functional forms yield similar results. The CES function estimated higher total costs into the future, leading to higher estimates of marginal cost. However, both estimate increasing marginal costs into the future, supporting the hypothesis of escalating costs. Because the CES cost function is a more flexible form than the Cobb-Douglas agreement between estimates indicates the projections are reasonably accurate.

Interpretation of Results

As hypothesized, marginal cost is increasing over time due to increasing scarcity and increasing demand. The CES and Cobb-Douglas functional forms comply with economic theory and project marginal cost increasing into the future. Depicted graphically it becomes apparent that marginal cost is rising:



Marginal cost is increasing over time and discontinuous at 2012. This is because the annual report gives MWD's projected output annually until that date, after which we have another source from MWD with a graph from which we were able to read an output for the year 2016. This latter data point may not be consistent with the annual report; we present it here as a matter of interest.

This means that over time the marginal cost of another unit of water is rising and will continue to rise into the foreseeable future. To an economist this is a signal that increasing scarcity and rising demand are going to drive costs up in the future, and this forecasts that revenue instability is going to be a problem in the future, a problem that can be mitigated by water conservation resulting from implementation of marginal cost based rate design..

Rate Design Implications

As hypothesized, we find that the marginal cost of water is rising into the foreseeable future. The cost of water is rising due to increasing scarcity, rapid urban growth, and more stringent water quality standards. Current rate designs fail to accurately capture and convey the rising cost of water and in the process the consumer is not able to receive price signals to adjust demand in response.

Each acre-foot of water contains approximately 435 billing units. Dividing the estimated marginal cost by 435 yields the marginal cost per billing unit to the consumer, outlined in the table below. This is the price that economic theory states the consumer should be charged per billing unit to efficiently price water. The marginal cost per billing

unit , within 6 years is between \$4.08 and \$6.45 based on CES and Cobb-Douglas estimates, respectively. It is immediately apparent that \$4 - \$6 per billing unit in real dollars is much higher than the second or third “tier” rates that most member agencies use, indicating efficiency gains from implementation of marginal cost rates.

Year	CES	Cobb-Douglas
2006	\$0.66	\$1.18
2007	\$0.70	\$1.23
2008	\$0.74	\$1.29
2009	\$0.38	\$0.72
2010	\$1.53	\$2.53
2011	\$1.62	\$2.65
2012	\$4.08	\$6.45
2016	\$5.59	\$3.57

A two-tiered marginal cost rate structure could be implemented in a revenue neutral fashion relative to current rates. A lower first block rate per billing unit would allow customers to buy amounts of water up to an essential amount at a low price, and additional water at the marginal cost. The essential amount can be determined by each community to meet a perceived fairness standard to make an essential amount affordable. The initial block rate can be adjusted automatically each quarter to allow the utility’s income to meet its revenue requirement. The second rate can be set equal to the long run marginal cost. This rate design allows for revenue stability for the water agency by automatically adjusting the lower first rate quarterly to meet the revenue requirement. This rate design is fair because it gives customers an essential amount of water at an affordable price. This rate design is efficient because it gives customers a real incentive to invest in water conservation, thereby delaying expensive acquisition of additional water.

Conclusion and Further Study

The calculation of marginal cost is not a straightforward application of neoclassical economics because water utility costs do not conform to the restrictions of economic theory. System demand and supply are uncertain and additional supply is discontinuous leading to large jumps in historical total cost. New methods of acquiring water, such as desalinization, may become more cost effective, but desalination relies on electricity, and we expect that the cost of electricity will continue to rise.

We recommend further study and serious consideration of marginal cost rate design. Further study should also be directed to the political feasibility of implementing marginal cost rates in the Metropolitan service area, taking into account pressure to maintain the current equilibrium of the system, but balancing that with the inevitable disruption of forecast future cost increases.

A final note is that this study was conducted without access to cost and demographic data from a specific agency except the Metropolitan Water District. Agency specific data could allow for applied analysis of the marginal cost rate structure,

breakpoints and rates could be calculated allowing for local utility revenue, demand, and supply plan analysis.

II. WATER CONSERVATION SURVEY

Survey Methodology

Upon researching Best Management Practices currently in use in the region, we designed a survey to evaluate the impact on water conservation decisions using a combination of a change in the rate design with rebates to encourage investment in a high efficiency clothes washer.

We met with faculty in the Marketing Department at Cal State Long Beach during survey design. The Intercept Water Conservation Questionnaire, see appendix B1, consists of four sections, and cards for participants to refer to when answering certain questions. We surveyed one hundred single-family homeowners in Long Beach in front of Lowe's located at 2840 Bellflower Blvd, Long Beach, CA 90815 over a series of surveying dates. Participants received a \$15 gift card to the store as an incentive to participate in the survey. We selected this location because it is surrounded by a number of different zip codes.

The first section of the questionnaire, Customer Home Inventory, asked participants about the indoor water fixtures and appliances they currently own. We also asked about respondents' perceptions and their current conservation measures.

The second section, Customer Resource Knowledge, asked participants to share their awareness and participation in current water conservation programs and resources available to them. We also asked respondents what they perceive to be the most effective way to obtain water conservation information.

The third section, Bill Formats, tested participant response to a current bill, designed after a review of a number of water bills used by several water utilities in Southern California, all with a familiar pricing structure. A fixed Monthly Customer Charge is added to charges of up to three pricing blocks, Block I, Block II, and Block III, depending on usage. Depending on information from the respondent, we present a bill based upon either 10 billing units (BU) per month, 20 BU/mo, or 30 BU/mo (Bill A1, A2 or A3, respectively). Then each respondent examined an alternative rate design that eliminated the fixed customer charge, and simplified the bill to just two tiers, called the initial block and the marginal block. For the alternative rate design, we set the marginal block equal to \$2.50 per BU. We set the initial block rate so that the total bill equaled the same as the amount on Bill Design A, with the fixed customer charge. In addition to the alternative rate design, we tested two bill formats, one without a rebate and the other with a rebate for investing in a high efficiency clothes washer.

Appendix B1 presents the two alternative bill designs, Bill Design B and Bill Design C. Both bill designs have identical rates. The marginal cost rate design (designs B and C) does not have a fixed monthly charge, and had a low First Block Rate, and a higher Marginal Cost Rate that applies to higher usage. Bill Design B does not have a statement at the bottom with information about savings from investing in a high efficiency clothes washer.. Two versions of Bill Design C contain the same marginal cost water pricing along with a water conservation note on the bottom of the bill, each

referring to a bill insert with a rebate amount for investment in a High Efficiency (HE) clothes washer. The bill inserts give annual water costs for a standard clothes washer and a HE clothes washer based on an average of loads per year at the marginal cost of water. The insert shows participants annual water, gas, and electric savings from HE clothes washers. One insert, Bill Insert X, lists the \$100 rebate adding up to a total estimated savings of \$191 in the first year and letting the participant know that their investment in a HE clothes washer could result in a pay off in about 5 years. The second insert, Bill Insert Y, contains the same savings with a \$200 rebate (instead of \$100) resulting in a total estimated savings of \$291 in the first year and a pay off in about 4 years.

The fourth section of the questionnaire, Demographics, collected participant information in a coded system to ensure confidentiality. The survey collected information on participant education, income, number of people residing in their household, and gender.

The bill formats were broken down into three generic water use categories: small water users at 10 billing units per month, medium water users at 20 billing units per month, and large water users at 30 billing units per month. All bill formats were revenue neutral to avoid participant bias based on the total charge on the bill. On the first day of surveying, we classified participants according to their self-reported usage. For the remaining surveying dates, interviewers classified participants according to a rough estimate of water usage based on zip codes. We surveyed two separate random homes representative of each zip code in eleven residential zip codes, and we estimated the area of the lot of the homes and the size of the house. With this information, we based water usage on lot size and house size for each zip code, and assigned to each zip code one of the three generic categories of water use.

To maximize the power of our statistics, we divided participants into thirds. All participants viewed the Current Bill Design. Approximately one third of the participants viewed Alternative Bill B that contained marginal cost water pricing only, after viewing the current bill design. Another one-third viewed Alternative Bill CX along with Bill Insert X (\$100 rebate), after viewing the current bill design. The remaining one-third viewed Alternative Bill CY along with Bill Insert Y (\$200 rebate), after viewing the Current Bill Design. For a summary of the survey design see the table below.

Bill Designs & Bill Inserts Viewed by Participants	
Current Bill Design	100%
Alternative Bill Design B, with no rebate	39%
Alternative Bill Design CX and CY, with a rebate	61%
Bill Insert with \$100 Rebate (X)	32%
Bill Insert with \$200 Rebate (Y)	29%

Both interviewers entered every observation from the surveys into separate spreadsheets, and we verified that the data were accurately entered by a data matching routine.

Interpretations & Recommendations

Clothes washers use the second highest amount of water (after toilets) in a household. Southern California water agencies have been very successful in implementing public programs to encourage residential use of water-efficient toilets. In our survey, nearly 70% of participants had low-flush toilets; for a summary of results see the table below. Additionally, 56% had low-flow showerheads. However, less than half of the participants surveyed had water-efficient clothes washers (34%). The average age of clothes washers owned by participants equals four and a half years, suggesting that in recent years many people in the market for washers have been purchasing traditional rather than water-efficient models.

Percentage of Appliance Types		
Appliance	Water Type	
	Traditional	Efficient
Toilets	23	69
Showerheads	31	56
Washers	59	34

We designed the bill insert to compare participant responses on the effectiveness of rebates as incentives to encourage investment in high-efficiency (HE) products, after viewing the alternative rate design, a simpler two-tier rate design without a fixed charge. Three-fourths of the participants surveyed agreed that rebates would encourage HE purchases, and 65% felt that seeing a comparison of costs and savings between standard and HE products would encourage investment in HE appliances. However, only 58% of people were aware that such rebates existed, and only 29% of those participants had actually taken advantage of the offers. This indicates that rebates are not being adequately promoted to the public.

During the survey, interviewers asked participants if they felt rebates encourage water-efficient product purchases, see table below. Although 60% of the responses show that rebates are effective incentives, the majority felt that the only benefit of rebates was to save money. Those that felt that rebates gave insufficient incentive (40% of responses) listed such reasons as: not enough money offered, the process is too complicated, and HE products are inefficient. Therefore, rebate policy should consider additional advertisement of rebates, offering a larger rebate amount, simplifying the rebate process, and providing information about how clean clothes are when washed in a HE washer.

73 observations: Rebates as Incentives			
Reason	# Responses		
	Yes	No	Maybe
Money	42	5	1
Product Effectiveness	-	3	3
Conservation	-	5	-
Rebate Process	-	5	-
Other	2	7	-
Total Responses	44	25	4

The extent to which residents are aware of rebates declines as income increases, as outlined in the table below. A possible explanation for this may be that people in the higher income brackets have more time and/or resources to research such things when in the market for a washer, while people in the lower income brackets may not have the time and resources to research it and will most likely purchase what they think to be the best priced object (usually the traditional washer). Our initial research found that few stores displayed any conservation information at all, and those that did mostly focused on energy savings; there was very little information on water efficiency and savings. Since the retailers that sell these products are the primary source of information for many residents, especially those in the lower income brackets, this is where water conservation information (with regards to HE products) could be distributed most effectively. A comparison would give customers a better idea of the “true” cost of a traditional clothes washer in the long run, after taking into account the greater cost of water and gas and electric bills. Additionally, the rebate process could be simplified greatly if the rebate forms were available to customers at the retail stores upon purchase of HE appliances. Such information could be provided by local water agencies to retailers of these appliances.

Role of Income on Rebates and Washer Types		
Income	As Incentive (%)	Received (%)
<\$10K-\$59K	60	40
\$60K-\$129K	77	38
\$130K-\$189K	83	36
\$190K->\$400K	70	0

The extent to which rebates serve as an incentive to purchase HE appliances increased with increases in income up until the highest income tier as shown above. This trend may be explained by financial ability of the middle brackets to invest in a high efficiency appliance, and yet still be at a point financially at which they still like to save money. The lower bracket may simply lack the funds to make the initial purchase of an HE product, while individuals in the highest income bracket value their time higher than the amount they can save if they invest in information about the savings. The focus of local water agencies, therefore, should be placed on those residents in the middle and

lower income brackets who may not have the extra amount of money needed to purchase the HE appliance. For these customers especially, an increase in the rebate amount is needed. The gap between the HE washer cost and the traditional washer cost must be further reduced if residents in the lower income brackets are to take advantage of the rebates.

Attention may also be directed to residents of “target” zip codes, outlined in the table below in bold. These are areas in the city in which residents mostly have traditional clothes washers and have the lowest levels of rebate awareness.

Target Zip Codes		
Zip Code	HE Washer (%)	Aware of Rebate (%)
90802	0	0
90803	14	100
90804	25	25
90805	0	0
90806	0	75
90807	0	100
90808	42	58
90810	0	50
90813	67	0
90814	29	86
90815	26	54

Participants are generally unaware of the various public programs offered by local water agencies, and participation levels were similarly extremely low. Participants were asked what they felt to be the best method to obtain water conservation information, see table below, and we find the greatest response (33%) to be the internet / website. Other responses include separate mailings, bill inserts, emails, magazines /newspapers, television ads, and contacting the city hall or local water agencies directly. No one method received a majority of the responses. A local water agency could take part in all of these activities, but perhaps a more efficient dissemination of information could be attained if the best method were determined by area or zip code.

Most Effective Means of Outreach	
Method	# Responses
Internet	33
Separate Mailer	23
Bill	21
Email	9
Magazine/Newspaper	8
TV Ads	6
City	4
Other	14

With respect to the bill formats, the alternative marginal cost, two-tier rate design is easier to understand for water customers than the current rate design with confusing fixed charges and up to three tiers. The majority of participants, 89%, correctly stated the total charge of water with the marginal cost bill designs and a slightly lower, 82%, correctly stated the total water charge based upon the current bill design, detailed in the table below. While 2% of participants were not sure of the total charge for water with the current bill design, not one participant was unsure of the total charge with the alternative bill designs. The majority of participants, 45%, correctly identified the price of additional water with the alternative bills compared to only 19% with the current bill design. Water usage was correctly identified by 35% of the participants with the alternative bills while only 27% were correctly identified with the current bill design. 15% were not sure of water usage with the current bill design, compared to only 2% with the alternative bill designs. The majority of participants responded to water usage in gallons rather than in billing units for all bill designs. The majority of the participants responded that they are not likely to use less water regardless of current or alternative bill designs, 74% and 61% respectively. More participants are likely to use less water with the alternative bill designs, 31%, than with the current bill design, 18%. A small percentage of participants, 4%, were very likely to use less regardless of the bill designs. These findings indicate that the ability of a participant to understand the total charge for water is not affected by bill design but more participants are able to understand the price of additional water with marginal cost water pricing. The majority of participants comprehend water use in gallons rather than in billing units. While the total amount of water is noted by participants in dollar amounts, when it comes to water usage, they refer to gallons. The majority of participants did not correlate water conservation directly with the design of the bill itself or with water pricing alone, and are rather influenced by the extra messages included on the bill. These messages could stand out from the usual pricing design resulting in a favorable response from the participant.

Bill Design	Current Bill	Alternative Bill
Charges		
Total charge of water correct	82%	89%
Not sure of total charge	2%	0%
Price of additional water correct	19%	45%
Not sure of price	42%	22%
Believe price is variable	26%	0%
Water Usage		
Water usage correct	27%	35%
Not sure of water usage	15%	2%
Answer in Billing Units (BU)	20%	32%
Answer in Gallons	65%	66%
Bill Design & Water Conservation		
Not likely to use less water with design	74%	61%
Likely to use less water with design	18%	31%
Very likely to use less water with design	4%	4%

Rate reform by itself, switching from the current bill design to a simpler two-tier increasing block, is now where nearly as effective to encourage water conservation as when it is accompanied by information on how to conserve water and save money. The effectiveness of Alternative Bill Design C to encourage water conservation yielded a response of 36%, compared to Alternative Bill Design B at 13%, and the current bill at 11%. One third of participants, 33%, were not encouraged to conserve water at all by the bill designs, see table below. More participants preferred to receive Bill Design C, 36%, than Bill Design B, 21%, and the current bill, 25%. We did not test the current bill design with and without a bill insert that contained a rebate, but we suspect that the water conservation message on the bottom of the bill is more effective in encouraging water conservation than the bill design or the rate design, with the caveat that the marginal cost of \$2.50 is substantially below the estimated \$4 to \$6.50 per BU that we project in 6 years. While more participants prefer to receive the alternative bill with marginal cost water pricing, the water conservation message, and the bill insert, the percentage that prefer to receive a familiar bill and one with a new pricing structure alone, is approximately the same.

Bill Design Effectiveness	
Encouraged to conserve water - Current Bill	11%
Encouraged to conserve water - Alternative B	13%
Encouraged to conserve water - Alternative C	36%
Not encouraged to conserve water at all	33%
Prefer to receive Current Design	25%
Prefer to receive Alternative B	21%
Prefer to receive Alternative C	36%

As outlined in the table below, almost all of the participants that viewed both bill inserts found them useful, 95%. Respondents rated the bill insert with the \$100 rebate slightly more useful than the respondents shown the insert with the \$200 rebate, 97% and 93%, respectively. The majority of the participants that viewed the bill inserts, 80%, stated that they would invest in a HE clothes washer after viewing the bill insert. Slightly more participants would make the investment after viewing the insert with the \$100 rebate, 81%, than after viewing the \$200 rebate, 79%. While almost all participants found useful a bill insert with savings broken down for them and a pay-off in years noted for an investment in a HE clothes washer and the majority would make the investment after becoming aware of their potential savings, there was only a slight difference in response between a \$100 rebate or a \$200 rebate. Doubling the amount of rebate does not make a significant difference in persuading participants to make the investment. This may be due to the fact that a HE clothes washer is a big investment and an extra \$100 rebate may not make a difference when compared to the total price of the washer, especially since the average cost of a HE clothes washer is generally much higher than a standard clothes washer. Perhaps an increase to \$300 would have a noticeable effect, or a larger sample size would allow us to statistically discern a difference.

Bill Insert Effectiveness	
Bill insert found useful	95%
Bill Insert with \$100 Rebate found useful	97%
Bill Insert with \$200 Rebate found useful	93%
Participants that would invest in a HE washer after viewing insert	80%
Participants that would invest after viewing \$100 Rebate insert	81%
Participants that would invest after viewing \$200 Rebate insert	79%

The range of participant education level was from no High School, 1%, to a Graduate Degree, 31%, as shown below. The majority of the participants had a University Degree or a Graduate Degree, 29% and 31% respectively. We could not discern a correlation between education and correctly responding to the survey because the majority of the participants being hold degrees in higher education. The median household income was in the category of \$100,000 to \$129,999. The total range of participant incomes was from less than \$10,000 to over \$400,000. The plurality of households contained two people residing in the home, 39%, with four people residing in the home being next at 20%. The range of people residing in the home was from one person to five persons. The majority of the participants were male, 61%. This may be due to the survey being located at a home improvement store. A more in depth study could be conducted to see if gender affects the outcome of a study such as this one.

Demographics	
Education	
No High School	1%
High School Graduate	2%
Technical/Vocational Graduate	4%
Community College Graduate	8%
University Graduate	29%
Graduate Degree	31%
Income	
Median Income: \$100,000-\$129,999	
Income Range: >\$10,000 to <\$400,000	
Number of people in household	
1	16%
2	39%
3	18%
4	20%
5	7%
Gender	
Female	39%
Male	61%

Conclusion and Further Study

Throughout the research, we faced many challenges that required creative solutions. The first challenge was our decision to focus on indoor rather than outdoor water conservation. Due to the extensive outdoor water conservation programs already in place with local water agencies as well as with MWD, we decided to investigate indoor water conservation. Another challenge was the choice between low flush toilets or clothes washers. We focus on HE clothes washers because of the 1992 California state law requiring all toilets to be manufactured as low flush, with a maximum of 1.6 gallons per flush. We identified a lack of HE clothes washer information available to customers as well as the fact that a customer can choose to purchase a traditional clothes washer and may not have the information necessary to choose to invest in a HE washer.

An important challenge was how to select numbers for the alternative marginal cost rate design, given the short time period between the official signing of the contract (January 2006) and the due date (April 18), when the estimation and forecast of marginal cost was not complete. We selected \$2.50/BU as the “marginal cost rate” because it is one of the higher rates now in use by Southern California water utilities. We now recognize that the forecast of marginal cost for MWD equals a higher number, in the range of \$4 - \$5.60 during the period of 2012 to 2016, based upon the CES technology. Additional survey results could include rate designs based upon this range of values for the marginal cost rate.

We also faced the challenge of how to design the alternative marginal cost rates in a fashion that is revenue neutral. To solve this problem, we assigned generic water usage categories to zip codes, and carefully designed bills alternatives for each level of usage that are revenue neutral to reduce bias from participants. Lastly, we did not have access to water usage information for homes in specific zip codes, so we visited each zip code in the area and selected two random homes in eleven residential zip codes to estimate the lot size and house size and assigned generic water use categories for each zip code.

Further study is needed to classify respondents in appropriate water usage categories based on their actual water usage to create accurate average water usage categories correlated to zip codes. With more time and resources a study such as this one has the potential to inform local water departments of which specific areas in their city should be “targeted” when distributing water conservation information. Additionally, with further study, insight could be attained into the level of resident awareness of various local water conservation programs and the success associated with each. Local water agencies would benefit from these types of knowledge because they could implement the appropriate types of programs in the areas that could most improve their water usage and water conservation habits. Water agencies would then be able to improve the overall effectiveness of their public outreach and water conservation programs.

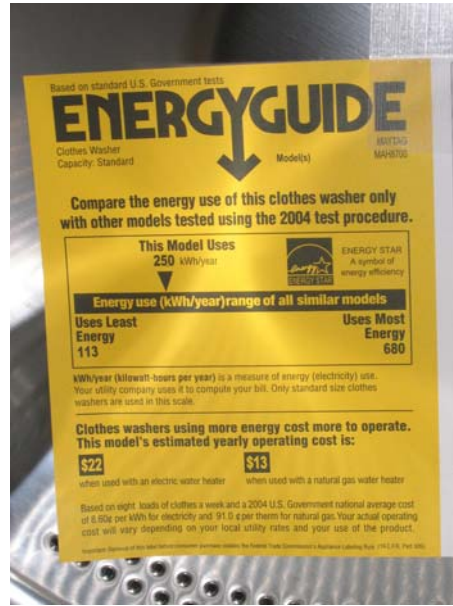
III. GLOBAL APPLICATION

Rate design is of secondary concern in any country that lacks basic water supply. In these countries economic thought should be devoted toward encouraging outside investment in the region. However, in any developing third world country with water problems but that has some infrastructure, marginal cost rates are applicable.

An increasing block marginal cost rate design can set a low price to make the amount of water essential for survival available at an affordable price, thereby ensuring an adequate supply to the poor. A developing country with a poor population would be able to set the first block rate at an affordable level without taking away from the economic efficiency of the rate design. Higher income residents or those who desire to use larger amounts of water can be charged the higher block marginal cost rate. These are the residents that want to purchase additional water supply and those who wish to buy greater amounts of water. In this situation those with higher income fund the water infrastructure and defray the costs to low income users for essential water use. This rate design can be set up to allow users to purchase a minimal amount of water to survive and additional units purchased can be charged at the marginal cost. Our results also support the benefit of providing information and incentives to water users about decisions that can lead the consumer to conserve water. Best available management practices are location-specific, and country-specific. It is important that best management practices are affordable and that customers are made aware of them when rate reform efforts are implemented.

On a global scale, water agencies can benefit from the findings in this report by gaining insight into possible courses of actions when devising new water conservation programs or reevaluating existing methods to implement conservation methods and best management practices. A newly formed water agency or existing water agency can increase effectiveness by taking the time to learn what outreach the specific community they serve responds to the best. For countries that do not have a current structure in place, this report presents for effective rates design, bill formats, and public conservation programs. For countries with existing infrastructure, this report presents examples of how to modify rate designs, bill designs, and to develop successful outreach for conservation programs. Additionally, information on investments and techniques for water conservation that includes upfront cost and payback, specific to the circumstances of the people who use water, can help customers decide whether conservation investments and techniques will pay-off within a reasonable time frame, and also support requests for international aid to help provide funding for capital investments that conserve water.

IV. PHOTO JOURNAL





V. EXPENDITURES

Indirect Costs	Amount
Univ. Admin. Fee	\$428
Stipends	Amount
Garcia, Mayra	\$1845.66
MacEwan, Duncan	\$1845.66
Norris, Christy	\$1845.66
<i>Subtotal</i>	<i>\$5536.98</i>
Supplies	Amount
Survey Copies & Cards	\$554.14
Participant Incentives	\$1,500.00
<i>Subtotal</i>	<i>\$2,054.14</i>
Equipment	Amount
Tape Measure	\$15.03
<i>Subtotal</i>	<i>\$15.03</i>
Mileage	Amount
MacEwan, Duncan	\$56.06
<i>Subtotal</i>	<i>\$56.06</i>
Grand Total	\$8090.21

APPENDIX A1

To determine the Cobb-Douglas functional form of Total Costs, begin with the general form of the Cobb-Douglas Production Function, defined as:

$$q = f(k,l) = k^\alpha l^\beta$$

q- total acre-feet, k- amount of fixed inputs, l- amount of variable inputs

with “Adverse Geography” this becomes

$$q = f(k,l) = \gamma e^{\theta t} k^\alpha l^\beta$$

t is time and $\gamma, \theta, \alpha, \beta$ are parameters of the model to be estimated

Let $\gamma e^{\theta t} = \delta$, where δ is a parameter that shifts the production function over time to reflect the fact that as the best sources of water are tapped and as the demand for water increases, it will become increasingly costly to obtain an additional unit of water, which is called Ricardian Scarcity. For the purposes of this model, δ will be defined as a parameter reflecting Ricardian Scarcity. The easiest to access, and therefore least costly to obtain, sources of water are the first to be tapped. As such, it becomes more difficult, and therefore more expensive, to obtain water over time.

Costs are defined as:

$$C = f(w,k,v,l) = vk + wl$$

v,w are the prices of fixed and variable inputs, respectively.

Derive long run total costs:

Minimize $C(w,k,v,l)$ subject to $q = f(k,l)$

$$L = vk + wl + \lambda(q - \delta k^\alpha l^\beta)$$

First Order Conditions:

$$(1) L_k = v - \delta \alpha \lambda k^{\alpha-1} l^\beta = 0$$

$$(2) L_l = w - \delta \beta \lambda k^\alpha l^{\beta-1} = 0$$

$$(3) L_\lambda = q - \delta k^\alpha l^\beta = 0$$

Dividing (2) by (1) yields:

$$\frac{w}{v} = \frac{\delta \beta \lambda k^\alpha l^{\beta-1}}{\delta \alpha \lambda k^{\alpha-1} l^\beta} = \frac{k}{l} * \frac{\beta}{\alpha}$$

$$\frac{w}{v} = \frac{k}{l} * \frac{\beta}{\alpha}, \text{ this yields the cost minimizing input mix.}$$

Solving for l^* and k^* , the cost minimizing selection of inputs, yields:

$$l^* = \left[\frac{v}{w} * \frac{\beta}{\alpha} \right] k \quad \text{and} \quad k^* = \left[\frac{w}{v} * \frac{\alpha}{\beta} \right] l$$

Substituting in k^* into the production function with Ricardian Scarcity and solving for l :

$$q = \delta \left(\frac{\alpha}{\beta} * \frac{w}{v} \right)^\alpha l^\alpha l^\beta = \delta \left(\frac{\alpha}{\beta} * \frac{w}{v} \right)^\alpha l^{\alpha+\beta}$$

$$q l^{-(\alpha+\beta)} = \delta \left(\frac{\alpha}{\beta} * \frac{w}{v} \right)^\alpha$$

$$l^{-(\alpha+\beta)} = \delta \left(\frac{\alpha}{\beta} * \frac{w}{v} \right)^\alpha q^{-1}$$

$$(4) \quad l = \left[\delta \left(\frac{\alpha}{\beta} * \frac{w}{v} \right)^\alpha q^{-1} \right]^{\frac{-1}{\alpha+\beta}} = \left(\frac{\beta}{\alpha} \right)^{\frac{\alpha}{\alpha+\beta}} \left(\frac{v}{w} \right)^{\frac{\alpha}{\alpha+\beta}} \left(\frac{q}{\delta} \right)^{\frac{1}{\alpha+\beta}}$$

Substituting in l^* into the production function with Ricardian Scarcity and solving for k :

$$q = \delta \left(\frac{\beta}{\alpha} * \frac{v}{w} \right)^\beta k^\alpha k^\beta = \delta \left(\frac{\beta}{\alpha} * \frac{v}{w} \right)^\beta k^{\alpha+\beta}$$

$$q k^{-(\alpha+\beta)} = \delta \left(\frac{\beta}{\alpha} * \frac{v}{w} \right)^\beta$$

$$k^{-(\alpha+\beta)} = \delta \left(\frac{\beta}{\alpha} * \frac{v}{w} \right)^\beta q^{-1}$$

$$(5) \quad k = \left[\delta \left(\frac{\beta}{\alpha} * \frac{v}{w} \right)^\beta q^{-1} \right]^{\frac{1}{\alpha+\beta}} = \left(\frac{\alpha}{\beta} \right)^{\frac{\beta}{\alpha+\beta}} \left(\frac{w}{v} \right)^{\frac{\beta}{\alpha+\beta}} \left(\frac{q}{\delta} \right)^{\frac{1}{\alpha+\beta}}$$

Now l and k are expressed as functions of their respective input prices and output, substituting (4) and (5) simultaneously into the cost accounting identity yields the total cost function:

$$TC = v \left[\left(\frac{\alpha}{\beta} \right)^{\frac{\beta}{\alpha+\beta}} \left(\frac{w}{v} \right)^{\frac{\beta}{\alpha+\beta}} \left(\frac{q}{\delta} \right)^{\frac{1}{\alpha+\beta}} \right] + w \left[\left(\frac{\beta}{\alpha} \right)^{\frac{\alpha}{\alpha+\beta}} \left(\frac{v}{w} \right)^{\frac{\alpha}{\alpha+\beta}} \left(\frac{q}{\delta} \right)^{\frac{1}{\alpha+\beta}} \right]$$

Simplifying,

$$TC = \left(\frac{q}{\delta} \right)^{\frac{1}{\alpha+\beta}} \left[\left(\frac{\alpha}{\beta} \right)^{\frac{\beta}{\alpha+\beta}} w^{\frac{\beta}{\alpha+\beta}} v^{\frac{\alpha}{\alpha+\beta}} \right] + \left[\left(\frac{\beta}{\alpha} \right)^{\frac{\alpha}{\alpha+\beta}} w^{\frac{\beta}{\alpha+\beta}} v^{\frac{\alpha}{\alpha+\beta}} \right]$$

$$TC = \left(\frac{q}{\delta} \right)^{\frac{1}{\alpha+\beta}} v^{\frac{\alpha}{\alpha+\beta}} w^{\frac{\beta}{\alpha+\beta}} \left[\left(\frac{\alpha}{\beta} \right)^{\frac{\beta}{\alpha+\beta}} + \left(\frac{\beta}{\alpha} \right)^{\frac{\alpha}{\alpha+\beta}} \right]$$

Let $D = \left(\frac{\alpha}{\beta} \right)^{\frac{\beta}{\alpha+\beta}} + \left(\frac{\beta}{\alpha} \right)^{\frac{\alpha}{\alpha+\beta}}$, some constant involving only parameters to be estimated.

Making this substitution, Total Costs with Ricardian Scarcity is defined as:

$$TC = D \left(\frac{q}{\delta} \right)^{\frac{1}{\alpha+\beta}} v^{\frac{\alpha}{\alpha+\beta}} w^{\frac{\beta}{\alpha+\beta}}$$

It follows that Marginal Cost is defined by:

$$\frac{\partial TC}{\partial q} = MC = \left(\frac{1}{\alpha + \beta} \right) D q^{\frac{1}{\alpha+\beta}-1} \delta^{\frac{-1}{\alpha+\beta}} v^{\frac{\alpha}{\alpha+\beta}} w^{\frac{\beta}{\alpha+\beta}}$$

To determine a functional form of Total Costs that is estimable using OLS Regression:

Substituting back in for δ into the Total Cost function:

$$TC = D q^{\frac{1}{\alpha+\beta}} \left(\gamma e^{\theta t} \right)^{\frac{-1}{\alpha+\beta}} v^{\frac{\alpha}{\alpha+\beta}} w^{\frac{\beta}{\alpha+\beta}}$$

Simplifying,

$$TC = D q^{\frac{1}{\alpha+\beta}} \gamma^{\frac{-1}{\alpha+\beta}} e^{\frac{-\theta t}{\alpha+\beta}} v^{\frac{\alpha}{\alpha+\beta}} w^{\frac{\beta}{\alpha+\beta}}$$

Let $B = \gamma^{\frac{-1}{\alpha+\beta}}$ and $BD = A$

Making this substitution and taking the natural logarithm of TC:

$$\ln TC = \ln A + \ln \left(q^{\frac{1}{\alpha+\beta}} \right) + \ln \left(e^{\frac{-\theta t}{\alpha+\beta}} \right) + \ln \left(v^{\frac{\alpha}{\alpha+\beta}} \right) + \ln \left(w^{\frac{\beta}{\alpha+\beta}} \right)$$

Simplifying using the laws of logarithms:

$$\ln TC = \ln A + \left(\frac{1}{\alpha+\beta} \right) \ln q - \left(\frac{\theta}{\alpha+\beta} \right) t + \left(\frac{\alpha}{\alpha+\beta} \right) \ln v + \left(\frac{\beta}{\alpha+\beta} \right) \ln w$$

The functional form of Total Costs to be estimated using Ordinary Least Squares is:

$$\ln TC = \ln A + \left(\frac{1}{\alpha+\beta} \right) \ln q - \left(\frac{\theta}{\alpha+\beta} \right) t + \left(\frac{\alpha}{\alpha+\beta} \right) \ln v + \left(\frac{\beta}{\alpha+\beta} \right) \ln w + \varepsilon$$

Where ε is a normally distributed error term. The above will be estimated subject to constraints on the coefficients:

The exponents on v and w must sum to one, namely: $\frac{\alpha}{\alpha+\beta} + \frac{\beta}{\alpha+\beta} = 1$

Similarly, $D = \left(\frac{\alpha}{\beta} \right)^{\frac{\beta}{\alpha+\beta}} + \left(\frac{\beta}{\alpha} \right)^{\frac{\alpha}{\alpha+\beta}}$, $\gamma = B^{-(\alpha+\beta)}$, and $A = BD$ from the specifications and substitutions in the model.

Once the regression results have been determined the coefficients will be derived and the resulting Total Cost function will be differentiated to determine Marginal Cost. The time parameter, t, combined with the future input price data will be used to project Marginal Costs into the future.

APPENDIX A2

To begin use the general form of the Constant Elasticity of Substitution (CES) production function:

$$q = f(k, l) = (k^\rho + l^\rho)^{\frac{\gamma}{\rho}}$$

Where k and l are the levels of fixed and variable inputs, γ is a returns to scale factor, and σ is a factor reflecting the elasticity of substitution.

$$\text{Where } \sigma = \frac{1}{1 - \rho}$$

The production function with Ricardian Scarcity becomes

$$q = f(k, l) = \delta e^{\alpha} (k^\rho + l^\rho)^{\frac{\gamma}{\rho}}$$

In this model, let $\delta e^{\alpha} = \psi$ where ψ represents Ricardian Scarcity, a parameter to be estimated that shifts the production function over time. This reflects the fact that the best sources of water are tapped first and, as demand continues to grow, it becomes increasingly costly to obtain an additional unit of water over time.

Costs are defined as:

$$C = f(v, k, w, l) = vk + wl$$

Where v and w are the prices of fixed and variable inputs, respectively.

To derive long run total cost function:

Minimize C subject to q:

$$L = wl + vk + \lambda (q - \psi (k^\rho + l^\rho))^{\frac{\gamma}{\rho}}$$

First Order Conditions:

$$(1) L_k = v - \frac{\psi \gamma}{\rho} (k^\rho + l^\rho)^{\frac{\gamma - \rho}{\rho}} (\rho k^{\rho - 1}) = 0$$

$$(2) L_l = w - \frac{\psi \gamma}{\rho} (k^\rho + l^\rho)^{\frac{\gamma - \rho}{\rho}} (\rho l^{\rho - 1}) = 0$$

$$(3) L_\lambda = q - \psi (k^\rho + l^\rho)^{\frac{\gamma}{\rho}} = 0$$

Dividing (1) by (2) yields:

$$\frac{w}{v} = \frac{\frac{\psi\gamma}{\rho}(k^\rho + l^\rho)^{\frac{\gamma-\rho}{\rho}}(\rho l^{\rho-1})}{\frac{\psi\gamma}{\rho}(k^\rho + l^\rho)^{\frac{\gamma-\rho}{\rho}}(\rho k^{\rho-1})} = \left(\frac{l}{k}\right)^{\rho-1}$$

$$\frac{w}{v} = \left(\frac{l}{k}\right)^{\rho-1}$$

Which yields the cost minimizing input mix, let these be k^* and l^* .

Solving this equation for l^* and k^* :

$$l^* = k \left(\frac{w}{v}\right)^{\frac{1}{\rho-1}}$$

$$k^* = l \left(\frac{v}{w}\right)^{\frac{1}{\rho-1}}$$

Substituting k^* into the production function with Ricardian Scarcity and solving for l :

$$q = \psi \left(l^\rho \left(\frac{v}{w}\right)^{\frac{\rho}{\rho-1}} + l^\rho \right)^{\frac{\gamma}{\rho}}$$

$$q = \psi l^\gamma \left(\left(\frac{v}{w}\right)^{\frac{\rho}{\rho-1}} + 1 \right)^{\frac{\gamma}{\rho}}$$

$$l^\gamma = q \psi^{-1} \left(\left(\frac{v}{w}\right)^{\frac{\rho}{\rho-1}} + 1 \right)^{\frac{-\gamma}{\rho}}$$

$$l = q^{\frac{1}{\gamma}} \psi^{\frac{-1}{\gamma}} \left(\left(\frac{v}{w}\right)^{\frac{\rho}{\rho-1}} + 1 \right)^{\frac{-1}{\rho}}$$

Simplifying exponents to eliminate ρ by replacing it with σ , the elasticity of substitution factor.

Previously defined, we have:

$$\sigma = \left(\frac{1}{1-\rho} \right)$$

Consequently,

$$1-\sigma = \frac{\rho}{1-\rho} \quad \text{and} \quad \frac{-1}{\rho} = \frac{\sigma}{1-\sigma}$$

Making these substitutions, eliminating ρ , and continuing with the derivation:

$$l = q^{\frac{1}{\gamma}} \psi^{\frac{-1}{\gamma}} \left(\left(\frac{v}{w} \right)^{1-\sigma} + 1 \right)^{\frac{\sigma}{1-\sigma}}$$

$$l = q^{\frac{1}{\gamma}} \psi^{\frac{-1}{\gamma}} \left(\left(\frac{v}{w} \right)^{1-\sigma} + \left(\frac{w}{w} \right)^{1-\sigma} \right)^{\frac{\sigma}{1-\sigma}}$$

$$l = q^{\frac{1}{\gamma}} \psi^{\frac{-1}{\gamma}} \left(\frac{v^{1-\sigma} + w^{1-\sigma}}{w^{1-\sigma}} \right)^{\frac{\sigma}{1-\sigma}}$$

$$l = q^{\frac{1}{\gamma}} \psi^{\frac{-1}{\gamma}} \left(v^{1-\sigma} + w^{1-\sigma} \right)^{\frac{\sigma}{1-\sigma}} \left(\frac{1}{w^{1-\sigma}} \right)^{\frac{\sigma}{1-\sigma}}$$

$$(4) \quad l = q^{\frac{1}{\gamma}} \psi^{\frac{-1}{\gamma}} \left(v^{1-\sigma} + w^{1-\sigma} \right)^{\frac{\sigma}{1-\sigma}} w^{-\sigma}$$

Substituting l^* into the production function with Ricardian Scarcity and solving for k :

$$q = \psi \left(k^{\rho} \left(\frac{w}{v} \right)^{\frac{\rho}{\rho-1}} + k^{\rho} \right)^{\frac{\gamma}{\rho}}$$

$$q = \psi k^{\gamma} \left(\left(\frac{w}{v} \right)^{\frac{\rho}{\rho-1}} + 1 \right)^{\frac{\gamma}{\rho}}$$

$$k^\gamma = q \psi^{-1} \left(\left(\frac{w}{v} \right)^{\frac{\rho}{\rho-1}} + 1 \right)^{\frac{-\gamma}{\rho}}$$

$$k = q^{\frac{1}{\gamma}} \psi^{\frac{-1}{\gamma}} \left(\left(\frac{w}{v} \right)^{\frac{\rho}{\rho-1}} + 1 \right)^{\frac{-1}{\rho}}$$

Simplifying exponents to eliminate ρ by replacing it with σ , the elasticity of substitution factor.

Previously defined, we have:

$$\sigma = \left(\frac{1}{1-\rho} \right)$$

Consequently,

$$1-\sigma = \frac{\rho}{1-\rho} \quad \text{and} \quad \frac{-1}{\rho} = \frac{\sigma}{1-\sigma}$$

Making these substitutions, eliminating ρ , and continuing with the derivation:

$$k = q^{\frac{1}{\gamma}} \psi^{\frac{-1}{\gamma}} \left(\left(\frac{w}{v} \right)^{1-\sigma} + 1 \right)^{\frac{\sigma}{1-\sigma}}$$

$$k = q^{\frac{1}{\gamma}} \psi^{\frac{-1}{\gamma}} \left(\left(\frac{w}{v} \right)^{1-\sigma} + \left(\frac{v}{v} \right)^{1-\sigma} \right)^{\frac{\sigma}{1-\sigma}}$$

$$k = q^{\frac{1}{\gamma}} \psi^{\frac{-1}{\gamma}} \left(\frac{v^{1-\sigma} + w^{1-\sigma}}{v^{1-\sigma}} \right)^{\frac{\sigma}{1-\sigma}}$$

$$k = q^{\frac{1}{\gamma}} \psi^{\frac{-1}{\gamma}} \left(v^{1-\sigma} + w^{1-\sigma} \right)^{\frac{\sigma}{1-\sigma}} \left(\frac{1}{v^{1-\sigma}} \right)^{\frac{\sigma}{1-\sigma}}$$

$$(5) \quad k = q^{\frac{1}{\gamma}} \psi^{\frac{-1}{\gamma}} \left(v^{1-\sigma} + w^{1-\sigma} \right)^{\frac{\sigma}{1-\sigma}} v^{-\sigma}$$

Simultaneously substituting (4) and (5) into the cost accounting identity yields:

$$C = v \left[q^{\frac{1}{\gamma}} \psi^{\frac{-1}{\gamma}} \left(v^{1-\sigma} + w^{1-\sigma} \right)^{\frac{\sigma}{1-\sigma}} v^{-\sigma} \right] + w \left[q^{\frac{1}{\gamma}} \psi^{\frac{-1}{\gamma}} \left(v^{1-\sigma} + w^{1-\sigma} \right)^{\frac{\sigma}{1-\sigma}} w^{-\sigma} \right]$$

Simplifying,

$$LRTC = \psi^{\frac{-1}{\gamma}} q^{\frac{1}{\gamma}} \left(v^{1-\sigma} + w^{1-\sigma} \right)^{\frac{\sigma}{1-\sigma}} \left[v(v)^{-\sigma} + w(w)^{-\sigma} \right]$$

$$LRTC = \psi^{\frac{-1}{\gamma}} q^{\frac{1}{\gamma}} \left(v^{1-\sigma} + w^{1-\sigma} \right)^{\frac{\sigma}{1-\sigma}} \left[v^{1-\sigma} + w^{1-\sigma} \right]$$

Substituting back in for ψ :

$$LRTC = \left(\delta e^{\theta} \right)^{\frac{-1}{\gamma}} q^{\frac{1}{\gamma}} \left(v^{1-\sigma} + w^{1-\sigma} \right)^{\frac{\sigma}{1-\sigma}} \left[v^{1-\sigma} + w^{1-\sigma} \right]$$

Thus the form of LRTC to be estimated is defined as:

$$LRTC = \left(\delta e^{\theta} \right)^{\frac{-1}{\gamma}} q^{\frac{1}{\gamma}} \left(v^{1-\sigma} + w^{1-\sigma} \right)^{\frac{\sigma}{1-\sigma}} \left[v^{1-\sigma} + w^{1-\sigma} \right] + \varepsilon$$

Where ε is a normally distributed error term with mean zero and variance sigma squared.

This function is nonlinear in its parameters, thus nonlinear regression techniques must be employed to determine estimates of the coefficients

Simple differentiation yields the CES functional form of Long Run Marginal Cost:

$$LRMC = \frac{\partial LRTC}{\partial q} = \left(\frac{1}{\gamma} \right) \left(\delta e^{\theta} \right)^{\frac{-1}{\gamma}} q^{\left(\frac{1}{\gamma} \right) - 1} \left(v^{1-\sigma} + w^{1-\sigma} \right)^{\frac{\sigma}{1-\sigma}} \left[v^{1-\sigma} + w^{1-\sigma} \right]$$

Simplifying,

$$LRMC = \left(\frac{1}{\gamma} \right) \left(\delta e^{\theta} \right)^{\frac{-1}{\gamma}} q^{\frac{1-\gamma}{\gamma}} \left(v^{1-\sigma} + w^{1-\sigma} \right)^{\frac{\sigma}{1-\sigma}} \left[v^{1-\sigma} + w^{1-\sigma} \right]$$

APPENDIX A3

Fiscal Year (Ending In)	TC \$2004	Yearly Wage \$2004	Yearly Capital \$2004	Acre Feet	IPD GDP
2004	981900000	36160.00	46300	1900000	1.08237
2003	1001840153	35861.84	47300	2340000	1.05998
2002	1019544043	35749.03	50500	2418000	1.04092
2001	844658509.4	35938.42	51900	2272000	1.02399
2000	710359431	35826.45	57700	2327000	1
1999	971023071.9	36120.29	54300	2165000	0.97868
1998	1055757287	36351.26	51200	2076000	0.96472
1997	731683662.8	35325.01	55500	1594000	0.95414
1996	599702084.1	34828.85	57500	1562330	0.93852
1995	639273532.7	34737.00	59500	1786224	0.92106
1994	589997717.7	34560.44	61900	1647331	0.90259
1993	787458741.1	34584.50	56300	1592779	0.88381
1992	731728980.7	35308.43	64100	1929320	0.86385
1991	890823682	35427.87	68900	1912816	0.84444
1990	720341843.4	35552.78	72500	1887841	0.8159
1989	614513239	35575.63	72400	2264530	0.78556
1988	621644211	35605.22	77600	2501262	0.75694
1987	672132309.9	35992.25	77300	2108889	0.73196
1986	480952058.9	36884.13	73800	1926703	0.7125
1985	410820222.9	36858.93	91800	1827430	0.69713
1984	356718947.1	36924.25	101500	1647197	0.67655
1983	403765324.9	36982.54	94700	1575741	0.65207
1982	366479721.5	36719.76	115700	1427941	0.62726
1981	323790091.1	36213.87	112300	1226567	0.59119
1980	346451329.6	35930.13	85100	1504299	0.54043
1979	222479156.9	35825.60	63900	1463012	0.49548
1978	216395939.4	35198.26	59000	856217	0.45757
1977	223773009.9	33925.33	55600	1235884	0.42752
1976	221383618	33336.01	64900	1198325	0.40196
1975	192573813.8	32355.46	68900	1390466	0.38002
1974	157032268.8	31730.82	60900	1389248	0.34725
1973	140946721.7	31197.70	51800	1329636	0.31849
1972	202548111.2	30713.67	52700	1139175	0.30166
1971	178516166.5	29875.52	57000	1177860	0.28911
1970	158346803.9	29639.97	65100	1248710	0.27534
1969	156915300.3	29305.82	58100	1133968	0.26149
1968	132676278.6	28674.35	45100	1165866	0.24913
1967	122131309.4	28448.85	39800	1057335	0.23893
1966	120353631.5	28021.32	38200	1077178	0.23176
1965	128593951.8	27569.58	32700	1059354	0.22535
1964	121193620.8	26996.89	32200	1059631	0.22131
1963	117996339.7	26813.46	32300	1148847	0.21798
1962	114447005.7	26596.32	31800	1064381	0.21569
1961	104256754.5	26349.64	34600	1020822	0.21278
1960	85109930.61	26234.91	37300	931795	0.21041
1959	77827765.04	26079.95	35900	935228	0.20751

1958	73875860.63	25556.99	35600	734919	0.20498
1957	72964734.22	25819.59	36000	601099	0.20038
1956	68739698.47	25338.83	29300	539734	0.19393
1955	62781213.62	24831.62	25300	543706	0.18743
1954	60374295.35	24565.93	23700	405962	0.18417
1953	59678160.58	24681.57	27200	385946	0.18243
1952	62934290.14	23422.72	21900	245875	0.18022
1951	62796745.71	22969.36	20000	219397	0.17718
1950	64258763.65	22523.46	19800	197210	0.16531
1949	64840052.66	22372.86	22100	165473	0.16352

APPENDIX A4

The NLIN Procedure
 Dependent Variable TC
 Method: Marquardt

Iterative Phase					
Iter	gamma	alpha	beta	theta	Sum of Squares
0	20.0000	0.3000	3.0000	-0.2000	1.364E19
1	31.6908	0.1443	3.4216	-0.1768	7.136E17
2	38.8718	0.3569	3.4238	-0.1641	4.016E17
3	31.6479	0.4075	3.1900	-0.1538	3.974E17
4	30.1496	0.3940	3.1454	-0.1512	3.959E17
5	29.9959	0.3949	3.1404	-0.1510	3.959E17
6	29.9502	0.3947	3.1392	-0.1509	3.959E17
7	29.9425	0.3947	3.1390	-0.1509	3.959E17

NOTE: Convergence criterion met.

Estimation Summary	
Method	Marquardt
Iterations	7
R	3.46E-6
PPC(gamma)	0.000053
RPC(gamma)	0.000256
Object	3.94E-10
Objective	3.959E17
Observations Read	56
Observations Used	56

Estimation Summary

Observations Missing 0

Note: An intercept was not specified for this model.

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	4	1.284E19	3.211E18	421.80	<.0001
Error	52	3.959E17	7.613E15		
Uncorrected Total	56	1.324E19			

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
gamma	29.9425	64.7947	-100.1	160.0
alpha	0.3947	0.6646	-0.9388	1.7282
beta	3.1390	1.7777	-0.4283	6.7062
theta	-0.1509	0.1028	-0.3572	0.0554

Approximate Correlation Matrix				
	gamma	alpha	beta	theta
gamma	1.0000000	0.3295825	0.9957398	-0.9298642
alpha	0.3295825	1.0000000	0.2647998	-0.6249497
beta	0.9957398	0.2647998	1.0000000	-0.9124731
theta	-0.9298642	-0.6249497	-0.9124731	1.0000000

The CAPABILITY Procedure
Variable: resid

Moments			
N	56	Sum Weights	56
Mean	-1125290	Sum Observations	-63016240
Std Deviation	84829628.8	Variance	7.19607E15
Skewness	1.15189553	Kurtosis	2.82289215
Uncorrected SS	3.95855E17	Corrected SS	3.95784E17
Coeff Variation	-7538.4682	Std Error Mean	11335836

Basic Statistical Measures			
Location		Variability	
Mean	-1125290	Std Deviation	84829629
Median	-3054726	Variance	7.19607E15
Mode	.	Range	484486145
		Interquartile Range	82346500

Tests for Location: Mu0=0			
Test	Statistic	p Value	
Student's t	t -0.09927	Pr > t 	0.9213
Sign	M -2	Pr >= M 	0.6889
Signed Rank	S -99	Pr >= S 	0.4243

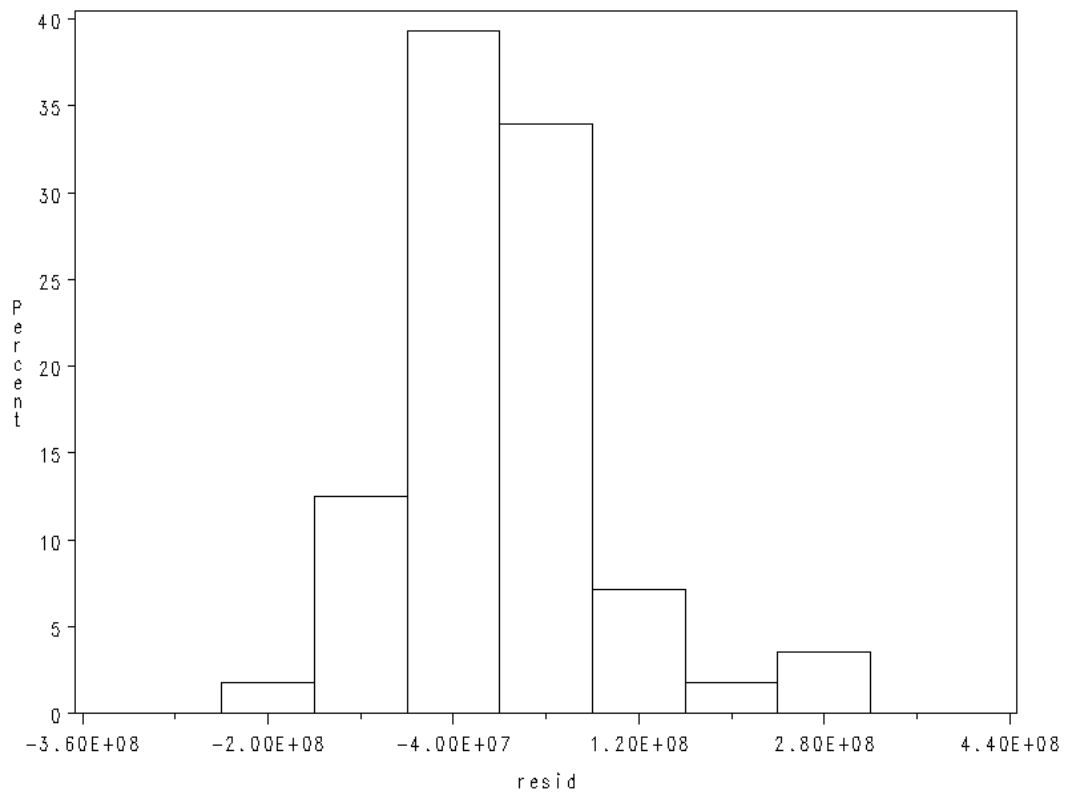
Tests for Normality			
Test	Statistic	p Value	
Shapiro-Wilk	W 0.903174	Pr < W	0.000
Kolmogorov-Smirnov	D 0.187013	Pr > D	<0.010

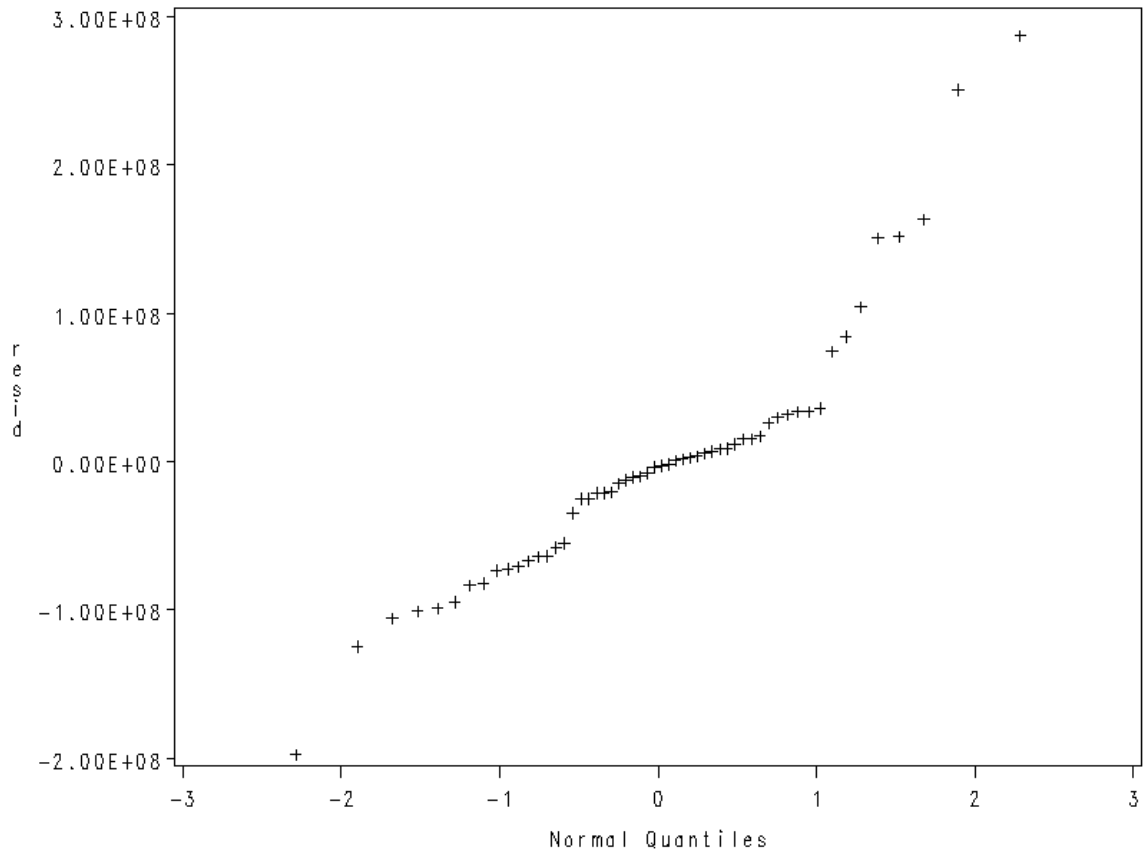
Tests for Normality			
Test	Statistic	p Value	
Cramer-von Mises	W-Sq	0.327489	Pr > W-Sq < 0.005
Anderson-Darling	A-Sq	1.839124	Pr > A-Sq < 0.005

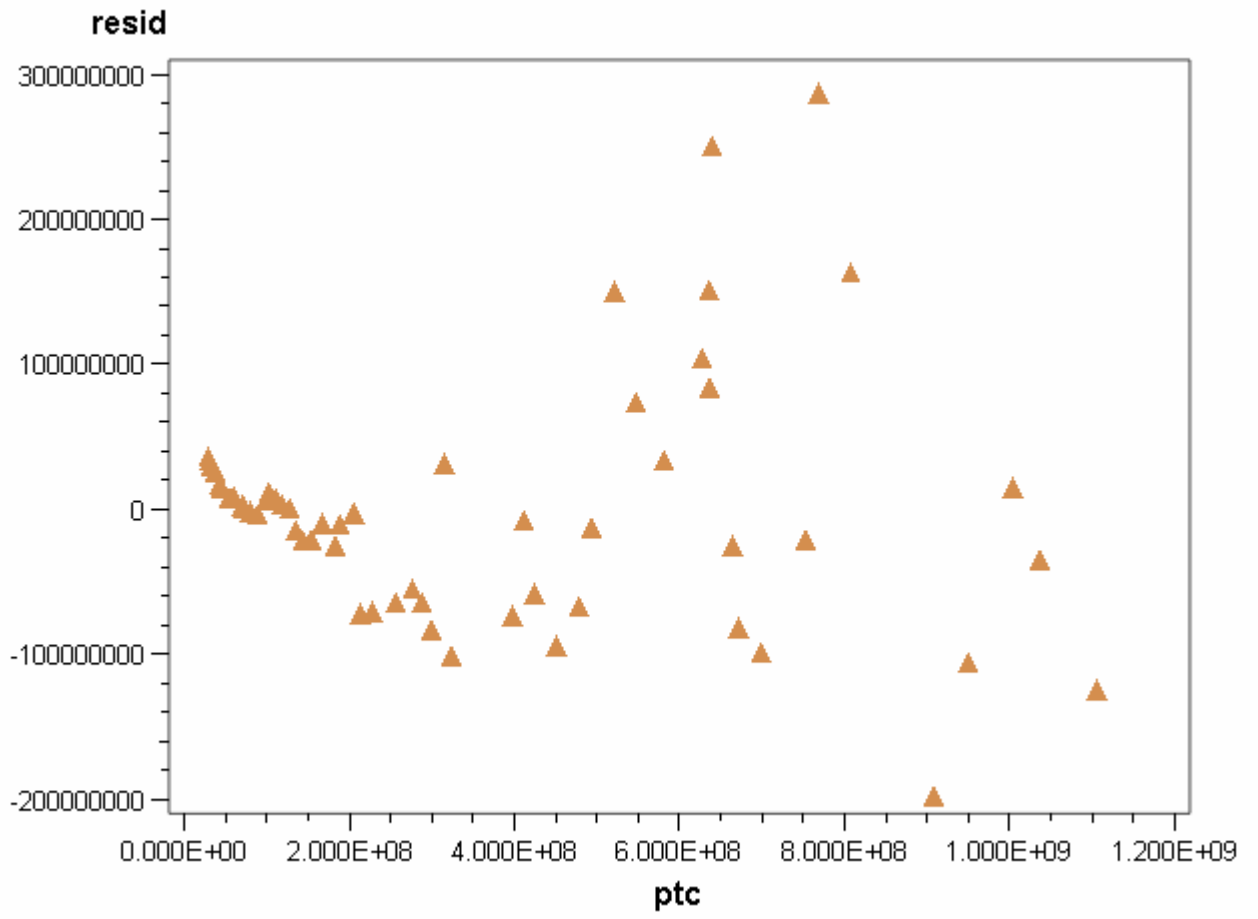
Quantiles (Definition 5)	
Quantile	Estimate
100% Max	287031410.15
99%	287031410.15
95%	163451348.21
90%	104538734.85
75% Q3	21530276.09
50% Median	-3054726.04
25% Q1	-60816223.55
10%	-94345635.26
5%	-105446132.45
1%	-197454735.31
0% Min	-197454735.31

Extreme Observations			
Lowest		Highest	
Value	Obs	Value	Obs
-197454735.3	5	150778255	18
-124313512.1	1	151719478	12
-105446132.4	4	163451348	6
-100840945.5	26	251067413	14

Extreme Observations			
Lowest		Highest	
Value	Obs	Value	Obs
-99022241.1	9	287031410	7







APPENDIX A5

The NLIN Procedure
 Dependent Variable TC
 Method: Newton

Iterative Phase					
Iter	gamma	delta	sigma	theta	Sum of Squares
0	4.5000	0.1000	1.1000	-0.2300	1.324E19
1	4.5000	58106.1	1.1000	-0.2300	4.35E17
2	4.5000	55866.6	1.1006	-0.2300	4.35E17
3	4.5000	55865.6	1.1006	-0.2300	4.35E17
4	4.5000	55860.9	1.1006	-0.2300	4.35E17
5	4.5001	55837.9	1.1006	-0.2301	4.35E17
6	4.5002	55731.3	1.1006	-0.2303	4.35E17
7	4.4978	55328.8	1.1006	-0.2307	4.349E17
8	4.4776	54252.5	1.1006	-0.2302	4.349E17
9	4.5516	54561.9	1.1012	-0.2343	4.349E17
10	4.5744	54561.9	1.1014	-0.2356	4.348E17
11	4.6303	54561.9	1.1019	-0.2388	4.348E17
12	4.6830	54561.9	1.1024	-0.2417	4.348E17
13	4.7294	54561.9	1.1029	-0.2443	4.348E17
14	4.7615	54561.9	1.1032	-0.2461	4.348E17
15	4.7800	54561.9	1.1033	-0.2471	4.348E17
16	4.7859	54561.9	1.1034	-0.2475	4.348E17
17	4.7866	54561.9	1.1034	-0.2475	4.348E17

Convergence met

Estimation Summary	
Method	Newton
Iterations	17
Subiterations	16
Average Subiterations	0.941176
R	2.96E-7
PPC(theta)	1.715E-6
RPC(theta)	0.00015
Object	6.33E-10
Objective	4.348E17
Observations Read	56
Observations Used	56
Observations Missing	0

Note: An intercept was not specified for this model.

Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	3	1.281E19	4.268E18	520.26	<.0001
Error	53	4.348E17	8.204E15		
Uncorrected Total	56	1.324E19			

Note: The (approximate) Hessian is singular.

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
gamma	4.7866	4.3949	-4.0285	13.6016
delta	54561.9	.	.	.

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
sigma	1.1034	0.0402	1.0227	1.1841
theta	-0.2475	0.2451	-0.7391	0.2441

Approximate Correlation Matrix				
	gamma	delta	sigma	theta
gamma	1.0000000	.	0.9984269	-0.9981959
delta
sigma	0.9984269	.	1.0000000	-0.9933102
theta	-0.9981959	.	-0.9933102	1.0000000

The CAPABILITY Procedure
Variable: resid

Moments			
N	56	Sum Weights	56
Mean	7526587.28	Sum Observations	421488887
Std Deviation	88590227.3	Variance	7.84823E15
Skewness	0.62642359	Kurtosis	2.42453864
Uncorrected SS	4.34825E17	Corrected SS	4.31653E17
Coeff Variation	1177.03049	Std Error Mean	11838367.1

Basic Statistical Measures			
Location		Variability	
Mean	7526587	Std Deviation	88590227
Median	19695481	Variance	7.84823E15
Mode	.	Range	524804793
		Interquartile Range	81523301

Tests for Location: Mu0=0			
Test	Statistic	p Value	
Student's t	t 0.635779	Pr > t 	0.5276
Sign	M 6	Pr >= M 	0.1409
Signed Rank	S 73	Pr >= S 	0.5563

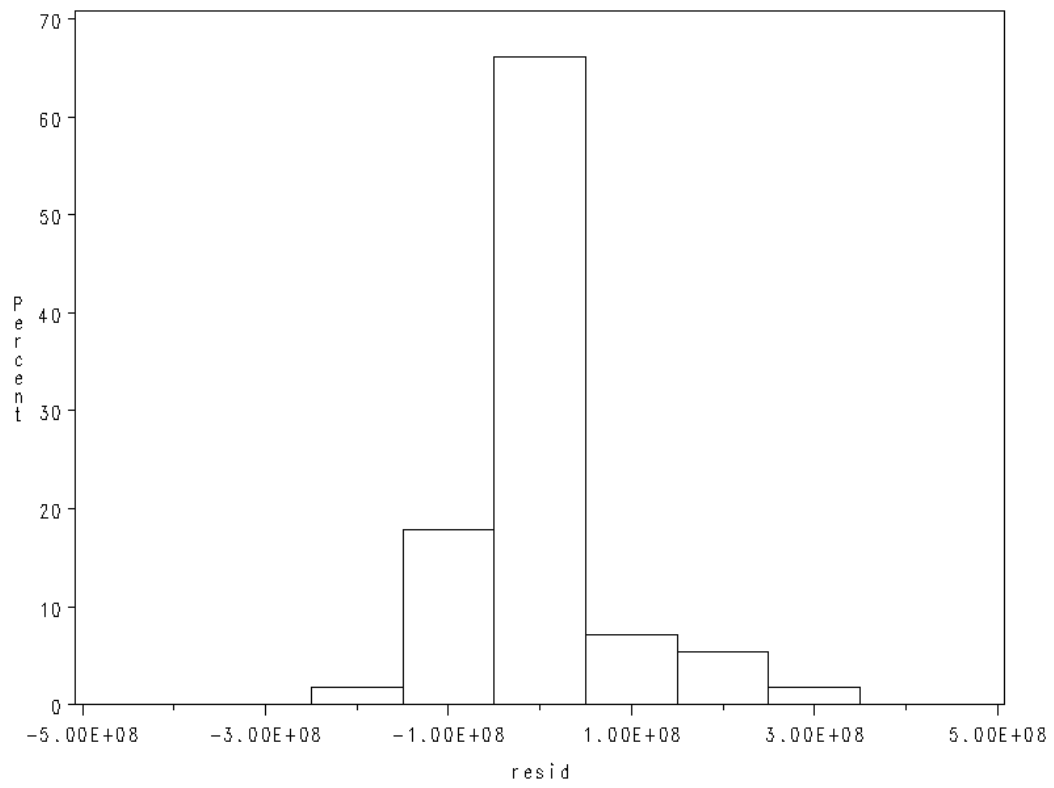
Tests for Normality			
Test	Statistic	p Value	
Shapiro-Wilk	W 0.928227	Pr < W	0.003
Kolmogorov-Smirnov	D 0.188851	Pr > D	<0.010

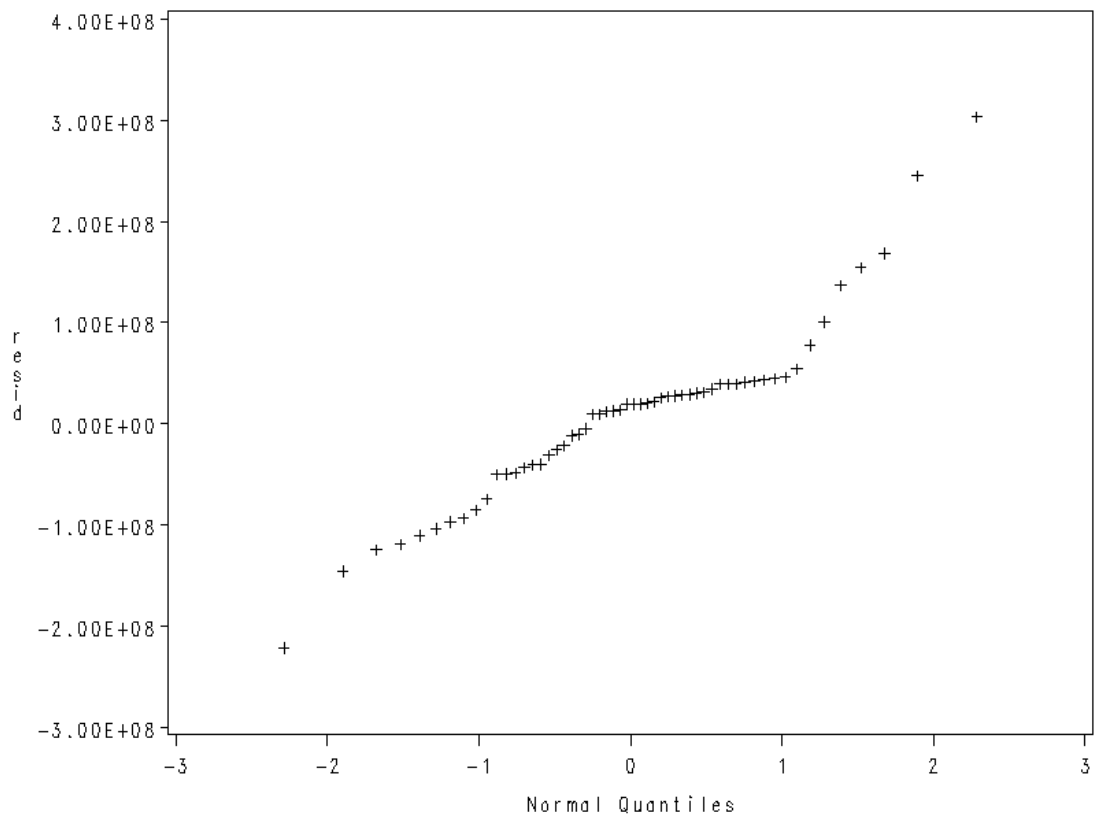
Tests for Normality			
Test	Statistic	p Value	
Cramer-von Mises	W-Sq	0.290536	Pr > W-Sq < 0.005
Anderson-Darling	A-Sq	1.542612	Pr > A-Sq < 0.005

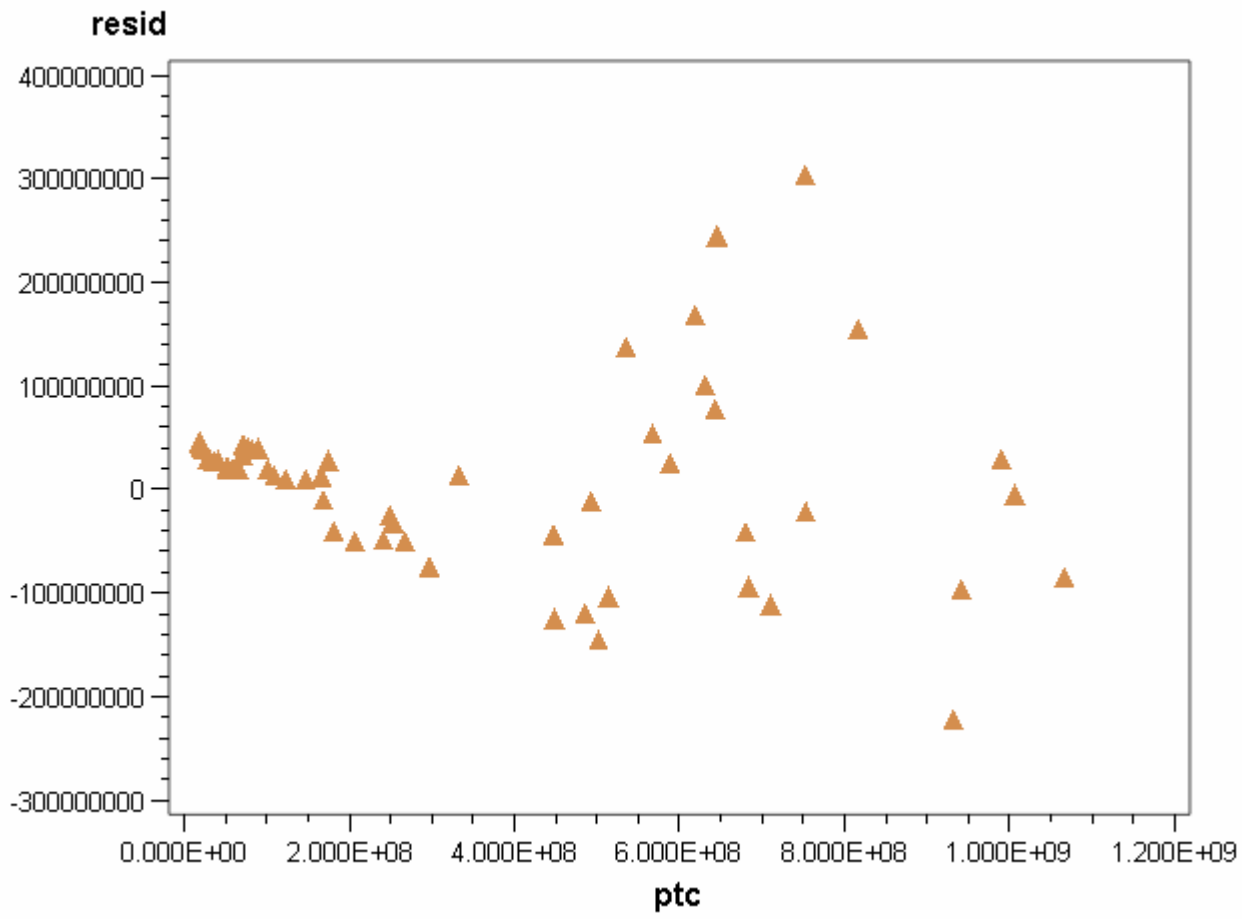
Quantiles (Definition 5)	
Quantile	Estimate
100% Max	303409864.7
99%	303409864.7
95%	168548329.2
90%	100786919.6
75% Q3	39325490.6
50% Median	19695481.2
25% Q1	-42197810.4
10%	-103281008.9
5%	-124863265.9
1%	-221394928.2
0% Min	-221394928.2

Extreme Observations			
Lowest		Highest	
Value	Obs	Value	Obs
-221394928	5	137197490	18
-145378156	21	154813113	6
-124863266	24	168548329	12
-119007120	23	245218186	14

Extreme Observations			
Lowest		Highest	
Value	Obs	Value	Obs
-110643362	9	303409865	7







APPENDIX A6

Parameter (CES)			
		Projected Total Cost	Incremental Marginal Cost
gamma	4.7866	442720352.8	-8.274622324
delta	54561.9	446361186.6	287.5117488
sigma	1.1034	475112361.5	303.3871332
theta	-0.2475	505451074.8	320.2105003
		537472124.8	165.5721591
sigma/(1-sigma)	-10.67117988	578865164.6	665.9385338
1-sigma	-0.1034	612162091.3	703.1618623
1/gamma	0.208916559	647320184.4	1773.242228
(1-gamma)/gamma	-0.791083441	682785029	3681.694159
		719601970.6	1970.530486
		759012580.3	869.3123008
		802478195.3	302.8219605

Parameter (Cobb-Douglas)			
		Projected Marginal Cost	Incremental Marginal Cost
Gamma	29.94	106.8990319	32.36712143
Alpha	0.3947	129.5333769	512.1373987
Beta	3.1389	130.3033884	535.3915999
Theta	-0.1509	131.3134409	559.896845
		132.5468941	312.8588244
Alpha+Beta	3.5336	128.056218	1100.045593
Beta/(Alpha+Beta)	0.888300883	131.7212969	1151.856763
Alpha/(Alpha+Beta)	0.111699117	135.5301459	2805.091683
D	1.419142864	140.6531328	5719.442413
(1-alpha-beta)/(alpha+beta)	-0.71700249	146.3815624	3063.541458
		151.9245858	1375.414174
		156.4022122	552.6628569

APPENDIX B1

Intercept Water Conservation Survey

Interviewer: **CN MG** Date: _____ Time: _____ **AM PM** Location: _____

Zip Code of Participant: _____

SECTION I: Customer Home Inventory

Interviewer: I will now begin the survey that will consist of four sections of questions. In two of the sections you will be handed cards to refer to. Please answer the following questions honestly and to the best of your ability.

Indoor

Number of Toilets: _____

Type: Low Flush Traditional Not Sure
Age of Toilet _____ Not Sure

Number of Showerheads: _____

Type: Low Flow Traditional Not Sure
Age of Showerheads _____ Not Sure
Bathtub Only

Number of Faucets: _____

Dishwasher Type: Water-Efficient Traditional Not Sure None

Clothes Washer Type: Water-Efficient Top Loading Side Loading
Age _____ Not Sure

Customer Perceptions

1) Do you plan on replacing your toilets, showerheads, faucets, dishwasher, or clothes washer in the near future? Yes No

If so, what item(s)? _____

2) Are you likely to purchase water-efficient fixtures and appliances? Yes No
Please explain why or why not:

3) Would rebates be an incentive for you to purchase water-efficient fixtures and appliances? Yes No

Please explain why or why not:

4) Do you believe that replacing a traditional toilet and clothes washer with a water-efficient model would save you money in the long-run? Yes No

Please explain why or why not:

5) Would viewing a comparison of how much you would save if you replaced your toilet and clothes washer with water efficient models persuade you to replace them?

Yes No

Comments:

6) What do you look for when reading over your bill?

Please explain:

Current Customer Conservation Measures

1) Have you taken any steps to reduce your water use inside and outside your home?

Yes No Not Sure

If so, what steps?

2) If you have implemented conservation measures, what type of reduction in water usage, if any, have you noticed in your water bill?

SECTION II: Customer Resource Knowledge

1) Are you aware of the rebates available for water efficient toilets and clothes washers?

Yes No

If so, have you received any?

Yes No

Which rebate? Toilet Washer

- 2) Are you aware that some local water agencies give free water efficient devices such as showerheads and garden hose nozzles to residents? Yes No
 If so, have you received any? Yes No

What device(s): _____

- 3) Are you aware of the free resident water-use surveys available from local water agencies? Yes No
 If so, have you participated? Yes No

- 4) Are you aware of the free water-conserving landscape classes given by local water agencies? Yes No
 If so, have you attended? Yes No

- 5) Have you visited the website of your local water agency? Yes No
 If so, did you find it useful? Yes No

Please explain why or why not:

- 6) Do you receive any water conservation information with your utility bill? Yes No
 If so, do you find it useful? Yes No

Please explain why or why not:

- 7) For you, what is the most effective mode to obtain information about water conservation?

SECTION III: Bill Formats (Cards A1-A3 and B1-B3 or C1X-C3X or C1Y-C3Y with either Bill Insert X or Y)

Current Bill Design – Cards A1-A3

Interviewer: What is your lot size? Small Medium Large

Please refer to the sample bill on this card and answer the following questions as if you were reading your own bill. (Interviewer hands corresponding card to participant based on lot size indicated.)

Card used: A1 A2 A3

1) How much is the total charge for water on this bill? \$ _____

2) What is the price of additional water? \$ _____

3) How much water did you use? _____

4) Could you tell, based on this design, how much money you would save if you conserved 2 billing units of water per month? Yes No

Please explain why or why not:

5) How likely are you to use less water with this bill design? Not likely Likely Very likely

Please explain why or why not:

Bill Design Alternative B or C – Cards B1-B3 or C1X-C3X or C1Y-C3Y

Interviewer: Please refer to this card and answer the following questions. (Interviewer hands corresponding card to participant based on lot size indicated and bill alternative used.)

Card used for this survey: **B1 B2 B3 C1X C2X C3X C1Y C2Y C3Y**

1) How much is the total charge for water on this bill? \$ _____

2) What is the price of additional water? \$ _____

3) How much water did you use? _____

4) Could you tell, based on this design, how much money you would save if you conserved 2 billing units of water per month? Yes No

Please explain why or why not:

5) How likely are you to use less water with this bill design?
Not likely Likely Very likely

Please explain why or why not:

Bill Insert X or Y

Interviewer: Please take a moment to look over this card and answer the following questions.

Note: Interviewer will alternate between Bill Insert X and Y for each person.

1) Is this insert useful to you? Yes No

Comments:

2) After reading this insert, would you invest in a high-efficiency clothes washer?
Yes No

Please explain why or why not:

All Bill Designs – Current Water Bill Design and Bill Design Alternative B or C

1) Which bill design out of these bills encourages you to conserve water and why?

2) What do you like and/or dislike from the Current Bill Design?

3) What do you like and/or dislike from Bill Design **B** or **C**?

4) Which bill would you prefer to receive?
Please explain:

SECTION IV: Demographics (Cards D & E)

Interviewer: Please refer to the cards handed to you and answer the following questions to the best of your ability. The lack of identifying information on this survey ensures that your answers will not be linked to you.

Education

Which letter describes your highest level of education? _____

Income – Card E

Which letter best describes income of all adults residing in the household? _____

How many people reside in your household? _____

Gender: **Female** **Male**

**Interviewer: This is the end of the survey. Thank you for taking time out of your day to help us with our research!
(Participant is handed gift card.)**

CARD A1

Example of Current Bill

Your Local Water Agency
 12300 Water Avenue, Your City, 90000
 (800) 123-0000

Previous Balance	Payment Received	Statement Date
\$25.78	\$25.78 on 10/26/05	11/5/2005

Account Number	Name on Account	Account Address
1234567	Your Name	1234 Your Street

Statement Period	Days in Period
10/05/05 to 11/04/05	31

Charges	1 Billing Unit (BU) = 748 Gallons
Monthly Customer Charge	31 days x \$ 0.30 = \$ 9.30
Block I	5 BU x \$ 1.45 = \$ 7.25
Block II	5 BU x \$ 1.60 = \$ 8.00
Taxes	\$24.55 x \$ 0.05 = \$ 1.23
Total Due on 11/26/05: \$25.78	

Usage History	Daily Usage
Previous Year: 10 BU used in 31 days	241 gallons
Current Year: 10 BU used in 31 days	241 gallons

CARD A2

Example of Current Bill

Your Local Water Agency
 12300 Water Avenue, Your City, 90000
 (800) 123-0000

Previous Balance	Payment Received	Statement Date
\$47.30	\$47.30 on 10/26/05	11/5/2005

Account Number	Name on Account	Account Address
1234567	Your Name	1234 Your Street

Statement Period	Days in Period
10/05/05 to 11/04/05	31

Charges	1 Billing Unit (BU) = 748 Gallons
Monthly Customer Charge	31 days x \$ 0.30 = \$ 9.30
Block I	5 BU x \$ 1.45 = \$ 7.25
Block II	10 BU x \$ 1.60 = \$16.00
Block III	5 BU x \$ 2.50 = \$12.50
Taxes	\$45.05 x \$ 0.05 = \$ 2.25
Total Due on 11/26/05: \$47.30	

Usage History	Daily Usage
Previous Year: 20 BU used in 31 days	483 gallons
Current Year: 20 BU used in 31 days	483 gallons

CARD A3

Example of Current Bill

Your Local Water Agency

12300 Water Avenue, Your City, 90000
(800) 123-0000

Previous Balance	Payment Received	Statement Date
\$73.55	\$73.55 on 10/26/05	11/5/2005

Account Number	Name on Account	Account Address
1234567	Your Name	1234 Your Street

Statement Period	Days in Period
10/05/05 to 11/04/05	31

Charges	1 Billing Unit (BU) = 748 Gallons
Monthly Customer Charge	31 days x \$ 0.30 = \$ 9.30
Block I	5 BU x \$ 1.45 = \$ 7.25
Block II	10 BU x \$ 1.60 = \$16.00
Block III	15 BU x \$ 2.50 = \$37.50
Taxes	\$70.05 x \$ 0.05 = \$ 3.50
Total Due on 11/26/05: \$73.55	

Usage History	Daily Usage
Previous Year: 30 BU used in 31 days	724 gallons
Current Year: 30 BU used in 31 days	724 gallons

CARD B1 Bill Design B

Your Local Water Agency

12300 Water Avenue, Your City, 90000

(800) 123-0000

Previous Balance	Payment Received	Statement Date
\$25.78	\$25.78 on 10/26/05	11/5/2005

Account Number	Name on Account	Account Address
1234567	Your Name	1234 Your Street

Statement Period	Days in Period
10/05/05 to 11/04/05	31

Charges	1 Billing Unit (BU) = 748 Gallons
Initial Block	5 BU x \$ 2.41 = \$12.05
Marginal Cost	5 BU x \$ 2.50 = \$12.50
Taxes	\$24.55 x \$ 0.05 = \$ 1.23
Total Due on 11/26/05: \$25.78	

Usage History	Daily Usage
Previous Year: 10 BU used in 31 days	241 gallons
Current Year: 10 BU used in 31 days	241 gallons

CARD B2 Bill Design B

Your Local Water Agency

12300 Water Avenue, Your City, 90000

(800) 123-0000

Previous Balance	Payment Received	Statement Date
\$47.30	\$47.30 on 10/26/05	11/5/2005

Account Number	Name on Account	Account Address
1234567	Your Name	1234 Your Street

Statement Period	Days in Period
10/05/05 to 11/04/05	31

Charges	1 Billing Unit (BU) = 748 Gallons
Initial Block	10 BU x \$ 2.005 = \$20.05
Marginal Cost	10 BU x \$ 2.50 = \$25.00
Taxes	\$45.05 x \$ 0.05 = \$ 2.25
Total Due on 11/26/05: \$47.30	

Usage History	Daily Usage
Previous Year: 20 BU used in 31 days	483 gallons
Current Year: 20 BU used in 31 days	483 gallons

CARD B3 Bill Design B

Your Local Water Agency

12300 Water Avenue, Your City, 90000

(800) 123-0000

Previous Balance	Payment Received	Statement Date
\$73.55	\$73.55 on 10/26/05	11/5/2005

Account Number	Name on Account	Account Address
1234567	Your Name	1234 Your Street

Statement Period	Days in Period
10/05/05 to 11/04/05	31

Charges	1 Billing Unit (BU) = 748 Gallons
Initial Block	15 BU x \$ 2.17 = \$32.55
Marginal Cost	15 BU x \$ 2.50 = \$37.50
Taxes	\$70.05 x \$ 0.05 = \$ 3.50
Total Due on 11/26/05: \$73.55	

Usage History	Daily Usage
Previous Year: 30 BU used in 31 days	724 gallons
Current Year: 30 BU used in 31 days	724 gallons

CARD C1X Bill Design C

Your Local Water Agency

12300 Water Avenue, Your City, 90000

(800) 123-0000

Previous Balance	Payment Received	Statement Date
\$25.78	\$25.78 on 10/26/05	11/5/2005

Account Number	Name on Account	Account Address
1234567	Your Name	1234 Your Street

Statement Period	Days in Period
10/05/05 to 11/04/05	31

Charges	1 Billing Unit (BU) = 748 Gallons
Initial Block	5 BU x \$ 2.41 = \$12.05
Marginal Cost	5 BU x \$ 2.50 = \$12.50
Taxes	\$24.55 x \$ 0.05 = \$ 1.23
Total Due on 11/26/05: \$25.78	

Usage History	Daily Usage
Previous Year: 10 BU used in 31 days	241 gallons
Current Year: 10 BU used in 31 days	241 gallons

If you invest in a high efficiency clothes washer,

you could save \$191 in the first year!

Refer to bill insert for details.

CARD C2X Bill Design C

Your Local Water Agency

12300 Water Avenue, Your City, 90000

(800) 123-0000

Previous Balance	Payment Received	Statement Date
\$47.30	\$47.30 on 10/26/05	11/5/2005

Account Number	Name on Account	Account Address
1234567	Your Name	1234 Your Street

Statement Period	Days in Period
10/05/05 to 11/04/05	31

Charges	1 Billing Unit (BU) = 748 Gallons
Initial Block	10 BU x \$ 2.005 = \$20.05
Marginal Cost	10 BU x \$ 2.50 = \$25.00
Taxes	\$45.05 x \$ 0.05 = \$ 2.25
Total Due on 11/26/05: \$47.30	

Usage History	Daily Usage
Previous Year: 20 BU used in 31 days	483 gallons
Current Year: 20 BU used in 31 days	483 gallons

If you invest in a high efficiency clothes washer,

you could save \$191 in the first year!

Refer to bill insert for details.

CARD C3X Bill Design C

Your Local Water Agency

12300 Water Avenue, Your City, 90000

(800) 123-0000

Previous Balance	Payment Received	Statement Date
\$73.55	\$73.55 on 10/26/05	11/5/2005

Account Number	Name on Account	Account Address
1234567	Your Name	1234 Your Street

Statement Period	Days in Period
10/05/05 to 11/04/05	31

Charges	1 Billing Unit (BU) = 748 Gallons
Initial Block	15 BU x \$ 2.17 = \$32.55
Marginal Cost	15 BU x \$ 2.50 = \$37.50
Taxes	\$70.05 x \$ 0.05 = \$ 3.50
Total Due on 11/26/05: \$73.55	

Usage History	Daily Usage
Previous Year: 30 BU used in 31 days	724 gallons
Current Year: 30 BU used in 31 days	724 gallons

If you invest in a high efficiency clothes washer,

you could save \$191 in the first year!

Refer to bill insert for details.

Bill Insert X

High Efficiency Clothes Washer Savings

<u>Annual Water Cost</u>		
Standard Clothes Washer	High Efficiency Clothes Washer *	<u>Savings</u>
\$77.30	\$25.22	\$52.00
You save 20 BU's per year!		
	Gas	\$13.00
	Electric	\$26.00
High Efficiency Clothes Washer Rebate		\$100.00
Estimated Total Savings in the First Year		\$191.00

With these savings, you can pay off your HE Washer in just over 5 years!

Calculations based on an average of 392 loads per year from the CA Energy Commission.

The High Efficiency washer annual water cost was based on an average of the following models:

GE WPGT9350CWW, Kenmore 4598, LG WM1812CW, Maytag FAV6800, Maytag MAH8700AWW, Whirlpool GHW9400P

(Average cost of listed models is \$1077)

Gas & Electric Savings from Energy Star (Annual savings with HE Washer)

Rebates are a one-time savings offer. For more information and applications, contact your local water agency.

Savings each additional year is \$91.00

Typical washer life is 13 years

CARD C1Y Bill Design C

Your Local Water Agency

12300 Water Avenue, Your City, 90000

(800) 123-0000

Previous Balance	Payment Received	Statement Date
\$25.78	\$25.78 on 10/26/05	11/5/2005

Account Number	Name on Account	Account Address
1234567	Your Name	1234 Your Street

Statement Period	Days in Period
10/05/05 to 11/04/05	31

Charges	1 Billing Unit (BU) = 748 Gallons
Initial Block	5 BU x \$ 2.41 = \$12.05
Marginal Cost	5 BU x \$ 2.50 = \$12.50
Taxes	\$24.55 x \$ 0.05 = \$ 1.23
Total Due on 11/26/05: \$25.78	

Usage History	Daily Usage
Previous Year: 10 BU used in 31 days	241 gallons
Current Year: 10 BU used in 31 days	241 gallons

If you invest in a high efficiency clothes washer,

you could save \$291 in the first year!

Refer to bill insert for details.

CARD C2Y Bill Design C

Your Local Water Agency

12300 Water Avenue, Your City, 90000

(800) 123-0000

Previous Balance	Payment Received	Statement Date
\$47.30	\$47.30 on 10/26/05	11/5/2005

Account Number	Name on Account	Account Address
1234567	Your Name	1234 Your Street

Statement Period	Days in Period
10/05/05 to 11/04/05	31

Charges	1 Billing Unit (BU) = 748 Gallons
Initial Block	10 BU x \$ 2.005 = \$20.05
Marginal Cost	10 BU x \$ 2.50 = \$25.00
Taxes	\$45.05 x \$ 0.05 = \$ 2.25
Total Due on 11/26/05: \$47.30	

Usage History	Daily Usage
Previous Year: 20 BU used in 31 days	483 gallons
Current Year: 20 BU used in 31 days	483 gallons

If you invest in a high efficiency clothes washer,

you could save \$291 in the first year!

Refer to bill insert for details.

CARD C3Y Bill Design C

Your Local Water Agency

12300 Water Avenue, Your City, 90000

(800) 123-0000

Previous Balance	Payment Received	Statement Date
\$73.55	\$73.55 on 10/26/05	11/5/2005

Account Number	Name on Account	Account Address
1234567	Your Name	1234 Your Street

Statement Period	Days in Period
10/05/05 to 11/04/05	31

Charges	1 Billing Unit (BU) = 748 Gallons
Initial Block	15 BU x \$ 2.17 = \$32.55
Marginal Cost	15 BU x \$ 2.50 = \$37.50
Taxes	\$70.05 x \$ 0.05 = \$ 3.50
Total Due on 11/26/05: \$73.55	

Usage History	Daily Usage
Previous Year: 30 BU used in 31 days	724 gallons
Current Year: 30 BU used in 31 days	724 gallons

If you invest in a high efficiency clothes washer,

you could save \$291 in the first year!

Refer to bill insert for details.

Bill Insert Y

High Efficiency Clothes Washer Savings

Annual Water Cost		
Standard Clothes Washer	High Efficiency Clothes Washer *	<u>Savings</u>
\$77.30	\$25.22	\$52.00
You save 20 BU's per year!		
		Gas
		\$13.00
		Electric
		\$26.00
High Efficiency Clothes Washer Rebate		\$200.00
Estimated Total Savings in the First Year		\$291.00

With these savings, you can pay off your HE Washer in just over 4 years!

Calculations based on an average of 392 loads per year from the CA Energy Commission.

The High Efficiency washer annual water cost was based on an average of the following models:

GE WPGT9350CWW, Kenmore 4598, LG WM1812CW, Maytag FAV6800, Maytag MAH8700AWW, Whirlpool GHW9400P

(Average cost of listed models is \$1077)

Gas & Electric Savings from Energy Star (Annual savings with HE Washer)

Rebates are a one-time savings offer. For more information and applications, contact your local water agency.

Savings each additional year is \$91.00

Typical washer life is 13 years

CARD D
Education

- A No High School
- B Some High School
- C High School Graduate
- D Technical/Vocational School
- E Some College
- F Community College Graduate
(AA Degree, AS Degree, or Certificate)
- G Some University
- H University Graduate
(BA Degree or BS Degree)
- I Graduate Degree
(MA, MS, MPH, JD, EdD or PhD)

CARD E
Total Household Gross Income
(Total Annual Income Before Taxes)

Annual

- A. Under \$10,000
- B. \$10,000 to \$19,999
- C. \$20,000 to \$29,999
- D. \$30,000 to \$39,999
- E. \$40,000 to \$49,999
- F. \$50,000 to \$59,999
- G. \$60,000 to \$69,999
- H. \$70,000 to \$79,999
- I. \$80,000 to \$89,999
- J. \$90,000 to \$99,999
- K. \$100,000 to \$129,999
- L. \$130,000 to \$159,999
- M. \$160,000 to \$189,999
- N. \$190,000 to \$219,999
- O. \$220,000 to \$249,999
- P. \$250,000 to \$279,999
- Q. \$280,000 to \$349,999
- R. \$350,000 or \$399,999
- S. \$400,000 or more