The Impact of Residential Water Price Increases and Subsidy Reductions on Elasticity of Demand in Abu Dhabi City

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The Impact of Residential Water Price Increases and Subsidy Reductions on Elasticity of Demand in Abu Dhabi City

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Abstract

The purpose of this study is to determine price elasticity of demand (PED) for residential water. Price elasticity of demand measures the responsiveness of household water demand to increases in the price of water, which is desalinated at great expense, but subsidized to consumers by the United Arab Emirates (UAE) government. The price of water is the main tool in water demand management, and consequently, manages the sustainable supply of the water resource. This is a short-term study that compares the change in consumption in 2015 against 2014 (full-year comparisons), among Abu Dhabi national and non-national residents, who are charged different marginal rates for household water. Importantly, 2015 marked the first year that Emirati residents paid for water, while the water price for non-national households has been unchanged almost 20 years, since 1997. The primary question that this research asks is: To what degree did the 2015 restructured water price increases impact the consumption choices of national and non-national households in Abu Dhabi?

I employed a blocked design to compare a representative sample of over 45,500 national and non-national households across the municipalities of Abu Dhabi and Al Ain. I also conducted a review of existing literature on residential water demand price elasticity in the Arabian Gulf, a review of the regional practice of subsidizing the cost of water, and the existing desalination processes in the UAE for their associated environmental impacts.

The results show that the median marginal price elasticity of demand was relatively inelastic at -0.23 for nationals and less than the median of non-nationals at -0.33. The marginal price elasticity was determined to range between -0.12 to -0.42 overall. Price elasticity was relatively less elastic in national households because the percent change in price remained far from recovering the cost of supply. This study introduced a new variable to calculate the impact of the government subsidy on demand elasticity. By calculating the area between the low price curve of water demand and the high cost curve of production, I have arrived at a new measure for demand elasticity, that takes the government subsidy into account. Contrary to the price elasticity results, the combined price and subsidy elasticity measures show that the national segment has exhibited greater elasticity at a median of -1.68, which is relatively elastic, compared to the non-national median at -0.41, which is relatively inelastic. The results reflect the extent to which household water has remained relatively elastic and devalued among the nationals segment. The results of this study are useful for researchers who seek to forecast the immediate short term impacts in demand elasticity in regions where consumption behavior has been ingrained and difficult to change.

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Chapter I

Introduction

Abu Dhabi’s residential water price is a topic of interest in environmental economics due to the integration of political, social, economic and environmental issues. Water scarcity in Abu Dhabi, the capital of the United Arab Emirates (UAE), and throughout the region has been alleviated through desalination, or the process of converting seawater to potable water, for over six decades. The UAE government has funded the growing water demand of its booming population by providing a tremendous supply of desalinated water at highly subsidized rates. This has led to profligate overconsumption and substantial environmental costs.

The combination of the UAE’s oil resource wealth, government investment in desalination technology, and subsidized utilities to consumers has led to a perception of the infinite supply of water (Gunel, 2016; Allan, 2001). Rather than enhancing the quality of life for its citizens, the UAE government subsidy has devalued water, as the price charged to consumers does not reflect its cost or use value. This has acted as a perverse incentive with unintended consequences, specifically the undervaluation and overconsumption of expensive desalinated water, evidenced in the highest per capita footprint in water worldwide. The per capita water footprint for Abu Dhabi in 2008 was at 525 liters per capita per day (l/c/d), while the global average for developed countries was 195 l/c/d (MoEW, 2010).

In 2010, the UAE government forecasted a growing desalination demand-supply gap to begin in 2017, and set a target of reducing average water consumption rates to 200 l/c/d (MoEW, 2010). To achieve this goal, a water conservation strategy was issued in 2010 by the Ministry of Environment and Water (MoEW) with an eight point plan of initiatives. Initiative 6 called for water tariff price reforms to reduce the subsidy and reflect the cost-recovery of desalinated water in tariff prices. An estimated AED 5.72 billion (US$ 1.56 billion) subsidy has been paid annually by the UAE government for desalinated water supplied to residential and industrial water consumers (MoEW, 2010).

Abu Dhabi's Residential Water Tariff Restructure in 2015

Prior to 2015, Emirati national households were provided expensive desalinated water at no charge, and were accustomed to free consumption since the country's establishment. Abu Dhabi's foreign residents also consumed desalinated water at highly subsidized rates prior to 2015. The water tariff price to non-national residents, a constant rate of AED 2.2/m3 (US$ 0.60/m3), was set in 1997 and only covered 29% of the cost of desalination production and distribution (Abu Qdais & Al Nassay, 2001; MoEW, 2010).

In 2015, Abu Dhabi implemented a unique water tariff (price) to household consumers, that charged foreign residents (non-nationals) 3.5 times (350%) more than local Emiratis (nationals). Abu Dhabi's 2015 residential tariff restructure is summarized in Table 1. The new tariff for households was segmented by citizenship (national or non-national), type of residence (apartment or villa), and an increasing block structure that set a higher price for water consumed past a threshold (Abdul Kader, 2014; Al Wasmi, 2014;

Hoath, 2015). The increasing block rate was set at a lower threshold for non-nationals residing in villas than nationals in the same category.

Table 1. Abu Dhabi residential water tariff before and at 1 January 2015 (Abdul Kader, 2014).

	National (Emirati)		Non-National (Expatriate)	
prices in AED per 1000 L^	Old (1997)	New (2015)	Old (1997)	New (2015)
Flat (<700L/day)	free	1.7	2.2	5.95
Flat (>700L/day)	free	1.89	2.2	9.9
Villa (<7,000L/day)	free	1.7	2.2	5.95*
Villa (>7,000L/day)	free	1.89	2.2	9.9*

*threshold set at 5,000 L/day; ^1000 Liters = 1 cubic meter (m3);
1 Dirham (AED) = US$0.27 or US$1 = 3.7 AED.

In the UAE, the marginal cost (MC) of producing and supplying desalinated water (or cost of supplying an additional unit of water) was valued at AED 7.6/m3 (US$ 2.07/m3) in 2010 (MoEW, 2010; RSB, 2013), up from AED 7.5m3 ($2.02/m3) a decade prior (Abu Qdais & Al Nassay, 2001). When this high marginal cost (MC) is compared to the low marginal price (MP) rates set by the 2015 water tariff (Table 1), it is clear that the price of water charged to consumers was below its cost. Importantly, the rate paid by non-nationals in 2015 recovered a greater portion of the marginal cost (MC) of desalination production and distribution. This is significant for consumers to appreciate the full value of desalinated water and reduce excessive consumption.

Research Significance and Objectives

The 2015 residential water tariff restructure in the emirate of Abu Dhabi provides a rare opportunity to observe consumers’ water behavior when water, an essential utility and basic need, is increased to recover a greater percentage of its cost of supply for some consumers, and priced significantly below its cost (undervalued) for other consumers. Pricing the same commodity at different prices for different consumer groups is referred to as third degree price discrimination.

The UAE has been the first among its neighboring countries in the Gulf Cooperating Council (GCC) to implement price discrimination in the residential water tariff structure. It is likely that the neighboring GCC countries, which share common themes in subsidizing desalinated water to households and high water consumption rates per capita, will adopt price discrimination to residential water tariff models in the near future. Therefore, the findings of this research have been designed to assist water planners and policy makers in the UAE and neighboring GCC countries on decisions regarding future water supply and demand efficiencies.

The objective of this study is to provide an analysis of the residential water tariff price increase, with subsequent reduction of government subsidies, on the impact to Abu Dhabi’s residential water consumption behavior in 2015. By understanding the responsiveness of demand to increases in price, or the price elasticity of demand (PED), policy makers and planners can design effective water tariff prices that balance consumption at equitable and sustainable limits. An accurate measure of price elasticity of demand (PED) allows planners to forecast the net effect of a price increase and estimate future water demand.

Background

The literature on residential water demand and the common econometric themes is extensive. The relationship between the need or demand for urban water supplies and different levels of urban economic development pre-dates even the less developed 1950s. This era marks a rapid urban growth pattern in both developed and underdeveloped countries, as well as the disparities within these two groups on providing an effectively managed supply of public utilities, namely water and electrical power. Between the 1950s and 1990s, most of the residential water demand literature was written by scholars of developed countries and on their respective regions. This is not surprising, given the economic, sociopolitical, infrastructure and academic progress of developed countries, which afforded scholars with precise data on household water consumption through individual household metered connections and clear water tariffs (price schedules) set by a dependable water-utility service. During this era, scholars have debated various economic approaches to water demand estimations and the set of explanatory variables that impact household demand, chief among them being water price. The price of water and how consumers respond to changes in price are important variables in drawing the demand curve models for existing and future water demand estimations.

Around the 1990s, as water was increasingly recognized as a finite and scare good, there was a marked shift in the approach to water management which deviated from the traditional supply-side focus toward an emphasis on demand-side management. This period is also characterized by a new attention to residential water management in regions of water scarcity, specifically the Arabian Peninsula, which was identified as the first region globally to run out of renewable water resources by the 1970s (Allan, 2001).

Determining an Efficient Price for Water

Residential water use differs from agricultural or industrial sector uses. Water is treated as an input of production in agriculture or commercial sectors, however, residential water use is not a source of revenue for households. The residential water demand curve represents a direct relationship between a consumer's willingness to pay and their perceived benefits of residential water utility per additional unit (marginal benefit), since water is a final good for households (Billi, Canitano, & Quarto, 2007). Nonetheless, the price of residential water that the consumer pays is dictated by government policy and regulation of the utilities sector for water and electricity, or lack thereof in areas facing water insecurity.

Appropriate water prices that reflect the full social costs of the resource create the incentives to use the resource efficiently and rationally. If the price of water is set too low, then the consumer will not appreciate the full extent of the resource benefits (undervalued water), resulting in overconsumption and a loss of social welfare. If the price of water is too high, as shown in areas of water insecurity, then water scarcity can lead to conflict (Ohlsson & Turton, 2000). Thus, the price of water does not represent the full benefits received by consumers, nor the full scarcity cost of future water. In other words, the price of water does not account for the full value of water, especially when taking into account opportunity costs, wastewater costs, or environmental and social costs for future water streams. This is due to the fact that the price of water is controlled by political regulation.

Water is a challenging commodity to characterize because of the need paradox. Water is necessary for life, but is priced too low, especially relative to other commodities. Allan (2001) described the economic features distinguishing conventionally valued waters as firstly, the characteristics of supply and/or demand, secondly, the quality needed by the user, and thirdly, the consequent costs of delivery and price.

The literature on water conservation distinguishes between two main areas: supply-side and demand-side management. Supply management focuses on the technical efficiency of water production including extraction, storage, distribution, treatment and disposal activities related to the water cycle and its variability. Technological efficiency refers to the production and processes of extracting more output from the same input resources, such as producing desalinated water at minimum cost, and is at the core of hydrological and engineering efficiencies. On the other hand, water demand-related components such as tariff prices, incentives, awareness campaigns, environmental taxes, and water access rights are addressed through economic principles and institutional efficiency. Demand-side management is considered the efficient progression for water management (Billie et al., 2007; Ohlsson & Turton, 2000).

Principles of Allocation Efficiency

Allocative efficiency, also known as economic efficiency, is the primary measure of welfare analysis to determine the impact of markets and public policy upon society and subgroups. Allan (2001, pg.185) has described the allocation efficiency of water in a straightforward question, “What activity brings the best return to water?”, to ask broadly whether it is efficient to allocate a finite water supply to one sector of the economy versus another. Turner et al., (2004) have provided a response to the allocation question, “As pricing of water affects the allocation decisions of those with competing wants, then by correctly pricing water, efficient allocation of water is achieved.” Ohlsson & Turton (2000, pg. 220) have argued, “The main societal tool to implement measures of end-use efficiency is an economic incentive, i.e. putting a price on water.”

Allan (2001) has also shown that an economy able to absorb increases to water price displays high social adaptive capacity. Higher water prices in an environment of water insecurity leads to a decrease in water demand and improvement in the economic return of resource distribution across society. Allan (2001, pg. 324) states, “An improvement in social adaptive capacity can compensate for a physical water shortage, the opposite is not true.” In other words, increasing a water supply does not improve the social adaptive capacity to face water scarcity. Institutional, infrastructural, and economic capacities are needed to ensure that consumers can absorb increases to the price of water.

In a perfect economy, which is in part characterized by where resources are used at the highest optimal level, it is said that the meeting point of marginal cost (MC) and marginal benefit (MB) (also measured as marginal utility) is the price and quantity level that balances fair distribution of the resource’s benefits and cost within that economy (Markowitz, 2008). The costs paid for producing the water source (supply curve) and the benefits received from consuming it (demand curve) are analyzed graphically. Allocative efficiency occurs where MB equals MC, reflecting the balance between marginal costs (MC) associated to the producer or supply curve, and marginal benefits (MB) associated to the consumer or demand curve. When the marginal water benefit is directly proportional to its full social costs of developing supplies, the incentives are created to use the resource efficiently and rationally (Billi et al., 2007).

Principles of Residential Water Demand Models

The economic models that estimate water demand follow some derivation of the formula Qd = f(P, Z), which relates water consumption (Qd) to a measured function of price (P) and other factors (Z). Some demand models are expressed in linear function, which draws the demand curve as a straight line, and implies that the demand curve slope is the same at every price level. Other models are formulated in a logarithmic equation that use regression to determine the differences in averages along the demand curve. Arbues, Valinas and Espineira (2003) show that there is no one agreed methodology to estimate water demand or price elasticity, and it is up to the researcher to explain the technical issues regarding the model employed in their study. The type of data set available, such as either aggregate (total) municipal water demand or individual household micro-data, will influence the overall demand model and price elasticity estimation technique.

Further, in economic theory, non-price variables shift the demand curve but do not affect the demand curve slope (the direct relationship between quantity and price). This follows that other determinants of demand such as income, tastes, population, substitutes, weather variables, indoor and outdoor use characteristics, reliability, etc. would cause the demand curve to shift in or out along the x-axis (Michelsen, McGuckin & Stumpf, 1998). Income is a variable that contains its own elasticity measure and is determinant of demand as well. Consistent with economic theory, income elasticity is a positive number, and demonstrates the positive influence of income on quantity demand, where more income usually leads to more quantity demanded, or shifts the demand curve to the right. Most recent studies have used linear or log-based regression to calculate the change in water demand quantity as a function of multiple variables that are contextually relevant.

Principles of Price Elasticity of Demand

Price elasticity of demand (PED) is not the same as the slope of the demand curve, which can be confusing, as the slope of demand is a representation of how the price of the good changes with the units of quantity demanded. Price elasticity of demand (PED) can be thought of as a measure of responsiveness, or sensitivity, of the demand slope to a change in price. PED is mathematically the *percent* change in quantity divided by the *percent* change in price, whereas the slope of the demand curve represents a change in quantity divided by a change in price, as plotted on the inverted price-quantity graph used by economists. For all commodities PED is a negative number, which is reflected in a percent decrease in quantity demanded (negative numerator) as a function of a percent increase in price (positive denominator), or vice versa, a percent increase in quantity demanded (positive numerator) as a function of a percent decrease in price (negative denominator).

Graphically, the PED reflects whether the demand curve appears as either relatively steep or sloping. A steep demand curve infers that the commodity is relatively price inelastic, meaning that a change in price has little effect on the quantity demanded, and is found at a number between -1 and zero ($-1 < PED < 0$). Most essential commodities are relatively price inelastic. This means that quantity demanded is not strongly affected by a change in price. Studies on residential water price elasticity have shown that water demand is relatively inelastic to pricing, however, consumer behavior is variable in local contexts.

Relevance of Elasticity to Government Conservation and Efficiency Aims

Modeling for future residential water demand, and determining therein a fair price for water, is important for ensuring future allocation and supply of the water resource. In their review of residential water demand estimation models, Arbues et al. (2003) summarize the objectives of designing effective residential water tariff price structures are to achieve social equity, public health, environmental efficiency, financial stability, simplicity, public acceptability, and transparency.

To achieve the aims of an effective water tariff design, it is preferable to have a relatively higher elasticity in the demand curve, so that there is a higher decrease in consumption when the price is increased. A higher absolute PED reflects that consumers will respond to a price increase by consuming less, conversely, a low absolute PED reflects little change to consumption choices. Therefore, among the goals of the government or utility management is to ensure that high levels of elasticity are reflected in overall water consumption.

Previous Residential Water Price Elasticity Studies

A study surveying both short and long-term residential water demand studies found price elasticities at a wide range from -0.01 to -1.63 (Cader, Marsh & Peterson, 2004). The low absolute value (0.01) is more inelastic, or would be reflected in a steeper demand curve, than the high absolute value (1.63), which is more elastic, or more responsive to a price change. Absolute values are commonly used when indicating elasticity, even though PED remains a negative number, because of the inverse relationship. In a 2003 meta-analysis of price elasticity of household water demand among 282 observations, the average PED of water averaged -0.38 (range -1.3 to +0.1), another conducted in 1997 showed an average of -0.51, while in developing countries the PED for household water connections ranged from -0.3 to -0.6 (DeFelice & Gibson, 2013). Price elasticities from studies of residential water demand are shown below in Table 2 in the far right column. Table 2 combines previous PED studies from developed countries along with more recent studies from the Arabian Peninsula. The price variable method is discussed in the following section on PED variables.

Table 2. Price elasticities from previous studies of residential water demand (Milutinovic et al., 2005; revised by author).

Authors	Study area	Price variable	Price elasticity
Foster and Beattie (1980)	USA	AP	-0.35 to -0.76
Billings (1982)	Tucson, Arizona	MP & D	-0.66/-0.56
Chicoine and Ramamurthy (1986)	Illinois	MP (AP)	-0.6 on MP
Nieswiadomy and Molina (1989)	Denton, Texas	MP & D	-0.86
Griffin and Chang (1990)	USA	AP	-0.16 to -0.37
Abu Riazaiza (1991)	Saudi Arabia	AP	-0.36
Hansen (1996)	Denmark		-0.10
Renwick and Archibald (1997)	California	MP & D	-0.33
Hoglund (1997)	Sweden	MP & AP	-0.20 on AP
Dandi et al. (1997)	Australia	MP & D	-0.63 to -0.77
Renwick, Green, and McCorkle (1998)	California	MP & D	-0.16 to -0.21
Nauges and Thomas (2000)	France	AP (&MP)	-0.22
*Abu Qdais and Al Nassay (2001)	Abu Dhabi, United Arab Emirates	AP	-0.10 (also -0.07)
Ayadi et al.(2003)	Tunisia	AP	-0.17
* Galaitsis (2013)	West Bank, Palestine	MP & D	-0.19 to -0.36
* Al-Qudah (2010)	Amman, Jordan	MP & AP	-0.81 to -0.97

Determinants of Price Elasticity for Residential Water Demand

There are a number of variables that scholars on the topic of residential water have identified as variables that impact PED. Arbues et al. (2003) and Galaitsis (2013) have compiled and reviewed a number of variables compiled from studies that have explored the relationship to water demand. The variables listed below have a direct relevance to the context of water demand behavior in Abu Dhabi and the outcome of this study. Price and income are significant factors that influence consumption choices, nonetheless, both economic theory and water demand literature emphasize the importance of contextual variables.

Water Price. Determining whether to use the average price (AP), marginal price (MP), or difference variable (D) has divided scholars of demand elasticity (Galaitsis, 2013) and impacts the results (Michelsen et al., 1998). The MP refers to the change on the margin in rate for the price tariff when one additional unit of residential water is consumed. AP is calculated as the total bill paid by the consumer, divided by the number of units of water used per billing period, and AP may include additional service charges beyond the MP. In some cases the price that water is sold at (AP) is greater than its base tariff rate (MP). Which of these prices consumers perceive and respond to is critical to understand. This is particularly important in studies where consumers are confronted with more than one water source, thereby having to pay at different rates, or in studies with an increasing block price structure, where the consumer may face savings from consuming at a cheaper rate. From the consumer perspective, there is difficulty in obtaining accurate and timely information about the price for the next unit of water consumed. Utility bills only convey historical information, and the water meter is not visible in the household, so consumers are not informed of switching to a higher consumption block in real time.

Previous research on residential water PED highlights the importance of the price difference variable (D) in differentiating between the customer's perception of AP (the bill total) and what the consumer would have been charged if all water was consumed at the lower MP block (the rate charged). The difference variable (D) is used in elasticity studies to compensate for the margin between AP and MP. It is a representation of the benefits that the consumer receives by paying a cheaper price for water before having to pay a higher rate for additional water. The standard formula for measuring the difference variable is to divide AP by MP [D=AP/MP]. Figure 1 indicates the difference variable within the shaded area that represents the surplus of consumer benefits. The contribution to the field that this study proposes is to indicate the consumer surplus from receiving subsidized water as a derivative of the difference variable.

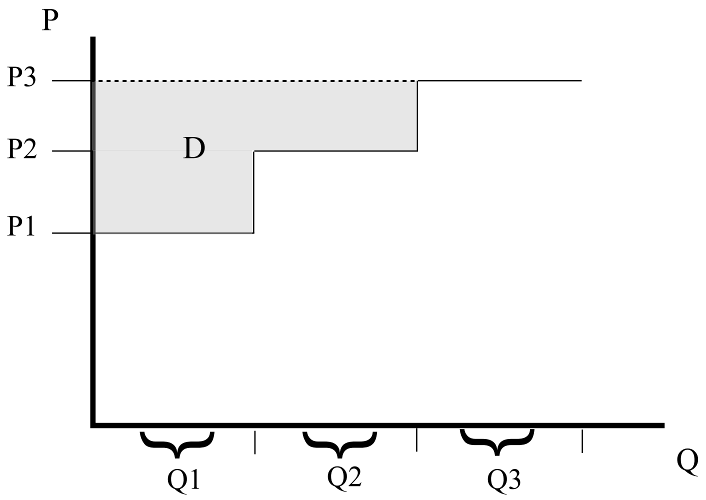

Figure 1. Difference variable for increasing block tariff structure.

Income. Household income is also an important independent variable in water demand elasticity models (Cader et al., 2004). Global average households spend about 4% of their income on water while the world's poor spend an average of 45% of their income for this important basic commodity (Galaitsis, 2013). Low income households are typically more responsive to price changes (higher PED) than high income households (Yoo et al., 2013). As the price of water increases to consume a larger portion of the household budget, and the consumer is faced with a higher potential rebate for tradeoffs between water expenditure and other commodities, elasticity would tend to increase even more so in the long term (Milutinovic et al., 2006), that is to say that the consumer is more responsive to reducing more quantity over time.

Household Characteristics. Household features are also indicative of household income. Variables regarding household infrastructure and water use, such as the household plot size, number of bedrooms and bathrooms, and garden size have been used in previous studies to correlate with residential water demand. Outdoor water use is allocated to garden irrigation, swimming pools and car washing, and is associated with high-income and higher water use consumers. Studies have found that outdoor water use is significantly more elastic than indoor use (Milutinovic et al., 2006). A study in the United States found that a 10% increase in water price reduced outdoor demand by 3% to 7%, while indoor demand was less responsive, at less than 2% (MoEW, 2010). Mayer and DeOreo (1999) found in a study of 12 major sites across the United States that 42% of annual water use was for indoor purposes while 58% was used for outdoor purposes, and further, that hot climate cities such as Phoenix had a higher percentage of outdoor use (59% to 67%) while cooler and wetter climates such as in Seattle showed lower percentages of outdoor use (22% to 38%). The main indoor water uses include toilet flushing, shower and bath use, faucet use, dishwasher use, and clothes washing. These variables are positively related to income and house size but can vary contextually when investigating other indicators of water use at the household. For example, renters have been found to consume 10% more indoor water than home owners, homes built prior to the 1990s have less water saving appliances, and children and teens have been found to use more water for showers and baths than adults (Mayer & DeOreo, 1999).

Duration. Another important aspect of PED studies is whether elasticity is measured over short or long time periods. Long-run PED is preferred for most residential water demand models, as it tends to show approximately 0.2 to 0.3 points higher (more elastic) than short-term elasticity (DeFelice & Gibson, 2013), indicating that it takes time for consumers to respond to rate changes and adjust their household consumption while guessing their historical consumption patterns. Also, utility companies typically adjust tariff rates on an annual basis at an incremental rate of increase (Allan, 2001). Small changes to water price would not impact household expenditure or water demand to a large degree. Nonetheless, many studies consider water demand changes over short periods, usually one year or less, due to the difficulty of aggregating data for individual households over time (Milutinovic et al., 2006).

Education and Awareness. Among the non-price determinants of demand, the education and awareness of household residents regarding water scarcity has had an effect on reducing water expenditure. Awareness campaigns have been found to reduce demand without a price increase, and the synergistic effects of a price increase and awareness campaign calling on public rather than private benefits of conserving water may also increase price elasticity (Michelsen et al., 1998).

Previous Residential Water Price Elasticity of Demand Studies in the Arabian Gulf

The first identified studies on residential water demand price elasticity for the Arabian Peninsula region were published by Abu Riazaiza (1991) for Saudi Arabia, and Abu Qudais and Al Nassay (2001) for Abu Dhabi in the UAE. The findings of these studies were used in modeling residential water demand in Kuwait City by Milutinovic et al. (2006), and referenced by DeFelice and Gibson (2013) in modeling the impact of residential water decreases on air pollution reductions in Abu Dhabi. In the Levant area, household water consumers in West Bank, Palestine, were first measured for elasticity by Mimi and Smith (2000), followed by Galaitsis (2013) who introduced the security of water supply as a variable that impacts consumption. Al-Qudah (2010) measured price elasticity for Amman, Jordan, using actual data collected from 1,200 households. These are the only identified published studies on the elasticity of residential water tariffs in the Arabian Peninsula on consumers' willingness to pay (barring the North African countries).There remains an overarching view from policy makers in the region that more studies are needed to investigate the impact of water tariff reform on changes in consumption in order to design effective tariff schedules for sustainable future water use.

Understanding how consumers respond to price changes is a fundamental tool to achieve this aim.

The study on Abu Dhabi residential water PED by Abu Qdais and Al Nassay (2001) determined a PED of -0.10, however, the authors overlooked important factors within their study. Abu Qdais and Al Nassay studied a critical transition. Individual water meters were first installed to Abu Dhabi's households in 1997, and customers were introduced to paying for household water according to the volume of water that was consumed, whereas previously were required to pay a flat rate fee regardless of quantity consumed. There was no increasing block structure applied in 1997, instead, a constant rate was charged per quantity consumed. Primarily, the authors have failed to specify whether their sample of 90 households were all paying customers. If this were the case, then Emirati households were not part of the study, as nationals received subsidized water freely. Also, the authors did not define the number of months that the data spanned prior or after the price transition. This did not allow for insightful analysis on consumer choices with enough time to consider behavior adjustments. The authors also did not factor income or any household-related determinants of demand in their measure of PED. The authors gave no indication of household type, size, location, or any additional characteristic that would influence household consumption. They concluded there was very low elasticity (or highly price inelastic) which means that the increase in price had a low impact on the reduction of quantity. This conclusion is logical, bearing in mind that the new price of water remained significantly below the cost, and therefore undervalued.

In the Saudi Arabia study, Abu Rizaiza (1991) determined PED using the AP variable in a comparison of households in four major cities (Jeddah, Makkah, Madinah, and Taif). AP was calculated by aggregating the total amount paid for water over the year divided by the total amount of water consumed over the year for each household. Due to the unreliability of the government water utility network, especially in the high altitude cities of Taif and Makkah, residents purchased additional household water through privately operated water tankers. The AP of the government-network (desalinated) water was approximately US$ 0.10/m3 (Abu Rizaiza, 1991), while the cost of desalination may have ranged between US$ 0.40 to USD 0.80/m3 (Ouda, 2013), reflecting the high government subsidy. The AP of the private tankers was as high as US$ 6.13/m3 in Taif (least network connected), US$ 1.60/m3 in Madina, and approximately US$ 3.50/m3 in the larger cities of Jeddah and Makkah (Abu Rizaiza, 1991). This also reflects a case of third degree price discrimination for water consumed from the private tankers. Within these wide ranges of price, the demand model found that households that paid less for water consumed more (cheap) water, and were more elastic to price increases. In Taif and Makkah, poor government water networks and dependency on expensive tanker water supply showed less elasticity at -0.4 (steeper curve, less responsive to price changes), than network covered areas in Jeddah and Madina at -0.76 (flatter curve, more responsive); the total average for the four cities was at -0.36 at a 95% confidence level (Abu Rizaiza, 1991). The results in Saudi Arabia show that households in areas that paid less for water (Jeddah and Madina) had greater decreases in their consumption when the price increased (ie. more elastic demand).

Variables in the Abu Dhabi Context

According to historical data regarding electrical connections in Abu Dhabi emirate, there were over 70,000 Emirati households and over 150,000 expatriate households by 2013 (RSB, 2013). Household type and the UAE government subsidy are important variables alongside price that impact the demand curve and responsiveness of consumer demand (or PED). The following explanation relates how the independent variables affecting water consumption behavior are implicated in this study.

Water Price. Residential water studies on price elasticity of demand (PED) have focused on consumer perceptions of the price of water when its price is at or greater than its full marginal cost, otherwise, subsidized water is inherently undervalued and elasticity— a causal relationship between price and quantity— may not apply (DeFilice and Gibson, 2013). However, I have argued it is possible to calculate PED of undervalued water, as evidenced in PED studies applied in Saudi Arabia and Abu Dhabi discussed above.

Abu Qdais and Al Nassay (2001) and Abu Rizaiza (199?) did not factor the marginal costs of water sources (desalination and groundwater) as I propose to do, thus does not account for the excess economic benefits passed onto customers accustomed to paying cheap rates for their water consumption. Also, it would have been difficult for Abu Rizaiza to capture the marginal cost of water supplied by tankers, as this ranges in cost. It is expected that introducing the government subsidy as a derivative of the difference variable that affects perception of price would result in a greater understanding of price impact on elasticity.

Income. Tong (2010) determined by a survey on UAE wage structure that Abu Dhabi paid the highest median salaries among the emirates. Emirati nationals were paid a median annual salary of AED 216,000 (US$ 58.8K) versus the non-national median at AED 36,000 (US$ 9.8K), while the median annual salary for Western expatriates (US, EU, etc.) was higher than Emirati nationals at AED 320,000 (US$ 87K) and Arab expatriate salaries median was at AED 78,000 (US$ 21K) (Tong, 2010). The low median is due to the high proportion of low wage Asian workers in the country.The majority of expatriate workers in Al Ain are low wage Asian workers with few other expatriates, also, nationals residing in Al Ain have a lower median salary at AED 84,000 (US$ 22.9K) (Tong, 2010). Al Ain has a lower level of economic development compared to Abu Dhabi city, reflected in lower income groups in relation to Abu Dhabi city.

Housing Characteristics. Unlike apartments, villas are associated with higher income residents, large families, and large outdoor water expenditure. Villas are defined as standalone houses and these are usually built with private areas for a gardens and vehicles. Apartments are defined as homes within a shared building complex and can range in the number of bedrooms/bathrooms. As well, many apartments have access to a private garage, though shared access to gardens or pools. From existing water consumption surveys it is clear that villas consume more water on outdoor facilities such as gardens, pools and car washing. Therefore, a generalization can be drawn between the household type and income level in Abu Dhabi.

A one-time survey conducted in 2007 by Abu Dhabi Water and Electricity Company (ADWEC) and its independent regulator, the Regulation and Supervision Bureau (RSB), found that residential water consumption varied by property types and not price alone (MoEW, 2010). The survey examined Abu Dhabi's nationals and non-nationals living in both villas as well as apartments. The literature did not identify the number of houses surveyed nor specify the subsidization effect on consumers, namely by identifying that all Emirati nationals received free residential water (100% subsidized), which are important details to note. Still, the results of the survey outlined in Table 3 below, showed that Emirati villas had greater rates of water consumption compared to non-national villas. This was to be expected given that nationals had fully subsidized consumption. Conversely, and surprisingly, Emiratis residing in apartments that received free water consumed almost equal amounts as paying non-national flats. Table 3 thus supports the notion that the quantity of water consumed is not a function of price alone. Property type is therefore an important factor in the Abu Dhabi residential water demand context. The results also show that both consumer groups residing in apartments, national and non-national, were shown to consume water within the global average for developed countries of 195 l/c/d).

Duration. This is a short-term study that compares the change in consumption in 2015 against 2014 (full-year comparisons) among residents. One year is sufficient time for residents to adjust their water consumption behavior retrospectively. Also, full year comparisons allow for weather changes within the year to be normalized by the data.

DeFelice and Gibson (2013) have estimated that a long-run price elasticity for Abu Dhabi city around -0.37 to -0.27 could be comparable with global findings, and have used three PED values (-0.07, -0.27, -0.37) to model three forecast scenarios of future desalination consumption. The -0.07 PED was cited from the result of the Abu Qdais and Al Nassay (2001) study. The difference between -0.07 and -0.1 elasticities is due to the researchers accounting for standard deviation.

Table 3. Abu Dhabi residential water consumption by group and property type (MoEW, 2010).

Segment	Property type	Min. Consumption	Max. Consumption
Emirati nationals	Apartment	165	220
	Villa	400	1,760
Non-nationals (expatriates)	Apartment	170	220
	Villa	270	730

Figures in liters/capita/day.

Education and Awareness. In Abu Dhabi, numerous awareness campaigns have been implemented in public mediums and through educational systems in both Arabic and English. At a policy level, non-price measures to reduce water such as smart technologies and green building codes do exist. Nonetheless, the persistently high per capita water footprint show that these campaigns have had little effect over the years.

The Abu Dhabi Distribution Company (ADDC) began in 2012 to provide residential customers with new information in their monthly utility bills that calculated the additional government subsidy amount provided as part of the total household consumption, along with a two color meter to indicate whether the household was consuming within green or red ranges of consumption (Collins, 2012). The local media identified that the new information in the bills signaled to residents that the government was preparing to reduce its commitment to annual subsidies. To introduce the new bill design, the government ran a highly visible public awareness campaign entitled "Are You In The Green or The Red?", referring to the ideal or over consumptive ranges respectively. The immediate aims of the new bill design and campaign were to gather data and educate consumers on the actual price of water, nonetheless, the management also identified that the awareness campaign effect of reducing overconsumption prior to a price increase was also important to the government agency (Ibid). Still, as consumers did not incur any penalty for red band consumption, financial or otherwise, these measures recorded little effect on consumption habits.

Desalination and Subsidized Water in the GCC

Desalination, or the process of converting seawater to potable drinking water, is expensive and environmentally damaging to produce, yet has been the source of water to households in the Gulf Cooperation Council (GCC) since the 1960s. The GCC, comprised of Saudi Arabia, UAE, Oman, Qatar, Kuwait, and Bahrain, have historically subsidized desalinated water to households, in most cases providing free water to national citizens, and at a fraction of actual costs of desalination to all residents. The GCC countries housed approximately 43% of the world's share of desalination plants, and consume almost 70% of the global desalination production, approximately 62.34 million m3/day (vs. global production at 94.5 million m3/day) (Gunel, 2016). Desalinated and reclaimed water (treated sewage water) are the GCC's future alternative water supply to groundwater and freshwater deficits (Poortman et al., 2005). The perverse government subsidies and pricing policies that keep these countries' citizens from having to pay the full economic cost of water production and distribution have led to wasteful consumption habits and excessive residential water demand, while ironically, the GCC is one of the most arid and water-stressed regions in the world.

The Political Price of Water

Understanding subsidies as a form of national wealth redistribution and cultural expectation clarifies why reducing or removing them is highly controversial. For the oil-rich GCC governments facing subsidy choices, providing water and electricity to residents below cost has been a political and social obligation (Allan, 2001; MoEW, 2010; Saif et al., 2014; World Bank, 2014). The GCC governments' argument for subsidization includes expanding access to energy and water, protecting the poor, fostering industrial development, controlling inflation, as well as avoiding conflict with citizens who value access to natural resources as a birth right (Allan, 2001; Saif et al., 2014).

GCC governments have spent more than US$ 160 billion on subsidies annually, approximately 10% of the GCC's combined GDP of US$ 1.64 trillion at end of 2012 (Trenwith, 2014). The global decline in oil price that began mid-2014 caused significant losses to GCC governments. The losses were estimated at US$ 300 billion by mid 2015 by the International Monetary Fund (IMF, 2015). This triggered GCC governments to restructure tariffs and reduce subsidies, beginning with the UAE in November 2014 (The National, 2014). The remaining GCC governments attempted to reduce subsidies in 2015, but were met with varying degrees of conflict put forward from their respective local populations (Apricum Group, 2014; Simms, 2015).

Water and electricity tariff reforms were met with violent social protests in Bahrain and Kuwait (Reuters, 2015a; Reuters, 2015b). In Bahrain, the outcome of clashes resulted in a segregated residential water tariff rate and a large margin between Bahrainis and non-nationals. Kuwait's parliament rejected proposals to increase residential water and electricity prices in 2015, which had been unchanged for over fifty years, until the law was modified in 2016 to apply to non-nationals and exempt Kuwaitis. In Qatar, utilities remained free for nationals. In Saudi Arabia, the minster of water and electricity was removed by royal decree after public outrage reached a tipping point, only six months after utility prices were increased (The National, 2016). In Oman, residential water tariffs remained unchanged, and equal among all household consumers, although industrial and government water tariffs were increased in 2015 for 2016 (Times of Oman, 2016). These examples show how the local populations in Kuwait, Bahrain, Qatar, Oman and Saudi Arabia pressured their respective governments to delay subsidy policy shifts through 2015, despite financial losses triggered by the global oil decline. Table 4 summarizes for the GCC countries the utility tariff schedules applied to households by end of July 2016, as well as the total marginal cost of production for water and electricity, and the calculated subsidization range paid by each government.

Table 4. Residential water tariffs in the GCC as of July 2016.

GCC Country (Population)	Product	Marginal cost (US$)	Tariff (US$)	Subsidization rate (%)	Source
KSA (31.54 million)	Water(^)	1.09/m3	0.04-2.43/m3	0-96	Global Water Intelligence (2016); Ouda (2013)
	Electricity	0.21/kWh	0.01-0.08/ kWh	62-95	Saudi Electricity Company (2016), Apricum Group (2014)
Oman (4.49 million)	Water	4.01/m3	1.14-1.43/m3	65-72	Times News Service (2016)
	Electricity	n/a	0.03-0.08/ kWh	n/a	MEDC (2016)
Qatar (2.36 million)	Water(*)(^)	2.74/m3	1.21–2.58/ m3	6-56	Kahrama (2016), Saif et al. (2014)
	Electricity(*)(^)	0.07/kWh	0.02–0.06/ kWh	14-67	
Kuwait (3.89 million)	Water(*)	n/a	0.7/m3	n/a	Fattouh and Mahadeva (2014)
	Electricity(*)	0.09/kWh	0.007-0.035/ kWh	61-92	
Bahrain (1.38 million)	Water(^)	1.92/m3	N: 0.21-0.79/ m3; NN: 1.06-1.99/m3	0-89	MEW (2016), Saif et al. (2014)
	Electricity (^)	0.07/kWh	N: 0.02-0.05/ kWh; NN: 0.04-0.08/ kWh	0-71	
UAE (9.16 million)	Water(^)	2.07/m3	N: 0.46-0.51/ m3; NN: 1.62-2.87/m3	0-78	RSB (2013; 2016); ADEWA, 2016
	Electricity(^)	0.07–0.09/ kWh	N: 0.01/kWh; NN: 0.06-0.09/ kWh	0-87	

N=nationals and NN=non-nationals; (^) tariff restructured in 2015 for 2016; (*) free for nationals; Marginal Cost of Production does not include Storage and Waste Treatment Costs.

UAE Demonstrates Social Absorption Capacity

The UAE utilities tariff restructure introduced in Abu Dhabi charged expatriate (non-national) residents up to three times more than the price paid by local Emirati citizens. Although the UAE's expatriates publicly complained of increased costs of living to local newspapers, the general population did not react to price hikes with social protests (Al Wasmi, 2014). The UAE government has not faced opposing social protests despite recurring tariff increases over three consecutive years (2015-2017). This reflects Abu Dhabi's social absorption capacity to institutionalize market shocks.

Abu Dhabi's residential water tariff was also adjusted in 2016, but only to expatriate (non-national) residents, where red band consumption was increased from AED 9.9/m3 to AED 10.55/m3 (RSB, 2016). At the end of 2016 the government again announced price increases to Abu Dhabi's national and non-national residential consumers for 2017. The tariff restructure for 2017 increased charges for nationals from AED 1.7/m3 to AED 2.09/m3 at the lower block and AED 1.89/m3 to AED 2.60/m3 at the higher block, while non-nationals were charged a new rate of AED 7.85/m3 from AED 5.95/m3 at the lower block and AED 10.41/m3 from AED 10.55/m3 at the higher block (the red band consumption for non-nationals was adjusted downwards) (Khaleej Times, 2016). Abu Dhabi's governing utility authority, ADEWA, stated that the 2017 adjustment to tariff was to reflect the average cost of supplying water and electricity to all categories of customers in the emirate and was in line with the goal of resource conservation.

UAE Desalination Ownership, Technologies, and Costs

Located on the toe of the Arabian Peninsula, the UAE is a confederation made of seven emirates (states), unified in 1971. The UAE's population jumped from 178,600 in 1968 to 5.6 million in 2010 in just three decades, while over just the past seven years, leaped to over 9 million residents (World Bank, 2016). Population growth and the rapidly urbanized standard of living have contributed to the country’s unsustainable water consumption rates (Gunel, 2016; Poortman et al., 2005). The Ministry of Environment of Water (MoEW; renamed Ministry of Climate Change and Environment in 2016) forecasted that the UAE’s demand for future desalinated water was expected to double from 1.7 km3 (2008) to 3.5 km3 (2030) a year considering population growth and average per capita water consumption rates (MoEW, 2010). This leaves a capacity gap for desalinated water that would grow to 1.14 km3 annually by 2030. Total desalination production in the UAE totaled 1.87 km3 in 2013 (NBS, 2015) (latest figures).

Table 5 reviews for each emirate the population, desalination water production (2013), water demand per capita (2008), residential water tariff (2015), residential water tariff policy changes up to 2016, and groundwater data. Water tariff rate changes in 2015 as an effect of the global oil price are detailed in the sixth row (Table 5). The emirate of Dubai was the first to charge Emirati nationals for water in 2010, while the remaining emirates introduced water tariffs to national residents starting in 2015, although national households were charged a relatively low price for electrical consumption prior. Abu Dhabi has restructured its water tariff prices beginning 2015, beginning 2016, and beginning 2017. Sharjah increased water tariff prices but only to industrial and government consumers in 2015. The remaining emirates hiked residential water prices for non-nationals in 2013 and did not make any changes by end 2016.

Table 5. UAE water use by emirate.

	Abu Dhabi	Dubai	Sharjah	Ajman	Fujairah	RAK	UMQ
population	2.65	2.53	1.4	0.24	0.15	0.25	0.18
nationals	0.51	n/a	n/a	n/a	n/a	n/a	n/a
demand per capita	526	377	158	295	136	266	225
authority	ADEWA	DEWA	SEWA	FEWA			
2013 desal production	1.1965	0.4576	0.1332	0.873			
residential water tariff policy changes by end 2016	increased to 10.55 Dhs/m3 limit for NN in 2016	increased June 2016 for N to 0.902 - 1.144 Dhs/m3	last adjusted end 2014	N: previously 1 fils/gallon, adjusted end 2014 NN: adjusted end 2013			
National water rate	1.7 - 1.89 Dhs/m3)	0.770 - 1.012 Dhs/m3	3.3 Dhs/m3 (1.5 fils/gallon)	3.3 Dhs/m3 (or 1.5 fils/gallon)			
Non-National water rate	5.95 - 9.9 Dhs/m3	6.6 - 8.8 Dhs/m3 (3-4.6 fils/gallon)	6.6 - 8.8 Dhs/m3 (3-4.6 fils/gallon)	6.6 - 10.1 Dhs/m3 (3 - 4.6 fils/gallon)			
groundwater reserves	353.5	1.07	1.04	0.01	0.45	1.66	0.25

N=nationals and NN=non-nationals
Sources: Population in million and desalination production in km3 provided by NBS (2015); Demand per capita in l/c/d 2008 figures provided by MoEW (2010); Tariff policy changes and rates as of 2016 published in authority websites for ADEWA, DEWA, SEWA and FEWA; Groundwater reserves (fresh + brackish water) in km3 showing 2005 data, provided by MoEW (2010).

Strategic decisions for new desalination plants are taken by the UAE's Ministry of Energy at the federal level, within the same organization as electricity, as it is mostly produced by a process of cogeneration. Desalination, sewage and wastewater production and infrastructure was previously the property and management of the UAE government sector, however new ownership models that range from full government ownership, to public private-partnerships, to concessions, have been in place since 1999. The result is a range of plants with differing ownership structures, infrastructure, and costs.

Desalinated water production and distribution is the responsibility of four main Electricity and Water Authorities that are associated to emirates by population. Each authority acts as the local government's regulating body for desalinated water production (supply) and distribution, therefore the responsibility of managing consumer water tariff prices (and payment collection), distribution, and sewage falls to the local emirate branches through ADEWA (Abu Dhabi), DEWA (Dubai), SEWA (Sharjah), and FEWA (remaining emirates Ajman, Fujairah, Ras Al-Khaima, and Umm Al-Quwain). Under each authority is a corresponding company, such as Abu Dhabi Water and Electricity Company (ADWEC),which oversees the underlying distribution company such as Abu Dhabi Distribution Company (ADDC). The four authorities in turn are overseen by the UAE's Ministry of Environment and Water, and regulated by an independent and autonomous Regulation and Supervision Bureau (RSB).

Desalination processes are divided into two categories: the first category is based on thermal processes, which includes the highly polluting yet economically effective Multi Stage Flashing (MSF) as well as Multi Effect Distillation (MED) and Vapor

Compression (VC), while the second category is based on membranes processes that include Reverse Osmosis (RO) and Electrodialysis (ED). Most plants cogenerate electricity and water simultaneously at power stations, by using the excess heat of desalinating seawater to generate additional electricity and heat.

Over half of the UAE’s desalination is produced through MSF technology, which requires more than double the energy use in desalination than other processes (10-16 kWh). Desalination costs had decreased significantly by the 2000s for all technologies, with the largest cost reduction occurring in RO technology (3-4 kWh), mainly due to nanotechnology improvements in membrane design. Future desalination plants in the UAE use a combination of MED (5.5-9 kWh) and RO technologies to reduce costs and environmental impacts.

Ghaffour et al. (2012) have consolidated the average values of large-scale desalinated water costs and energy consumption as seen in Table 6, and have noted that thermal process (MSF and MED) have been widely accepted in the Arabian Gulf region, due to their proven record for reliability and potential for cogeneration of both power and water. The MSF process appears more costly and environmentally damaging than alternative processes, due to the higher energy requirement, but MSF is relatively energy efficient and produces better economies of scale, while MED is better suited to smaller-sized plants. The RO process has been slow to enter the region as the high seawater salinity and the occurrence of marine life in the shallow waters of the Arabian Gulf created inefficiencies and challenges to adopting this technology locally (MoEW, 2010).

Table 6. Average energy consumption and water cost of large-scale desalination (Ghaffour et al., 2012).

Process	Thermal Energy kWh/m3	Electrical Energy kW/m3	Total Energy kWh/m3	Total Water Cost US$/m3
MSF	7.5-12	2.5-4	10-16	0.8-1.5
MED	4-7	1.5-2	5.5-9	0.7-1.2
RO	-	3-4	3-4	0.5-1.2

Environmental Costs

Producing the UAE's incredible volume of desalinated water requires enormous amounts of seawater and energy. According to the mix of UAE's desalination technology, 4.8 km3 of seawater was pumped to produce 1.75 km3 of potable desalinated water in 2009 (MoEW, 2010). Desalination uses 12 to 22% of the total electricity produced in the UAE (DeFelice & Gibson, 2013). The UAE's desalination environmental impacts, such as air pollution contribution through greenhouse gas emissions, coastal habitat damage from brine discharge and salinity, or indirect effects on the health condition of its citizens, have been noted but not monetized in previous studies (Saif et al., 2014; Burt, 2014; DeFelice & Gibson, 2013; MoEW, 2010). Though the environmental costs of desalination cannot be quantified and are out of the scope of this study, the following primary environmental impacts of desalination are noted for their potential to impact costs and concern the hazard to marine life.

Life-cycle assessments have shown that more than 90% of the environmental load of desalination plants, including energy use, raw materials, emissions and waste products, are associated with the operating stage of the plants, while less than 10% of the load attributed to construction and end-of-life emissions (DeFelice & Gibson, 2013). The brine discharge concentrate levels of saline and various chemicals used in pre and post desalination production is usually the primary environmental impact parameter. Acceptable safe levels of discharge content and temperature may vary depending on the receiving water properties, as well as varying country regulations. There is no uniformity in brine discharge regulations across the GCC nations, even though, these six countries as well as Iran and Iraq rely on the same body of seawater for desalination.

Berktay (2011) has discussed the relationship between concentrated brine discharge from desalination and the occurrence of harmful algae bloom, also known as red tide, in the Arabian Gulf. The effect of red tide is commonly associated with wildlife mortalities in marine and coastal species of fish, birds, and marine organisms, due to the depletion of oxygen and production of natural toxins caused by the rapidly accumulated algae. The impact of red tide extends to fishery operations, damages coral reefs, and impacts coastal tourism, and causes disruption to desalination production as well. This occurred during 2008-2009 when red tide posed a threat to the drinking water supply in the Arabian Gulf region and forced RO desalination plants to shut down temporarily (Berktay, 2011). However, there is no evidence to date directly linking brine effluent from desalination processes with red tide formation. Berktay also notes that brine effluent produced from RO plants can have up to 200% more salt concentration than the receiving water, while the concentrate produced from MED may have only 10% higher concentration than the receiving water. Since the efficiency of RO increases as salinity reduces, this process is not considered the best suited to desalinate the increasingly saline seawater of the Arabian Gulf. Bashitialshaaer et al. (2011) has estimated that brine discharge from desalination from all countries bordering the Arabian Gulf will increase salinity by an additional 2.24 grams/liter (g/l) by the year 2050, whereas the Red Sea and Mediterranean Sea would be increased by 1.16 g/l and 0.81 g/l respectively.

DeFelice and Gibson (2013) have investigated how reduced water consumption would benefit air quality in Abu Dhabi through the reduction of greenhouse gas emissions under different scenarios. Greenhouse gas emissions from desalination plants include nitrogen oxides, sulfur dioxide, particulate matter, carbon monoxide and carbon dioxide. Ambient air pollution that contributes to annual deaths is an increasing concern in the UAE, though there are no studies that accurately measure the direct contribution of desalination to the air pollution emitted.

Determining the share of total energy used for water production at cogeneration plants is complex and ranges from 24% to 46% depending on the accounting method and power to water ratio used (MoEW, 2010), nonetheless, the MoEW (2010) have estimated that greenhouse gas production attributed to the UAE’s desalination water sector production was between 11 and 21 million tons of carbon dioxide emissions annually. This estimate does not include the large amount of energy required to pump water for distribution to consumers. DeFelice and Gibson (2013) have estimated that air pollutants and emissions would be reduced by one to five percent (1-5%) through tariff reform (price incentives), while reducing per capita water levels to 155 l/c/d would reduce emissions by ten to eleven percent (10-11%), and reducing water loss through leakage during distribution would reduce emissions by three percent (3%). The authors used three elasticity measures (-0.07, -0.27, -0.37) to model varying demand response to tariff reform.

Marginal Cost

Among the RSB’s duties is to ensure cost standardization so that the regulatory process of setting allowable profits for independent water and power producers is uniform and unbiased. RSB estimated the marginal cost (MC) of producing and supplying desalinated water (cost of supplying an additional unit of water) for the UAE is valued at AED 7.6/m3 (US$ 2.07/m3) since 2010, taking into account the variety of desalination technologies and plant costs across the UAE (MoEW, 2010; RSB, 2013). Therefore the estimated cost of producing 1.87 km3 of desalinated water in the UAE in 2013, multiplied by its MC, equals AED 14.2 billion (US$ 3.87 billion).Future desalination capital (CAPEX) and operating (OPEX) costs are not expected to decline any further than present day values due to rising equipment, raw materials, and energy costs (Ghaffour et al., 2012, pg. 206). The MoEW (2010) estimated future OPEX costs for desalination to average AED 11.01 billion (USD 3 billion) annually, and future CAPEX investments of AED 66.06 billion (USD 18 billion) required for new desalination plants, over the period 2017-2030.

Cost-Price Recovery

The UAE government paid an estimated AED 62.4 billion (US$ 17 billion) in total subsidies and transfers in 2014 (11% of government spending) (Das Augustine, 2015). Approximately 44% was allocated to water subsidies, valued at an estimated AED 27.2 billion annually (US$ 7.4 billion) in 2010, including groundwater subsidies for agriculture (AED 9.2 billion), forestry and landscaping subsidies (AED 9.5 billion), desalination subsidies (AED 8 billion), reclaimed water subsidies (AED 2.6 billion) and others, while the UAE government reclaimed only 11% from paying consumers (AED 2.9 billion) (MoEW, 2010, pg.156). Desalination and reclaimed water subsidies comprise approximately 39% of the overall water subsidy total for the UAE in previous years. The restructured 2015 water tariff in Abu Dhabi is expected to recover a substantial portion of the annual expense paid by the UAE government.

Abu Dhabi Residential Water Demand

The emirate of Abu Dhabi is the largest of the UAE's seven emirates and constitutes approximately 85% of the geographical land area of the UAE. Abu Dhabi is also the name of the capital city, and constitutes the largest of the three municipal regions of the emirate, the remaining two being the eastern region Al Ain, and the western region Al Gharbia. Abu Dhabi has historically produced two-thirds of all desalinated water produced in the UAE (Table 5). In the emirate of Abu Dhabi, the population was projected to double from 1.5 million in 2008 to 3 million residents by 2030, however by 2014 it has already passed the mid-way estimate at 2.65 million (SCAD, 2015).

Desalination Production and Consumption

As a percentage or share of the UAE's total desalination production at 1.87 km3 in 2013 (NBS, 2015), Abu Dhabi's production is significant. Desalination production in the emirate totaled 273.96 billion (UK) gallons in 2014 (ADWEC, 2015), equal to 1.245 km3, and relatively stable at 274.875 billion gallons in 2015, equal to 1.2496 km3 (RBS, 2017). According to the RSB (2017), thermal desalination accounted for 92.4% of the desalinated gross water production in 2015 (74.4% by MSF and 18% by MED), with the remaining 7.6% produced by seawater RO. Most of desalination consumption in the Abu Dhabi emirate is allocated to the greater city area, with approximately 60% of total consumption since 2012, while 27% and 13% is consumed in the Al Ain and Al Gharbia regions respectively (RSB, 2017).

The total amount of desalinated water production is distributed among various customers. According to the data provided by ADDC (2017) for 2015, residential customers constituted 47% of the emirates' total desalinated water consumption, while the remaining distribution was divided at 20% for commercial customers, 15% for agricultural customers, 15% for government customers, and 3% for industrial customers. As residential water consumers represent the largest consumers of desalinated water, the end uses of water at the home are important to note, in order to capture the extent of customers' motivation to respond to the tariff increase.

Table 7. Population distribution of Abu Dhabi municipalities in 2014 versus 2005 (SCAD, 2015).

	Abu Dhabi	Al Ain	Al Gharbia
Nationals			
2014	262.2	215.8	29.6
2005	177.6	143.9	20.2
% increase	48%	50%	47%
Non-Nationals			
2014	1,376.8	488.3	283.9
2005	631.4	300.7	88.3
% increase	118%	62%	222%
Total			
2014	1,638.9	704.1	313.5
2005	809	444.7	108.6
% increase	103%	58%	189%

Figures in thousands (‘000).

Population and Growth Rate

Table 7 shows the distribution of the national and non-national residential populations across the three municipal regions. The comparison between these figures for 2005 and 2014 reflects the booming population growth over ten years, particularly the jump in the non-national population. The non-national population increased by 118% in Abu Dhabi, 62% in Al Ain, and 222% in Al Gharbia. The growth rate for the national population between the same years was relatively consistent to all regions. The national to non-national ratio is small as nationals represented approximately 16% of the population in Abu Dhabi city, 31% in Al Ain, and 9% in Al Gharbia in 2014.

Residential Water Demand Behavior

Among the seven emirates, Abu Dhabi has the highest per capita water consumption average at 526 l/c/d, and demand for desalinated water in Abu Dhabi is expected to grow to about 1.8 km3 by 2030 (MoEW, 2010). RBS (2017) reported that an initiative was undertaken by ADEWC in 2015 to study the factors driving high water consumption among 45 villas and shaablat located in Abu Dhabi and Al Ain cities. These households, occupied by national citizens, were consuming water above the 7,000 liter per day threshold. A water audit of consumption behavior found that an estimated 47% of total water consumption was used for outdoor purposes, with 97% of this amount used for irrigation of gardens, and 3% for washing vehicles. Indoor water use consisted of 53% of total water consumption, where 31% of this amount was used in sink faucets, 26% in showers, 15% in toilets, 12% in kitchen faucets, 9% in toilet hoses, and 7% in laundry. The audit concluded that potentially 30% of water consumption could be saved by implementing a number of measures, primarily by changing irrigation practices which had the highest potential for water savings, and replacing fixtures and appliances with newer technology that managed water flow rates particularly in kitchen and sink faucets.

Future Demand Projections

The water demand forecast for the emirate of Abu Dhabi by sector shows that residential and commercial mega-projects, as well as industry, would require larger amounts of water in the near future (Figure 2). The categorical demand for villas and shaablat on the other hand are seen to show consistent demand in the projection. This low projection for villas and national households is in line with the low growth rate of Emirati nationals, but not in accordance to the average consumption behavior. The growth of water demand in the residential category highlights the urgency of water conservation in Abu Dhabi's households. Therefore it is the important to understand how the independent variables of price, household type, and government subsidy influence water demand elasticity, given the local issues.

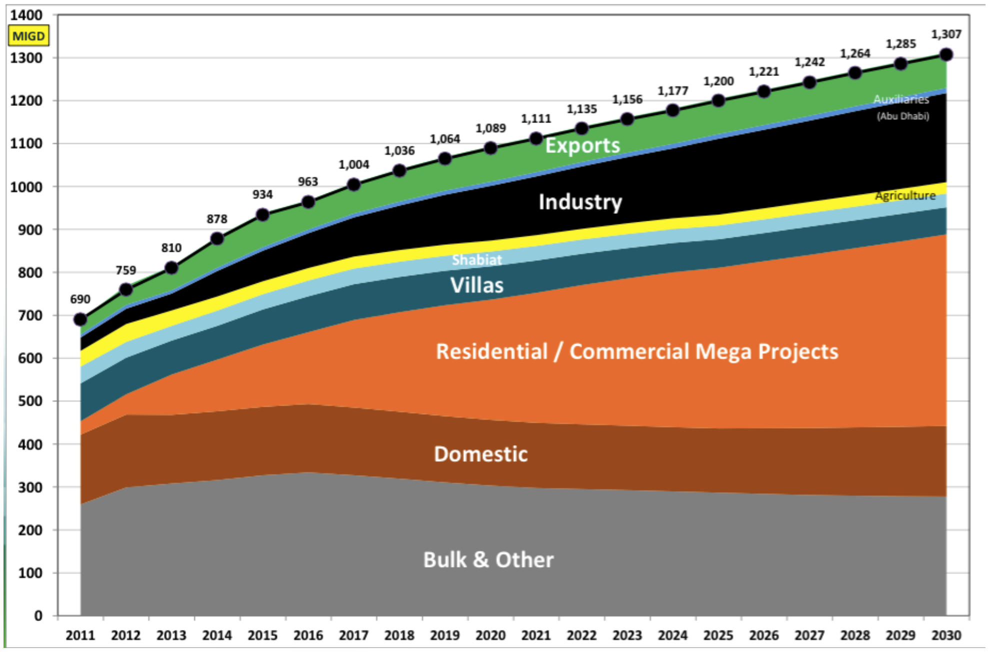

Figure 2. Abu Dhabi desalinated water demand forecast by sector 2011-2030 (ADWEC, 2013). Amounts in million gallons daily (MIGD).

Research Questions, Hypothesis and Specific Aims

It is imperative for the UAE government to invest in future desalination plants to meet the future water demand gap. Simultaneously, the UAE government needs to implement demand-side management policies in order to bring residential water consumption to global averages. These tasks require understanding the impact that the 2015 water price reform in Abu Dhabi has had on consumption demand on customers.

The primary question that this research asks is: To what degree did the 2015 residential water tariff price increase change water consumption choices of both the national and non-national residents in Abu Dhabi? There are additional key questions that branch out from price elasticity. Are there other variables that influence elasticity beyond price, and are any of these variables that the government may influence through policy?

The perspective of third degree price discrimination in this study raises interesting questions, such as, is it economically efficient, fair, or sustainable to charge nationals a lower rate for water comparing to non-nationals? How does this tariff structure impact low income households among both segments? Is it efficient to subsidize water to some groups and not others? Will national households reduce their overconsumption if the price point remains low?

On a political and economic regulatory level, the real costs of water are quite extensive, so an efficient and fair water price is necessary to incentivize conservation. Will it be possible to manage the forecasted desalination supply-demand gap through demand-side management? Is it possible to quantify the environmental costs of desalination and include them in the price of water?

At the household level, why is the Abu Dhabi per capita residential water consumption at the highest in the world, and what are the main variables that influence consumer behavior choices? Are consumers aware that residential water is heavily subsidized? What can be done to reduce overconsumption beyond price increases?

Hypotheses

The main hypothesis follows that foreign (non-national) households in Abu Dhabi will exhibit higher values of price elasticity relative to Emirati (national) households, on average and by end 2015, due to the higher marginal rate imposed through the tariff. The null-hypothesis follows that there are equal elasticity outcomes among both nationals and non-nationals. The null hypothesis may find support because 2015 is the first year that nationals have been economically incentivized to reduce water consumption.

The secondary hypothesis stems from the point that it should be possible to quantify the impact of the government subsidy on overall demand. I will attempt to calculate the government subsidy as a second price variable that impacts demand with its own elasticity measure. I hypothesized that the subsidy variable will produce an elasticity measure that shows national households would have higher values of overall demand elasticity compared to non-national households. This would mean that the subsidy variable would produce an elasticity measure above -1. This is based on the observation that the subsidy margin affects the perception of the value of water (devalued), such that when price is increased, consumers would decrease consumption at a greater rate. The null hypothesis follows that nationals would not reduce percent quantity at a level higher than the percent change in price compared to non-nationals, or in other worlds, that demand is relatively price inelastic among both groups.

Specific Aims

The specific research objectives and the associated calculations that answer the research questions are to:

1) Explore previous research in residential water price elasticity and the parameters of elasticity in the context of regional and local demand factors; this entails reviewing the previous studies and summarizing the main findings to implicate the impact of variables selected for this study
2) Explore the economic, environmental, and social costs of desalination and costs of subsidization in relation to the price of water to residential consumers
3) Develop a framework for measuring the marginal price elasticity of demand
4) Calculate price elasticity by employing a blocked design to determine which consumer segments had greater responses in water reduction as a result of the calculated weighted average price increases
5) Provide the justification for the quantification of the subsidy variable and the need for an economically efficient price of water
6) Calculate the impact of the subsidized price of water on overall demand elasticity
7) Analyze and discuss the results in order to support practical applications of the research in tariff policy adjustments

Chapter II

Methods

This study uses data that was provided by the local water agencies in the emirate of Abu Dhabi, Abu Dhabi Distribution Company (ADDC) and Al Ain Distribution Company (AADC), and aggregates the water reductions in 2015 versus 2014 for over 45,500 homes. While this data may limit analysis of the variables impacting behavior within individual households, it does allow for a greater population size sample that is not randomly selected, and less error in data collection.

In order to explore the responsiveness of the 2015 restructured water tariff price on residential consumption for the consumer segments in Abu Dhabi, I employed a linear formula to arrive at a mid-point PED estimate of the marginal price, and a natural logarithm formula to estimate the impact of the government subsidy. This study relied on ADDC (2016) data regarding the percent reductions in Abu Dhabi's representative sample household consumption for each consumer segment and within the two-step inclining block structures over the periods 2014 and 2015. Therefore I calculated the weighted average marginal price (AMP) paid by segments at each of the two inclining blocks. Data was provided to me in November 2016 by a director at the AADC. A standard Excel template was used to arrange the data and calculate where indicated.

Calculating Price Elasticity of Demand

Applying the price point formula for own-price PED (PED = (Q1 — Q0 / Q0) / (P1 — P0) / P0) to the given data for Abu Dhabi's water demand would void the result of PED for this study and create invalid results. This is due to the fact that the initial price (P0) for residential water paid by Emiratis is zero, therefore, the denominator to the formula would equal zero. Another formula that arrives at arch elasticity or mid-point PED by way of estimation of averages where PED = [(Q1 — Q0) / (Q1 + Q0)] / [(P1 — P0) / (P1 + P0)]. This mid-point price formula alleviates the discrepancy for the fully subsidized price in the available data set. Thus the formula I employed to calculate PED for this study is:

$$PED = \Delta Q \ / \ [(P1 - P0) / (P1 + P0)]$$

The symbol P0 represents the marginal price paid in 2014 and P1 represents the new marginal price paid in 2015. The change in quantity demanded (ΔQ) over the same years was inputted from the data provided by AADC (2016).

Sample Population Methodology

The data sets were extrapolated from the respective databases of the AADC and ADDC, then screened following the same methodology, in order to obtain a stable sample population from each localized database. These separate data sets were analyzed for each distribution area separately as well as combined for emirate-wide results in percent change in water consumption quantity. The following data sets show that results are specific to the regions of Abu Dhabi and Al Ain municipalities separately as well as aggregated for total changes in water consumption for the whole emirate of Abu Dhabi. The sample population compiled data from a stable population that did not move or significantly change consumption over the three year period (start 2013 to end 2015). The percent changes in residential water consumption were 2015 data compared to 2014 for each consumer segment.

Both distribution companies have applied the same data screening methodology to compile an accurate population sample with no errors or anomalies. The screening methodology assured that customers continuously occupied the same address for over three years (starting 2013) with regular water meter readings, were not classified as exempt from paying for water usage in 2015, and had no greater than +25% or -75% change in water usage from 2014 to 2015. This ensured that occupants did not move households and were used to consuming water in the same household for a period of two years prior to the 2015 water tariff increase.

A combined total of 82,799 water consumers across the emirate of Abu Dhabi passed the screening requirements and were analyzed by the water companies jointly, where 55% of the total sample population represented residential consumers, translating to 45,539 households. This residential customer sample population also represented 30.2% of total water consumed in 2015 by households across Abu Dhabi emirate, thus, the sample population size can be considered robust for statistical analysis. Residential consumers within each distribution company were segmented by premise type (villa, apartment, or shaablat), tariff type (national or non-national), and green or red band consumption. It is not possible to account for each individual household's income due to the aggregated dataset. Nonetheless, it is possible to infer generalized observations of income based on the property type, as well as distribution of properties within the greater metropolitan areas of Abu Dhabi city and Al Ain. Shaablat are exclusively inhabited by Emirati nationals and are government subsidized housing, therefore correlate to lower income households among the nationals' segment.

Table 8. Residential water consumption % change by premise type, 2014-2015 (ADDC, 2016).

	Property Type	AADC	ADDC	Emirate-wide
Nationals	Apartment	-14.2%	-12.2%	-12.5%
	Villa	-30.9%	-21.2%	-25.6%
	Shaablat	-21.5%	-25.9%	-24.0%
All Nationals		-26.5%	-20.8%	-23.0%
Non-Nationals	Apartment	-18.6%	-14.2%	-14.6%
	Villa	-16.6%	-21.2%	-19.7%
All Non-Nationals		-17.0%	-17.1%	-17.1%
Total		-25.3%	-19.8%	-21.5%

Data on Quantity Reductions for Consumer Segments

Table 8 shows the calculated percent reduction in water quantity consumed in 2015 against 2014 values by property type for each consumer category. These figures represent the percent change in quantity consumed used for the calculation of PED.

Calculating Weighted Marginal Price Averages

Table 9 shows the distribution of residential customers within green or red band consumption for 2014 and 2015 as provided by the water companies. The AADC and ADDC have designated color bands to indicate the water use quantity at threshold limits. The green band reflects an acceptable consumption threshold that is charged at the starting marginal price. The red band reflects overconsumption past the threshold quantity and therefore charged at the high marginal price. The 2015 threshold quantities and corresponding tariff rates for each block marginal price respective to each consumer segment is shown in Table 1.

Table 9. Comparison of green and red band consumption, 2014-2015 (ADDC, 2016).

			Green Usage			Red Usage		
	Property Type	Year	AADC	ADDC	Emirate-wide	AADC	ADDC	Emirate-wide
Nationals	Apartment	2014	27.8%	29.0%	28.8%	72.2%	71.1%	71.2%
		2015	37.8%	35.1%	35.6%	62.2%	65.0%	64.4%
	Villa	2014	30.9%	45.3%	38.8%	69.1%	54.7%	61.2%
		2015	48.9%	56.1%	53.0%	51.1%	43.9%	47.0%
	Shaablat	2014	63.2%	47.8%	54.5%	36.8%	52.2%	45.5%
		2015	76.5%	65.6%	71.2%	23.5%	34.4%	28.8%
Non-Nationals	Apartment	2014	48.9%	55.5%	54.9%	51.1%	44.5%	45.1%
		2015	61.0%	63.4%	63.3%	39.0%	36.6%	36.7%
	Villa	2014	68.8%	63.3%	65.1%	31.2%	36.7%	34.9%
		2015	86.3%	82.1%	83.7%	13.7%	17.9%	16.3%

Throughout 2014, all national households consumed water at no cost, while non-nationals paid a flat rate of AED 2.2/m3 at every level of quantity consumed. This means that for 2014 where there was a flat rate fee, the average marginal price (AMP) paid for nationals would equal zero, while the AMP paid by non-nationals would equal AED 2.2/ m3, regardless of the customers' quantity consumed. The AMP paid in 2015 changes with the introduction of the two-block inclining structure.

In order to determine the AMP paid in 2015 for each customer segment, I calculated a weighted average by combining the respective 2015 figures in Table 9 with their respective marginal rates shown in Table 1. For example, 35.6% of Emirati nationals living in apartments at the emirate-wide total consumed water at the marginal price rate of AED 1.7/m3 (Table 9), while 64.4% consumed water at the marginal price rate of AED 1.89/m3, in 2015. Therefore the weighted AMP equals (0.356 x 1.7) + (0.644 x 1.89) = 0.6052 + 1.21716 = 1.82236, or AED 1.82/m3 is determined as the weighted AMP paid by this consumer segment in 2015.

Percent Change in Red Band Consumption

It is important to note the percent change in red band consumption from 2014 to 2015 for each consumer segment (Table 10). This indicates the percentage of the sample population that reduced water usage from upper to lower boundary levels. Red band reduction reflects the effectiveness of the inclining block tariff structure in charging a higher rate for higher than average levels of consumption, i.e. the price incentive for reducing consumption. The percent reduction in red band consumption for each level was not used for the PED calculation directly but supports the discussion.

Table 10. Percent change in red band consumption 2015 versus 2014 (ADDC, 2016).

		AADC	ADDC	Emirate-wide
Nationals	Apartment	-13.9%	-8.6%	-9.6%
	Villa	-28.0%	-19.8%	-23.3%
	Shaablat	-36.1%	-34.1%	-36.7%
Non-Nationals	Apartment	-23.6%	-17.9%	-18.7%
	Villa	-56.1%	-51.3%	-53.2%

Quantifying the Government Subsidy Impact on Demand

The difference between the low price that the customer pays and the high cost of desalinated water production represents additional benefits to the consumer. The excess benefits are not quantified in the undervalued marginal price that customers have paid. The excess benefits to the customer are congruent (equal) to the efficiency losses that the government accrues by devaluing the price of water through the subsidy. The aim is to determine how paying a portion of the cost (undervalued water) can be measured as a deviation from the point of allocative efficiency, and therefore the impact to the overall perception of fair value, for each consumer segment.

When the 2015 tariff structure was applied, the marginal price curve would incline in line with the two-block tariff rate, as seen in Figures 3 and 4 in the curves labeled MP 2015. Figure 3 shows the theoretical marginal price curves in 2014 and 2015 for non-national households while Figure 4 shows the same for national households.

Since the price of water was fully subsidized for national households in 2014, the marginal price curve for 2014 is seen overlapping the x-axis at the price of zero (Figure 4). A demand curve at the price of zero does not accurately reflect actual demand or the customer's willingness to pay for water. The marginal cost of desalinated water is drawn at AED 7.6, as seen by the dotted red line (MC) in Figures 3 and 4.

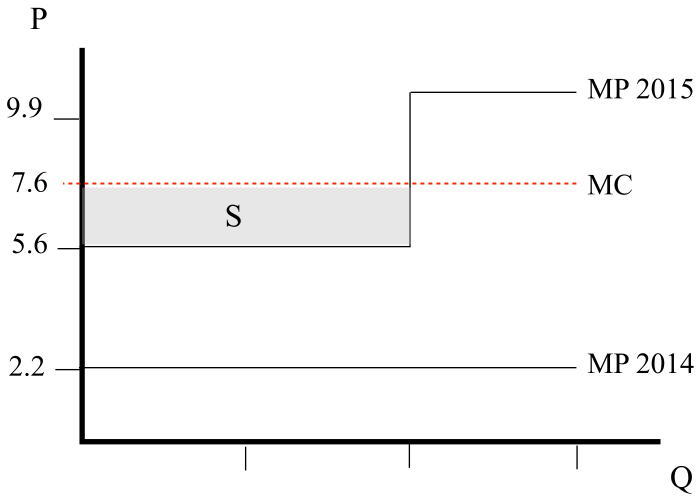

Figure 3. MP/MC as *S* for non-nationals.

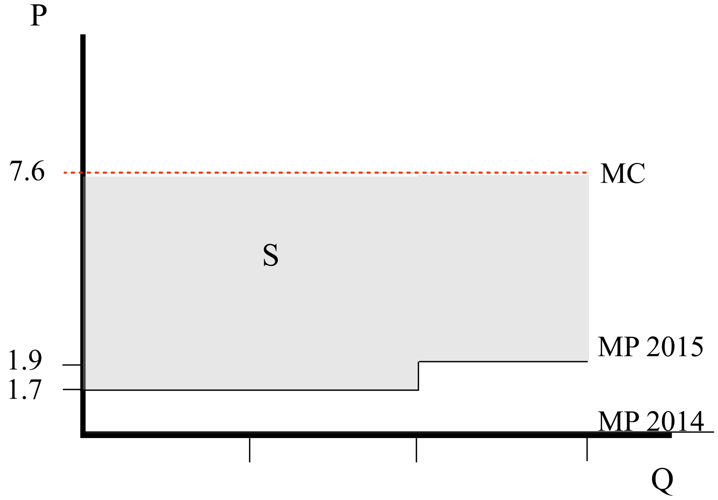

Figure 4. MP/MC as *S* for nationals.

The excess benefits that customers received by paying for undervalued water is marked by the shaded area between the marginal cost and 2015 marginal price curve, and is denoted as *S* for the subsidized area.

One way to consider the mathematical explanation of *S* is to first consider the ratio form MP:MC. This is equal to MP/MC, or the percentage of the cost of water that customers did pay. In other words, this defines the small portion of the marginal cost that customers have paid through their marginal rate, or what the consumer perceives as the economic marginal value. The area of *S* is not just a representation of the excess benefits that the customer does not pay for, but can also be considered the consumer's perceived value for each additional drop when not paying the full cost of water, i.e. paying an undervalued price.

By calculating the area of *S* mathematically, the outcome derivative will represent the excess benefits at no price to the consumer, or a measure of the perceived value of water as an effect of the government subsidy. In order to arrive at the area of *S*, I applied a natural logarithm (ln) to the subsidy ratio variable (MP/MC) in the following formula:

$$S = \ln\left(MP^{2015} / MC\right)$$

The following calculations provide a further explanation of *S*. At the allocative or economically efficient price of water, the price and cost would be equal, therefore the MP/MC ratio would be equal to 1. The natural logarithm (ln) of 1 is equal to zero. This means there would be no area between the two curves, or in other words, no difference in the price and cost. By considering a price that is higher than cost, such as 1.5 times greater than cost, the ln(1.5) is a positive decimal (0.41). This is representative of the area above the MC curve and under the MP curve, as price is higher than cost, and indicates the area of the price of water that is over the economically efficient intersection (overvalued perception). Considering a price that is lower than cost, where the MP/MC is a fraction, the ln will always result in a negative number (undervalued perception). This indicates the area between the MC curve and MP curve that does not meet at any point to intersect for economic efficiency, and this also represents the degree that water is undervalued. For a high government subsidy, where the customer pays only 20% of cost, the ln(0.20)= -1.61. For a low government subsidy, where the customer pays 95% of cost, the ln(0.95)= -0.05. As the price-cost ratio ratio moves closer to 1, thereby reducing the government subsidy, the natural logarithm outcome will move closer to 0, which illustrates the reduced area between MC and MP, as ln(1)=0.

The natural logarithm is also applied because it calculates the price-cost ratio variable as a direct expression of elasticity where elasticity is equal to 1. This is based on the property for natural logarithm where $\ln(x^y) = y\ln(x)$ for $x>0$. The y variable in this equation represents the target elasticity. In the demand curve with the elasticity of -1, a percent change in price would produce the equal inverse percent change in quantity, which is economically efficient. This follows that the derivate of x represents the elasticity needed to grow the variable (price-cost ratio) to efficient demand.

As a final step, I add the outcome of the calculation of *S* to the calculated PED for each consumer segment respectively to determine a second elasticity measure of demand. This second measure of elasticity aims to identify a more accurate reflection of the responsiveness of the demand curve in 2015 when the impact of the undervalued price paid by various consumer segments is factored as a variable that has impacted the actual quantity demanded. Accounting for excess benefits is expected to draw a more accurate representation of actual demand.

Chapter III

Results

The formulas described in the previous chapter provided the findings for 1) the weighted average marginal price (AMP) paid in 2015 and mid-point percent change in price, 2) price elasticity of demand (PED), 3) the subsidy impact on the elasticity of efficient demand, and 4) the combined impact of marginal price and subsidy elasticity on the overall demand curve elasticity. The calculations resulted in the following outcomes.

Weighted Average Marginal Price in 2015

The introduction of the tariff in 2015 meant that non-national customers were subjected to two different price increases, a 170% increase for those in the green band, and a 350% increase for those in the red band. Accounting for the actual distribution of consumption within the red and green bands for each consumer segment (Table 9) increased the accuracy in measuring PED. The AMP results showed that both national and non-national customers residing in apartments paid a higher AMP than their respective counterparts residing in villas (Table 11). Though customers residing in apartments paid a higher marginal rate on average, their counterparts residing in villas paid a higher average price (total water bill), as a factor of the property size. The percent change in price for each segment is determined by the mid-point formula (Table 12).

Table 11. Weighted average marginal price paid.

	Property Type	Year	AADC	ADDC	Emirate-wide
Nationals	Apartment	2014	0.00	0.00	0.00
		2015	1.82	1.83	1.82
	Villa	2014	0.00	0.00	0.00
		2015	1.80	1.78	1.79
	Shaablat	2014	0.00	0.00	0.00
		2015	1.74	1.77	1.75
Non-Nationals	Apartment	2014	2.20	2.20	2.20
		2015	7.49	7.40	7.40
	Villa	2014	2.20	2.20	2.20
		2015	6.49	6.66	6.59

Figures in AED, rounded to two decimals.

Table 12. Percent change in marginal price (mid-point).

	Property Type	AADC	ADDC	Emirate-wide
Nationals	Apartment	1.00	1.00	1.00
	Villa	1.00	1.00	1.00
	Shaablat	1.00	1.00	1.00
All Nationals		1	1	1
Non-Nationals	Apartment	0.55	0.54	0.54
	Villa	0.49	0.50	0.50
All Non-nationals		0.52	0.52	0.52

Figures rounded to the nearest two decimals.

Calculated Price Elasticity of Demand

The percent change in marginal price (MP) was applied to the PED formula to calculate the first estimate of PED for each customer segment (Table 13). The findings showed that marginal price PED ranged between -0.12 to -0.42 overall. These values fell within the range of PED determined by Abu Qdais and Al Nassay (2001) at the lower boundary of -0.10, as well as the long term PED estimates for Abu Dhabi modeled by DeFelice and Gibson (2013) at the upper boundary of -0.37 to -0.27. These findings were also within the ranges determined by global studies on residential water PED (Table 2).

Table 13. Calculated marginal price PED for Abu Dhabi.

	Property Type	AADC	ADDC	Emirate-wide
Nationals	Apartment	-0.14	-0.12	-0.13
	Villa	-0.31	-0.21	-0.26
	Shaablat	-0.22	-0.26	-0.24
All Nationals		-0.27	-0.21	-0.23
Non-Nationals	Apartment	-0.34	-0.26	-0.27
	Villa	-0.34	-0.42	-0.39
All Non-Nationals		-0.33	-0.33	-0.33

Figures rounded to the nearest two decimals.

The marginal price PED was higher for non-nationals at every segment when results were compared between non-nationals and nationals for each property type within the same area. Therefore, the first hypothesis of this study that predicted non-nationals to exhibit greater price elasticity relative to nationals is accepted. The median marginal price PED at -0.23 for nationals was less than the median of non-nationals at -0.33.

Government Subsidy Impact on Elasticity

The subsidy variable (*S*) was calculated by applying a natural logarithm (ln) to the price to cost ratio (Table 14). By adding together the 2015 price elasticity and 2015 subsidy elasticity results, a new measure of the elasticity of demand is drawn (Table 15).

Table 14. Calculated subsidy variable (*S*) elasticity.

	Property	Year	MP/MC			LN (MP/MC)		
			AADC	ADDC	Emirate	AADC	ADDC	Emirate
Nationals	Apartment	2014	0.00	0.00	0.00	-Infinity	-Infinity	-Infinity
		2015	0.24	0.24	0.24	-1.43	-1.43	-1.43
	Villa	2014	0.00	0.00	0.00	-Infinity	-Infinity	-Infinity
		2015	0.24	0.23	0.24	-1.44	-1.45	-1.45
	Shaablat	2014	0.00	0.00	0.00	-Infinity	-Infinity	-Infinity
		2015	0.23	0.23	0.23	-1.47	-1.46	-1.47
Non-Nationals	Apartment	2014	0.29	0.29	0.29	-1.24	-1.24	-1.24
		2015	0.99	0.97	0.97	-0.01	-0.03	-0.03
	Villa	2014	0.29	0.29	0.29	-1.24	-1.24	-1.24
		2015	0.85	0.88	0.87	-0.16	-0.13	-0.14

Figures rounded to the nearest two decimals.

Table 15. Combined elasticity for Abu Dhabi.

		Standard PED			Combined Demand Elasticity		
	Property	AADC	ADDC	Emirate	AADC	ADDC	Emirate
Nationals	Apartment	-0.14	-0.12	-0.13	-1.57	-1.55	-1.55
	Villa	-0.31	-0.21	-0.26	-1.75	-1.66	-1.70
	Shaablat	-0.22	-0.26	-0.24	-1.69	-1.72	-1.71
Median		-0.27	-0.21	-0.23	-1.67	-1.66	-1.68
Non-Nationals	Apartment	-0.34	-0.26	-0.27	-0.36	-0.29	-0.30
	Villa	-0.34	-0.42	-0.39	-0.49	-0.55	-0.54
Median		-0.33	-0.33	-0.33	-0.41	-0.41	-0.41

Figures rounded to the nearest two decimals.

Contrary to the standard PED results, the combined price and subsidy elasticity measures showed that the national segment exhibited a higher elasticity at a median of -1.68, which is relatively elastic, compared to the non-national median at -0.41, which is relatively inelastic (Table 15). The second hypothesis of this study, where the subsidy variable elasticity outcome was expected above -1 for the national category, is confirmed. The contribution of the high government subsidy in the national category results in the devaluation of water in relation to its efficient price. Nationals would therefore reduce water consumption at a greater percentage than the percent increase in price, compared to non-nationals, until the point in time that the marginal cost of water is reflected in the marginal price.

Chapter IV

Discussion

Both the primary and secondary hypotheses are confirmed by the elasticity results for the marginal price and government subsidy variables (Table 15). When price elasticity of demand (PED) was calculated independently of the cost of water, then PED was found to be greater among non-nationals than nationals, since non-nationals were more economically incentivized to reduce water consumption as they paid a higher tariff rate. When the government subsidy variable (*S*) was calculated for its effect on overall demand elasticity, nationals were found to be relatively elastic to reducing water consumption compared to non-nationals. This indicated the extent to which water is undervalued due to *S* and its larger role on the perception of the price of water. The combined elasticity calculation provided more insight into the short-term impact of a price increase on residential water consumption in the emirate of Abu Dhabi.

Subsidy Impact on the Perception of Price

For nationals in the year 2014 in all property types, *S* was found at negative infinity (Table 14), because water was subsidized at 100%. The outcome (negative infinity) reflects a perfectly elastic curve, or a straight horizontal line, such as the marginal price line for nationals in 2014 (Figure 3). Perfectly elastic demand is not a desirable demand curve for the utility provider, as in theory, any change in price would cause demand to fall to zero. This does not mean that nationals would not be willing to pay for water, rather, would not be economically incentivized to value water at its efficient cost. When nationals were introduced to paying for water in 2015, the impact of *S* on overall elasticity was measured by the parameter of allocative efficiency (Table 14).

Similarly for non-nationals, the impact of *S* on demand in 2014 was an elasticity above -1, reflecting the case that when non-nationals paid only 29% of the water cost, the category was relatively elastic or responsive to a price increase. When the subsidy to non-nationals was significantly reduced in 2015, the impact to demand was a very low *S* elasticity, at a median of -0.03 in apartments and -0.14 in villas. This indicated that *S* produced a slightly greater effect of undervaluing water among non-nationals residing in villas relative to those in apartments in 2015. Residents of apartments displayed lower elasticity than did villas, particularly among non-nationals, as they received less quantity of subsidized water allocated by the consumption threshold.

Comparison between National and Non-national Segments

By end 2015, only 16% of non-nationals in villas remained in the red band, versus 47% of nationals in villas, emirate-wide (Table 9). In comparison, only 36.7% of non-nationals in apartments remained in the red band by end 2015, versus 64.4% of nationals (Table 9). There is a large headway for the national category to reduce red band overconsumption.

The marginal price PED results for nationals was between 0.10 to 0.14 points lower (less elastic) than respective non-national segments in most segment comparisons

(Table 13). In two comparisons, the difference in price elasticity extends to 0.20. The 0.20 point difference in marginal price PED was found in the comparison between non-nationals and nationals residing in villas in Abu Dhabi municipality, and non-nationals and nationals residing in apartments in Al Ain municipality (Table 13). To explain this large difference as a function of price requires the outcomes in overall quantity reduction and red band reduction (Tables 8 and 10 respectively).

In the Abu Dhabi villa segment comparison, both nationals and non-nationals had reduced overall water consumption by 21% (Table 8), though the reduction in red band consumption among non-nationals at 51% was significantly higher than the red band reduction in nationals at 20% (Table 10). In Al Ain, both nationals and non-nationals living in apartments had reduced water consumption by 14% and 19% respectively, while the reduction in red band consumption was higher for non-nationals at 24% versus 14% for nationals. Non-nationals were more economically incentivized to reduce overconsumption as a function of the marginal price variable primarily.

On the other hand, the low PED variance at just 0.03 was found when comparing respective residents of villas in Al Ain, where PED for nationals was at -0.31 versus the non-national PED at -0.34. Nationals residing in villas in Al Ain had the greatest reduction in water consumption quantity among all other nationals at 31%, which was higher than the consumption reduction among non-nationals at 17%, for the same category (Table 8). Further, nationals showed a high reduction in red band reduction at 28%, though not as high as non-nationals in this segment where red band reduction was highest at 56% (Table 10). This means that although non-nationals did not reduce as much respectively in quantity, they showed a greater response to reducing their red band or overconsumption, registering a reaction to price.

Overall, the non-national segment residing in villas showed a relatively high PED, at -0.39 emirate-wide. This relatively high PED is in line with the 53% percent reduction in red band consumption by this segment. Nationals residing in villas also displayed a relatively elastic PED at -0.26, and red band reduction of 23%, at the emirate-wide average.

Comparisons Within Property Types and Regions

When comparing elasticity outcomes within the same citizenship category, the household type and income variables were important to consider alongside price, as price was equal within the same citizenship category. The comparison of PED response between villas and apartments showed a high difference among all segments and regions, with the exception of non-nationals in Al Ain where the PED was equivalent.

As average incomes were lower in the municipality of Al Ain than that of Abu Dhabi for both citizenship categories, it was assumed that Al Ain residents would be more economically incentivized to reduce greater consumption levels, and display more elastic PED, than Abu Dhabi residents. Nationals residing in villas in Al Ain showed a PED of -0.31. the highest among the national segment, for example (Table 15). This was the overall trend with two exceptions, first among nationals residing in shaablat, and second among non-nationals residing in villas. Nationals residing in shaablat in Abu Dhabi had consumed at the red band at a higher average in 2014 (Table 8), and reduced water to a greater extent than their counterparts in Al Ain (Table 9). Regarding non-nationals in villas, those in Abu Dhabi continued to pay a higher average marginal rate (Table 11) and consume more water in the red band than their Al Ain counterparts (Table 9), but displayed greater levels of water reduction overall (Table 8). Therefore, though incomes were higher in Abu Dhabi, these segments had more overconsumption to reduce than their respective counterparts in Al Ain.

Conclusions

The price of residential water plays a key role in achieving economic and environmental efficiency goals. This study investigated the parameters associated with residential water consumption, the economic inefficiencies associated with the government subsidy devaluation and consequent overconsumption of water, and the environmental impacts of existing desalination processes in the UAE. This study also investigated what has been done to reduce the country's high residential water footprint through initiatives other than price. The Abu Dhabi utility company has educated consumers on price changes, conducted awareness campaigns and consumption audits, and implemented green building codes and smart meter systems. However, price controls are the most economically effective tool to managing the country's enormous water footprint and ingrained water consumption behavior. The 2015 water tariff impacted the consumption choices of both national and non-national residents of Abu Dhabi to varying degrees of reduction. The respective elasticity outcomes for each group would assist in projecting future consumption and structure tariff responsiveness with more confidence.

Policy Recommendations

The historical Abu Dhabi per capita residential water consumption is the highest in the world, nonetheless, the UAE government restructured the water tariff for three consecutive years over 2015 to 2017 with the aim of achieving full cost recovery, at least from non-national consumers. Non-nationals represent the largest population segment in Abu Dhabi emirate, at 81% of the population in 2016. The allocative efficiency of water addresses the value of any use of water in relation to alternatives uses of the same water. Social concerns of justice and equity are considered in the allocation of resources, but these can have subjective contexts. While one perspective may consider the restructured Abu Dhabi tariff rates as discriminating for non-nationals, another perspective may consider it fair to distinguish among groups of consumers for sociopolitical interests. This study has reviewed the political price of water and the demonstrated strength of the UAE economy to institutionalize price increases among the greater population of non-nationals. The evidence shows that the price discrimination tariff structure is being adopted by neighboring countries. After decades of providing free water, the example that the Abu Dhabi government provided to its neighbors is that it is politically effective to introduce water price increases in phases, and maintain economic transparency and communication with consumers.

The question remains whether the Abu Dhabi government will equalize the water tariff price among nationals and non-nationals in the future. By applying the principles of economic efficiency through the government subsidy (*S*) variable, one of the main findings of this study showed that the combined impact to demand in the national segment is relatively elastic. In this case, an increase in price would result in a greater percent decrease in consumption, which is effective in reducing overconsumption in the national segment in the short-term. This is desired up to the point in time that the marginal cost of water is reflected in the marginal price. Over a long-term, a relatively elastic demand curve would generate losses to the utility company, since the percent reduction in consumption would be greater than the percent reduction in price. An increase to the water price for national households could result in a significant drop in demand from this category. As desalination production is reliant on economies of scale and requires stable demand, a fluctuating demand scenario would complicate desalination production in the Al Ain or Al Gharbia regions, where national households are in higher density yet incomes are low. A threat to the reliability of water in the municipal regions in this scenario would stir a public outcry from the national segment.

The two-block inclining structure of the water tariff showed some efficacy in reducing consumption. Even while maintaining a small margin of the government subsidy among non-nationals. This shows that the price of water can remain subsidized as long as consumption achieves the designed target consumption rate of 200 l/d/person. The current threshold for apartments at 700 l/day sufficiently covers the requirement for a family of 3.5 persons consuming water at the target. However, the threshold for villas at 5000 l/day for non-nationals and 7000 l/day for nationals would meet the requirements for a family of 25 or 35 persons respectively, given the 200 l/day target. Customers residing in villas have between seven to ten times more water to consume relative to apartments before being charged at the red band rate. Reducing the high threshold for villas among both categories is an alternative to increasing the price of water.

The future challenge for the UAE government concerning water demand management is to continue quantifying the real cost of water to ensure that the price to consumers alleviates the risks of environmental and future scarcity costs. Desalinated water is not just required by households, but also by all consumers including industrial and government, and increasingly agriculture. The efficient allocation of water across these segments requires a measured approach to the benefits and return of the value of water and its contribution to society, the economy, and the environment.

Research Limitations and Further Study

Further research on the relationship between water price and environmental impacts would help to quantify the high financial and environmental costs of desalination. Only a few studies have been published that investigate the environmental impacts of desalination in the Arabian Gulf, and specifically, only one that specified the environmental costs of forecasted water price policy on greenhouse gas emissions in Abu Dhabi. The aim of promoting sustainable water management is to reduce the high costs of the consequent environmental degradation. The absence of such a strategy would result in higher environmental costs. With this estimate of PED and subsidy elasticity, it is possible for the country's planners to develop tariff structures that achieve the desired goal of water reduction. Water demand measures should be targeted at all groups in order to be consumed efficiently and effectively for the entire population.

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