PRICE WORKS: SEASONALITY AND DETERMINANTS OF TORONTO'S AMAZING DECLINE IN WATER DEMAND

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Abstract

Over the past eight years, the City of Toronto has experienced a dramatic drop in both its absolute and per capita water consumption rates. Water demand in Toronto has declined by 14% overall and by 24% on a per capita basis over the same period. At first glance, this appears to be a huge success for the City's water conservation efforts. This study investigates the cause of the decline by exploiting two unique datasets to decompose the effects of weather and seasonal variation, infrastructure improvements and varying price structures. While seasonal variation and improvements in infrastructure jointly play a large role in determining short run water demand, this study finds that, even though consumers in the City of Toronto have inelastic demand curves, the majority of the decline in water consumption is attributable to the increasing price of water.

1. Introduction

In a world with a rapidly growing population and a scarce supply of natural resources, Canada is fortunate to enjoy access to the some of the largest freshwater lakes in the world. As the largest city in Canada, the City of Toronto has a unique challenge of providing safe, potable water to over 3.3 million residences and businesses in Toronto and nearby regions. With over 2.62 million people residing in the City of Toronto alone, Toronto Water manages a distribution network consisting of over $28 billion worth of infrastructure, including over 6,000 kilometers of underground pipes, 22 major water pumping stations and a variety of above-ground and underground water storage facilities[1].

Municipal water consumption planning continues to receive attention due to the high cost of infrastructure construction and maintenance, maintaining potable water quality and ensuring that there is adequate supply to meet demand. One of the biggest challenges of providing water to such a large population is being able to support the increased seasonal demand that accompanies the warm summer months. Understanding the fluctuations of seasonal water demand is critical to be able to continue to provide good quality water to Toronto's expanding population.

Over the past several years, the City of Toronto has experienced a dramatic drop in both its absolute and per capita water consumption rate. Water demand in Toronto has

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[1] Information from Toronto Water available online at http://www.toronto.ca/water (Accessed 7/1/2013)

declined by 14% from an average of 270,898,234 gallons per day in 2005 to 232,728,154 gallons per day in 2012. However, consumption has fallen by approximately 24% on a per capita basis over the same period. At first glance, this appears to be a huge success for the City's water conservation efforts. This study determines the cause of the decline by exploiting two unique datasets to decompose the effects of weather and seasonal variation, infrastructure improvements and varying price structures.

First, daily water consumption data was obtained from the City of Toronto to examine the determinants of water demand in the short run, with a focus on the impact of seasonal variation and improvements in infrastructure. The presence of precipitation has more of an impact on demand than the amount of precipitation, with any precipitation leading to a 1% decline in daily water consumption. Similarly, any precipitation over the past five days leads to a 1.3% decline in daily water consumption. Infrastructure improvements do not appear to be a significant determinant of the decline in water consumption, as the decline in watermain breaks only accounts for 0.06% of yearly water consumption.

Second, the effect of price on water demand is determined by using data on Toronto's 44 wards over a period of eight years. By exploiting cross-ward variation and controlling for the time trend, the price elasticity of demand for water is calculated for residential and commercial consumers. Based on the estimates obtained and given that the price of water has increased by 70% over the relevant time period, the demand for water is expected to decline by 36.4%. On a per capita basis the actual decline in water demand is 24%. This leads to the conclusion that price is still the most effective water conservation policy available to governments.

Very little research has been conducted to understand the determinants of municipal water demand and consumption in the Canadian context. This paper extends the existing literature in several ways. First, this paper uses unique datasets that are rare to find in the existing literature. Daily frequency for water consumption data is difficult to obtain from municipal water providers, and the dataset used for this analysis is not publically available. Furthermore, the Canadian literature on water demand does not have any contributions using a daily frequency for water consumption. In addition, using ward-level data for examining water consumption in small districts in a Canadian city has not been done before. Second, an examination of the daily water consumption data reveals a surprising phenomenon for Canada's largest city – there has been a huge decline in water demand even though the population has been growing steadily. Third, price elasticities are estimated for both residential and commercial consumers, which is rare to find in a Canadian context. Finally, this paper identifies the water conservation capabilities of price increases.

The remainder of this paper is organized into several sections. Section 2 provides background information on Toronto Water, including Toronto's water infrastructure, price schedule and climate conditions. A review of the existing literature is provided in section 3. Section 4 describes the two datasets used for analysis. Short run water demand is explored in section 5 and the role of prices is analyzed in section 6. A discussion of key insights takes place in section 7 and concluding remarks are summarized in section 8.

2. Background on Toronto Water

Infrastructure and Operations

Toronto Water delivers safe drinking water, collects and treats wastewater and provides stormwater management services to the City's former municipalities – now considered communities under the umbrella of the City of Toronto – including East York, Etobicoke, North York, Scarborough, Toronto, York and portions of the southern Region of York. The population of Toronto has experienced significant growth, growing at a rate of 4.5% over the period of 2006 to 2011 according to Statistics Canada 2011 census data.

The City of Toronto's source of water is Lake Ontario. Given that the City of Toronto is built on the side of a hill, all of the water distributed in the city is pumped up by 22 major water pumping stations. The top ground-level elevation of the City of Toronto is 133 meters higher than Lake Ontario, presenting a challenge of providing adequate water pressure to the entirety of the City's population. The water pumping stations use pumps that use centrifugal force, meaning that there are no pulsations in water pressure and water pressure is entirely dependent upon water demand.

The entire system is managed at the Transmission Control Center that uses sophisticated electronic equipment so that all pumping stations can be monitored, controlled and integrated with other pumping stations in the same pumping district. The operator at the control center is able to maintain a proper balance between all of the pumping stations in a district, allowing total control over balancing water supply and demand while ensuring adequate water pressure throughout the network, 24 hours a day[2].

Price Schedule

The City of Toronto's water pricing schedules have changed over the relevant time period. Prior to 2008, the price of water was based on a seven-step block rate structure. In 2008, following a review of the block rate structure, Toronto adopted a general rate for all water consumed for consumers using less than or equal to 6,000 cubic meters[3]. To encourage water efficiency and industrial expansion, the City of Toronto decided to offer a second rate to industrial consumers that met specific guidelines, including consuming in excess of 6,000 cubic meters of water and the submission of a comprehensive water conservation plan.

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[2] Information obtained from Water Supply – Pumping available online at http://www.toronto.ca/water (Accessed 7/1/2013)

[3] More information on the restructuring of Toronto's water rates is available online at http://www.toronto.ca/finance/waterrates.htm (Accessed 7/1/2013)

Climate

The City of Toronto enjoys a relatively mild climate due to its proximity to Lake Ontario. According to Environment Canada's Climate Normals (1971-2000), the daily average temperature reaches its highest point in July and lowest in January, with a range between 20.8 degrees Celsius and -6.3 degrees Celsius. Yearly precipitation is fairly evenly distributed with slightly higher precipitation during the May through September period and a total amount of precipitation averaging 792.7 mm.

Water consumption in Toronto

Residential water usage accounts for approximately 51% of water consumption in the city, with toilets being the highest indoor water user, accounting for 28% of indoor water use. Daily water demand averages approximately 1,194 megaliters per day with maximum daily water demand reaching as high as 1,885 megaliters. The maximum daily water demand consistently tends to occur in July, the warmest month in Toronto. Every year there are approximately 1,500 watermain breaks, with the average age of watermains being approximately 54 years old[4].

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[4] Water consumption information obtained from Quick Facts available online at http://www.toronto.ca/water (Accessed 7/1/2013)

3. Literature Review

Previous research has found that the demand for water is relatively inelastic since there are no substitutes for water for basic uses. Regardless, prices can play an important role in managing the demand of water when the elasticities are nonzero. In addition, consumers appear to have a low level of perception with regards to the rate structure, as studies have found that the average water bill typically only represents a small proportion of household income (Chicoine and Ramamurthy 1986).

The effects of the local weather and climate are important determinants of water demand on any given day. There are many different ways of incorporating climate effects in models. Foster and Beattie (1979) incorporated precipitation during the growing season in their model. Griffin and Chang (1990) used summer precipitation, cooling degree days based on the extent to which the mean temperature exceeded 58 degrees Fahrenheit and average monthly temperature when analyzing the water demand of thirty communities in Texas. Including weather as an explanatory variable in an ordinary least squares regression inherently assumes that the impact of weather is linear in parameters, but this is the most common way that weather is accounted for in water demand models. The linear approach is mainly chosen for model simplicity, with temperature and rainfall data being chosen for it's availability. Maidment and Miaou (1986) criticized this approach and instead proposed that rainfall has a dynamic effect on water demand. They suggested that while rainfall decreases water demand initially, the impact diminishes with time. Miaou (1990) returned to this line of thinking a few years later and proposed a non-linear model that “outperformed the linear models in terms of adjusted R-squared, Akaike information criterion value and ability to estimate the high summer use in wet and dry years”. In addition to the diminishing effect of rainfall over time, Maiou (1990) found that there is also a state-dependent effect, where the higher the water consumption prior to a rainfall, the larger the reduction in consumption afterwards. Maiou’s results were based on monthly data, however. Other research by Martinez-Espineira (2002) suggests instead that the effect of rainfall is psychological, as the reduction in water use did not appear to increase as the amount of rainfall increased. In this case it would be better to add the number of rainy days as an explanatory regressor in the model instead of amount of rainfall.

Very little research has been conducted to understand the determinants of municipal water demand and consumption in the Canadian context. Olmstead et al. (2007) estimated the price elasticity of water demand using household level data from 11 urban areas in the United States and Canada, where households were either facing increasing block rates or uniform marginal prices. Renzetti (1988) examined the determinants of industrial water demand in British Columbia, Canada using a relatively simple model of input demands. Renzetti found that industrial water use is responsive to changes in input prices and the level of output. Renzetti (1991) used simulations to quantify the effect on consumer surplus of moving from a water utility provider’s current pricing scheme to an efficient pricing scheme in Vancouver, Canada. He found that switching to a seasonally differentiated pricing model would raise consumer surplus by approximately 4%. Bougadis et al. (2005) studied the determinants of short-term municipal water demand for making forecasts using weekly water demand data, rainfall and maximum air temperature for the City of Ottawa, Canada. They found that the best results were obtained when a lagged dependent variable was included in the regression. In addition, they found that the amount of rainfall was more significant than the occurrence of rainfall, contradicting the results found by Martinez-Espineira (2002). It is possible that the weekly nature of the data is driving this particular result.

There has been considerably more research done on municipal water demand outside of Canada. Arbues and Villanua (2006) conducted an empirical study to estimate the urban residential demand for water in Zaragoza, Spain. The authors found that water demand is responsive to high temperatures and they estimated the elasticity of demand with respect to prices to be -0.08. Schleich and Hillenbrand (2008) investigated the determinants of residential water demand in Germany. The authors were able to estimate the price elasticity to be -0.24 and they also determined that rainfall patterns (e.g., whether it rained) instead of rainfall amounts were affecting water consumption. Returning to North America, Renwick and Green (2000) explored the effectiveness of demand-side management policies as an urban water resource management tool for eight water agencies in California. The authors found that the household’s responsiveness to price varied with the season, finding a price elasticity of -0.20 in the summer months. The authors suggested that this could be due to the more discretionary nature of water use outdoors, such as watering lawns and washing cars.

Other research has examined the impact of nonlinear pricing, such as block pricing, on the decision making of consumers. Ito (2013) empirically tested whether consumers respond to marginal prices or average prices when facing a nonlinear pricing scheme using data from the residential water market in Southern California. Ito found strong evidence that consumers were responding to the average price as opposed to the marginal price or expected marginal price when facing the nonlinear block-pricing scheme for water. This is contrary to economic theory, in that consumers are expected to optimize their consumption with respect to the marginal price. This result may be echoing the earlier results of Chicoine and Ramamurthy (1986) who found that consumers tend to have a low level of perception of the rate structure for municipal water pricing.

4. Data[5]

Daily water consumption data was obtained from Toronto Water for the period between 2005 and 2012. While Toronto Water provides a daily water consumption report on their website[6], historical data is not published or available for download. The Manager of Watermain Asset Pricing in the Water Infrastructure Management division at Toronto Water provided the historical data used in this paper. The data was provided net of storage reservoir changes, which is more representative of actual daily consumption, and is aggregate at the city-level. While the data was originally measured in cubic meters, it was converted to gallons for use in the statistical models. Graphing the data over time

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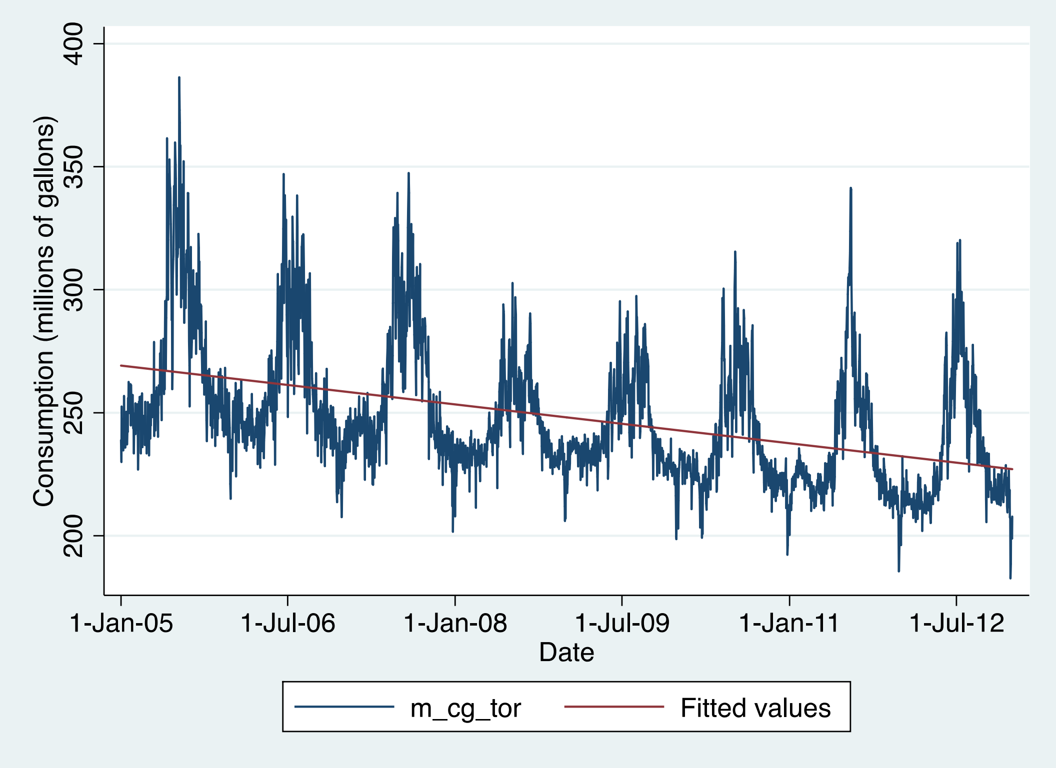
[5] All data and code (written in Stata) related to this paper will packaged in a zip file and made publicly available at http://www.brandonschaufele.com/data-and-code

[6] Water Production Reports
http://www.toronto.ca/water/consumption/report.htm (Accessed 7/1/2013)

shows two very distinct qualities of the data as seen in Figure 1. First, the seasonal pattern of water demand is extremely prevalent with peaks every year around July. Second, there is a noticeable downward time trend in consumption over time. This is unexpected as the data is not in per capita terms and the population of the City of Toronto has grown significantly over the reported time period.

Figure 1: Daily water consumption over time for the City of Toronto



Other potential explanatory variables that were identified in the literature as determinants of short run demand were obtained to supplement the daily data. Every day from January 1, 2005 to December 31, 2012 was cross-referenced with its associated day of the week and day of the week binary variables were generated. In addition, binary variables were generated for each month. Since infrastructure improvements could be a source of the variation in short run demand, data on the daily watermain breaks was obtained from an OpenData Toronto publication (OpenData Toronto 2013). This data was used in two ways: the number of watermain breaks on any given day was tabulated and the number of watermain breaks in any given year was calculated. Furthermore, weather data was obtained from Environment Canada to account for some of the seasonal variation over the time period (Environment Canada 2013). Daily weather and climate data were obtained from Environment Canada's weather reporting stations at Toronto's Pearson International Airport as well as Toronto's Buttonville Airport (Environment Canada 2013). Information was gathered on the daily maximum and minimum temperature as well as the average temperature, reported in degrees Celsius. Heating degree days and cooling degree days variables were generated based on the difference between the average temperature from 18 degrees Celsius. Precipitation data was obtained based on the daily rainfall, snowfall and total combined rainfall and snowfall, measured in millimeters. In addition, a binary variable was generated to indicate whether there was rainfall in the past five days and another variable was constructed to give the total amount of precipitation in millimeters over the past 10 days. The following table provides the descriptive statistics for the key variables used in the analysis:

Table 1: Descriptive statistics of daily data

Variable	N	Mean	Std. Dev.	Min	Max
Daily water consumption (gallons)	2922	248,000,000	27,800,000	183,000,000	386,000,000
Max temperature (Celsius)	2922	13.8	11.3	-16.4	37.9
Mean temperature (Celsius)	2922	9.2	10.6	-20.3	32
Daily precipitation (millimeters)	2922	2.27	5.54	0	53.2
Precipitation today (binary)	2922	0.85	0.36	0	1
Total precipitation (millimeters) over the last 10 days	2922	22.68	18.86	0	131.6
Daily watermain breaks	2556	3.11	3.65	0	39

It is evident that there is a significant amount of fluctuation in daily water consumption with a peak at 386 million gallons of water used in one day. The average temperature throughout the year is 9 degrees Celsius with the hottest temperature recorded being 38 degrees Celsius. The average day has 2.27 millimeters of precipitation, which is inclusive of both rain and snow. The maximum amount of precipitation in one day however is 53.2 millimeters. Precipitation of any kind occurs 85% of the time. On average there are about 3 watermain breaks per day, but that number can jump as high as 39. Watermain breaks are more prevalent during the cold winter months.

In addition to the daily data, a second dataset was obtained from OpenData Toronto from the year 2000 to 2011 containing consumption information for residential and commercial accounts for each of Toronto’s 44 wards (OpenData Toronto 2013). This dataset includes the number of accounts in each ward as well as annual, average and total consumption in gallons separated by residential and commercial uses. This dataset is supplemented by water pricing data obtained from the City of Toronto, which is available in per gallon pricing and per cubic meter pricing. It is important to note that in 2008 the City of Toronto changed from a seven-block pricing structure to one general rate for residential consumers. To encourage water efficiency and industrial expansion, the City of Toronto decided to offer a second rate to industrial consumers that met specific guidelines, including the submission of a comprehensive water conservation plan. This significant change in the water price schedules over the time period of interest suggests that there may be a structural break in the data in 2008. The following table provides the descriptive statistics for the key variables used in the analysis:

Table 2: Descriptive statistics of ward-level data

Variable	N	Mean	Std. Dev.	Min	Max
Number of residential accounts	352	8,997	3,154	2,312	15,949
Number of commercial accounts	352	154	84	45	436
Average residential consumption (cubic meters)	352	380	123	240	930
Annual residential consumption (cubic meters)	352	3,195,034	997,485	1,480,234	9,214,242
Average commercial consumption (cubic meters)	352	28,287	8,014	9,471	70,753
Annual commercial consumption (cupic meters)	352	4,493,914	2,892,359	454,613	14,900,000
Residential price (per cubic meter)	352	1.710	0.331	1.271	2.284
Commercial price (per cubic meter)	352	1.449	0.113	1.269	1.624

It is immediately evident that there is a significant amount of cross-ward variation in the number of residential and commercial accounts in each ward. While the average residential consumption is 380 cubic meters, it peaks as high as 930 cubic meters in one of the wards. Average commercial consumption varies significantly as well, especially on an annual basis. The price per cubic meter of water for residential consumers has increased significantly over the period of interest. The price per cubic meter of water for commercial consumers of water has not increased to the same extent because the definition of commercial consumer changed in 2008 when the old seven-step block pricing structure was replaced with a flat rate for residential consumers and commercial consumers. In 2008 the commercial price per cubic meter decreased as the residential price per cubic meter increased, explaining the difference in the maximum price.

5. Forecasting Short Run Water Demand[7]

This section of the paper will explore the role of short run demand for water consumption to see if it can explain the noticeable downward trend that the City of Toronto has been experiencing over the last eight years. Short-run forecasting is inherently important for water management and planning. While some analysis on the interaction between weather and weekly water consumption has been completed (for Ottawa), this is the first analysis (to the best of my knowledge) to exploit daily water consumption data, precipitation and temperature. As previously stated, the City of Toronto's water consumption follows a very prevalent seasonal pattern every year. Given the daily nature of the data, there is a significant amount of variation that can be exploited for forecasting water consumption in the short run. In addition to the monthly effects, the fact that the data is daily allows day of the week effects to be estimated. Furthermore, daily weather data will be incorporated into the model to determine how weather impacts demand in the short run.

Binary variables for day of the week effects and monthly effects are generated and incorporated in a linear regression model. Logged daily water consumption in gallons is regressed against day of the week binary variables, monthly binary variables, various weather variables, daily watermain breaks and a linear time trend. The day of the week effects and monthly effects are presented in the table below.

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[7] Appendix A includes an analysis of some time series properties of the daily water data. Appendix B includes several tables of coefficients as, for some tables, only selected coefficients are presented in the text.

Table 3A: Coefficient estimates for seasonal effects

Dependent variable: logged daily consumption (in gallons)	Coefficient	Std. Err.	
Tuesday	-0.00037	0.00322	
Wednesday	0.00370	0.00323	
Thursday	-0.00067	0.00323	
Friday	-0.00748	0.00323	**
Saturday	-0.03136	0.00325	***
Sunday	-0.03309	0.00324	***
February	0.00523	0.00429	
March	-0.01778	0.00439	***
April	-0.02137	0.00511	***
May	0.02469	0.00571	***
June	0.10908	0.00655	***
July	0.13493	0.00696	***
August	0.11076	0.00680	***
September	0.07202	0.00614	***
October	0.00988	0.00528	*
November	-0.00664	0.00473	
December	-0.01518	0.00429	***

*** p-value < 0.01; ** p-value < 0.05; * p-value < 0.10
R-squared = 0.8295; Adjusted R-squared = 0.8268; N = 2556
F-stat (25,2530) = 488.83 ***
Standard errors calculated conventionally

Compared to Monday, there is no significant change in demand on Tuesday, Wednesday or Thursday. However, demand on Friday decreases by 0.7% while Saturday experiences a decrease in demand of 3.1% and Sunday experiences a demand decrease of 3.3%. Since the daily data includes both residential and commercial water consumption together, it is impossible to determine whether the decrease in demand is driven by residential accounts or commercial accounts. However, a likely explanation for the decrease is that commercial users of water tend to use water during the workweek (Monday to Friday) and cease operations over the weekends. Residential consumption is unlikely to be the driving force behind the decrease in consumption, as residential consumption would be expected to increase on weekends when more members of the household are home and not at work. Switching focus to monthly effects now, compared to January, February does not have a significant difference in water consumption. Both March and April experience declines in water demand as compared to January, with declines of 1.8% and 2.1% respectively. As the weather begins to warm up, May sees an increase in water consumption by 2.5%. June experiences a large increase in water consumption of 11% and July experiences a massive increase in water consumption of 13.5% or 33.8 million gallons of water. After the peak in consumption in July, water consumption in August compared to January is up 11% and water consumption in September is up 7.2%. October and November do not have significant differences in water consumption as compared to January. Water consumption in December is 1.5% less than water consumption in January, which again might be explained by commercial consumers closing down for the holiday season.

This general pattern of water consumption is a valuable input into water infrastructure planning and has potential welfare implications. For instance, Toronto sets fixed annual price schedules and guarantees at least 24 hours of supply in its reservoirs at all times. However, these restrictions, when examined through the lens of seasonality, imply that Toronto must plan infrastructure around peak demand in July where consumption is notably greater than in winter months. This entails two things. First, significant excess storage capacity will exist in low consumption months and, second, seasonal pricing may be able to reduce summer consumption and generate net welfare gains as higher prices are traded off against reduced infrastructure spending. Of course, as a prerequisite to this analysis, one must know the price elasticity of water demand, a statistic that has rarely been estimated in Canada.

Daily weather data from Environment Canada was also incorporated into the linear regression model as determinants of water demand in the short run. The estimated effects of various weather regressors are presented in the table below.

Table 3B: Coefficient estimates for weather effects

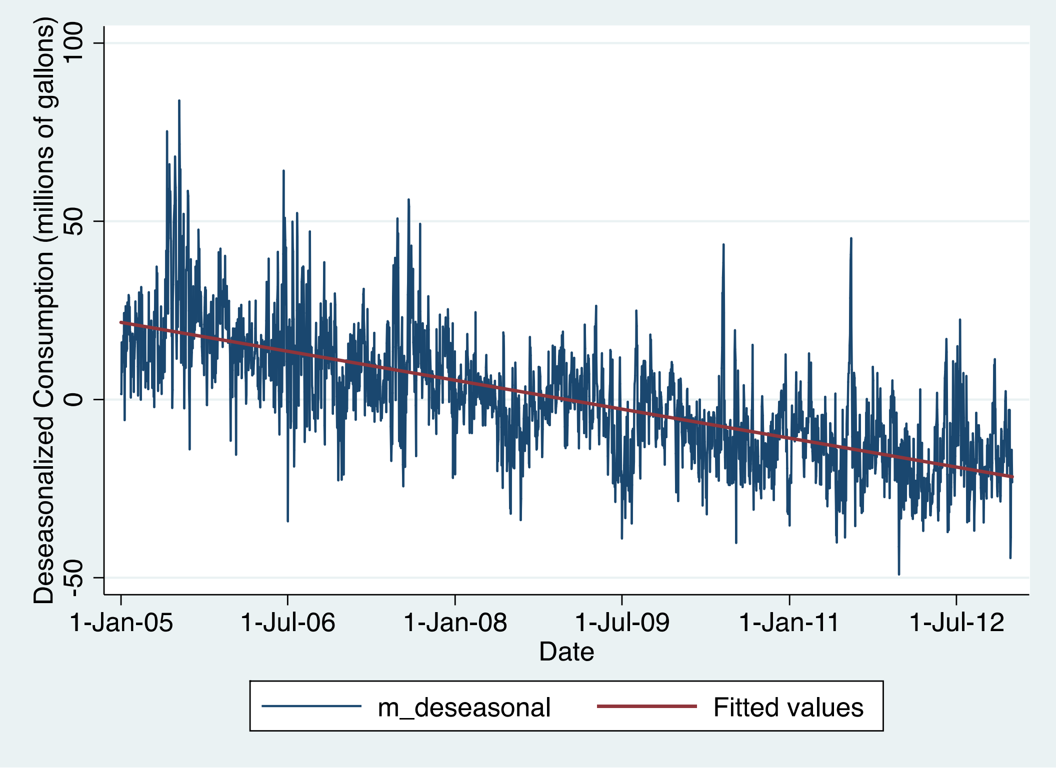
Dependent variable: logged daily consumption (in gallons)	Coefficient	Std. Err.	
Precipitation (mm)	-0.00043	0.00019	**
Precipitation today	-0.00953	0.00220	***
Mean temperature	-0.00025	0.00064	
Maximum temperature	0.00309	0.00057	***
Precipitation in last 5 days	-0.01311	0.00271	***
Precipitation over last 10 days	-0.00069	0.00005	***

*** p-value < 0.01; ** p-value < 0.05; * p-value < 0.10
R-squared = 0.8295; Adjusted R-squared = 0.8268; N = 2556
F-stat (25,2530) = 488.83 ***
Standard errors calculated conventionally

The average daily temperature did not have a significant effect on water consumption, but an increase in the daily maximum temperature by 1 degree Celsius increases water consumption by 0.3%. Interestingly, precipitation appears to have a greater impact on water consumption than the daily temperature. A one-millimeter increase in precipitation per day decreases water consumption by only 0.04% and a one-millimeter increase in the precipitation total over the past 10 days decreases consumption by 0.06%. However, any precipitation on a given day is associated with a 1% decrease in water demand. While a 1% reduction may seem small, this is a substantial amount of water for the City of Toronto. It equals a 2,599,841 gallon decline in water consumption. Similarly, any precipitation over the last five days decreases water consumption by 1.3%. These results appear to suggest that the mere presence of precipitation seems to have more of an impact on water consumption than the actual amount of precipitation. This is in line with the results obtained by Martinez-Espineira (2002) who suggested that the presence of rainfall had a psychological effect on water consumption.

Even though controlling for seasonal demand patterns explains approximately 60% of the variation in daily water consumption, Figure 2 shows that there is still a distinct downward time trend in the deseasonalized data.

Figure 2: Deseasonalized daily water consumption over time for the City of Toronto



One possible explanation for the decline in water consumption over the observed time period is an improvement in the water infrastructure in the City of Toronto.

To test the possibility that the decrease in water consumption is being driven by fewer watermain breaks occurring, daily watermain breaks from OpenData Toronto were obtained and aggregated to an annual level to be incorporated into the linear regression model. In 2011 there were 1,107 watermain breaks within the City of Toronto. The model results when daily watermain breaks are included as an explanatory regressor are presented below.

Table 3C: Coefficient estimates for infrastructure improvements effect

Dependent variable: daily consumption (in gallons)	Coefficient	Std. Err.	
Watermain breaks (ln)	8,692,628	1,361,755	***

*** p-value < 0.01; ** p-value < 0.05; * p-value < 0.10
R-squared = 0.8122; Adjusted R-squared = 0.8103; N = 2556
F-stat (25,2530) = 437.64 ***
Standard errors calculated conventionally

Each 1% decrease in watermain breaks would lead to 8,692,628 fewer gallons lost. In 2011 alone, the City of Toronto consumed 85,814,443,874 gallons of water. A 6% decrease in watermain breaks, as Toronto experienced from 2005 to 2011, would only account for 0.06% of the decline in water consumption. It is clear from this statistic that the decline in watermain breaks is not driving the massive decline in water consumption in the City of Toronto.

6. Role of Prices

The City of Toronto has adopted an aggressive water pricing strategy; the price of water has been increasing every year since 2003 with increases ranging from 6% to 10.8%. In fact, the price of water has increased from \$1.35/m^3 in 2005 to \$2.28/m^3 in 2011[8] for residential customers. This represents a price increase of almost 70% over seven years. In order to determine whether the increase in the price of water is driving the decline in water consumption in Toronto, a separate dataset will be exploited.

The dataset used to explore the impact of pricing on water consumption is a unique dataset that includes residential consumption data and commercial consumption data for each of Toronto's 44 wards from the year 2000 to 2011. There is information on the number of accounts in each ward as well as annual, average and total consumption separated by residential and commercial accounts. Water price data, historically available from 2004 for the City of Toronto, is added to supplement the consumption data and allow for elasticities to be calculated. The strong benefit of this dataset is that residential and commercial consumption is differentiated unlike the daily data used in the previous section that did not distinguish between water uses for residential or commercial purposes. This will allow elasticities to be calculated individually for both residents in the City of Toronto as well as commercial entities, as residential consumers face different prices than commercial consumers.

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[8] Information obtained from http://www.toronto.ca/utilitybill/water_rates.htm (Accessed 7/1/2013)

As a starting point, non-parametric local regression (LOESS) is run and plotted for each ward. LOESS allows for the combination of the simplicity of the linear regression model and the flexibility of the non-linear regression model by fitting simple models to localized subsets of the data to build a function that describes the deterministic variation in the data. The procedure of fitting simple models to localized subsets of the data does not require a global function to be defined. This type of modeling method was chosen because of the expected differences in the relationship between average consumption and price across the 44 wards and also across residential and commercial consumers. Figures 3 and 4 plot the relationship between average water consumption and prices for residential and commercial account holders, respectively.

Figure 3: Relationship between price and average residential consumption by ward

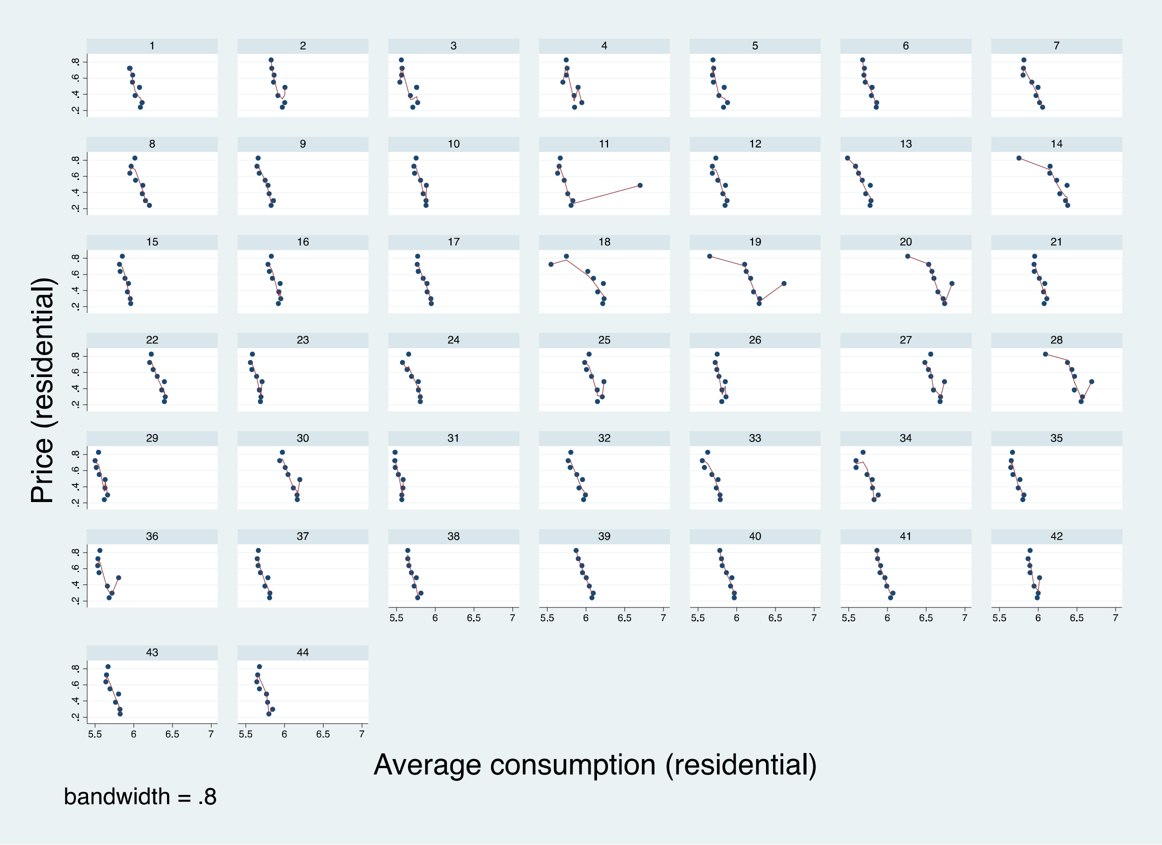
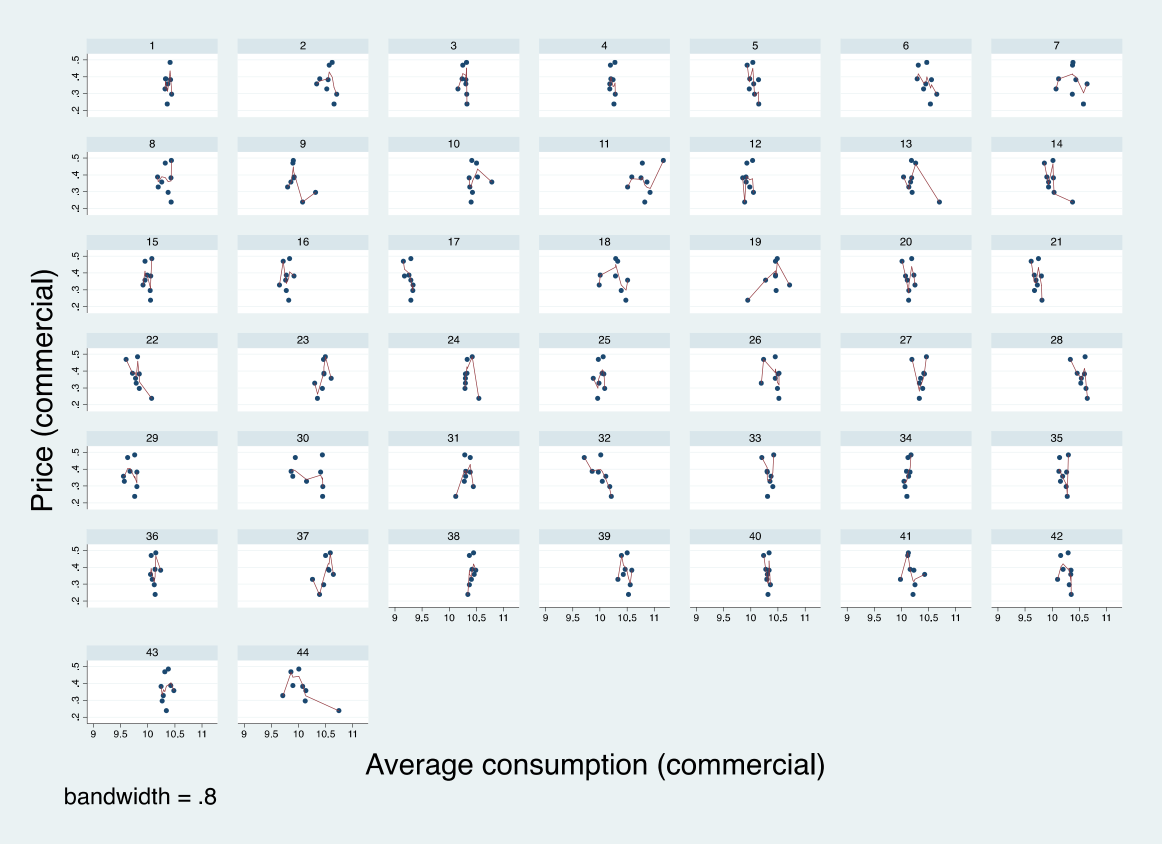


Figure 4: Relationship between price and average commercial consumption by ward



It is visually apparent that the demand curves for water are inelastic but are responsive to price, especially in the case of residential consumers. It is possible to identify demand curves because all water prices for the City of Toronto are set exogenously every year. The demand curves for commercial consumers are messier and not as well defined as compared to residential consumers, and this is likely due to the fact that there is a measurement error in the price variable prior to 2008. As previously mentioned, the City of Toronto switched from a seven-part block pricing strategy to a general rate that only varied depending on whether consumption was above or below a certain threshold. For residential consumers, the price chosen during the period of 2004 to 2007 was the price for the second block. The second block is where the average household would be expected to be in terms of water consumption. The price for the second block was also chosen for commercial consumers. While it is very likely that the vast majority of residential consumers are in the second block (only extremely low water using accounts or extremely large households would be outside the second block), it is unrealistic to believe that all commercial consumers are consuming in the same block. In fact, it is likely that commercial consumers vary in their consumption widely and likely face different prices depending on which of the seven blocks they fall under based on their consumption. However, the data does not have enough information to distinguish between how much water individual commercial account holders are using. The only thing that is known for certain is that the commercial account holders, on average, use 10 times more water than residential consumers.

The panel nature of the dataset is exploited to estimate the price elasticities for residential and commercial water users. To ensure that the results are robust, several model specifications are used. Common amongst all models are time fixed effects to control for cross-ward-invariant effects such as weather and ward fixed effects to control for time-invariant effects such as differences in ward geography and demographics. In addition, all models incorporate standard errors clustered on wards to account for any intra-ward heteroskedasticity. The first set of regressions is estimated using nominal prices for residential and commercial accounts. Log-log models are estimated first using unweighted observations and then using weighted observations based on the total number of residential and commercial accounts in each ward. The results of the regressions are presented below.

Table 4: Estimated (nominal) water price elasticities for consumers

Dependent variable: average consumption (ln)

	Residential		Commercial	
	(1)	(2)	(3)	(4)
Price per cubic meter (ln)	-0.54 ***	-0.52 ***	0.145	0.177 **
	(0.036)	(0.027)	(0.097)	(0.083)
Ward fixed effects	yes	yes	yes	yes
Time trend	yes	yes	yes	yes
Method	unweighted	weighted	unweighted	weighted
Prices	real	real	real	real
R-squared (overall)	0.9998	0.9998	0.9999	0.9999
N	352	352	352	352

*** p-value < 0.01; ** p-value < 0.05; * p-value < 0.10

Clustered standard errors in parentheses (clustered on wards)

Observations weighted by number of accounts when indicated

These estimates confirm the graphical analysis previously presented in the figures and are consistent with results found in other studies. Based on real prices adjusted using the Consumer Price Index for the Toronto region from Statistics Canada (2013), Toronto's demand for water is inelastic with elasticity values ranging between an estimated -0.52 and -0.54 for residential consumers. Determining the elasticity for commercial consumers on the other hand yields an insignificant result when using unweighted observations and a weak positive price elasticity when using weighted observations. These unexpected results for commercial consumers is probably due to the fact that it is difficult to identify the price block faced by each commercial account. As the LOESS curves for commercial consumers were messier and not as well defined as they were for residential consumers, these regression results are not unexpected.

Recalling that the price of water has increased by approximately 70% from \$1.35/m^3 in 2005 to \$2.28/m^3 in 2011 for residential customers, this increase in price predicts a 36.4% decline in water demand. Water demand in Toronto has declined from an average of 270,898,234 gallons per day in 2005 to 232,728,154 gallons per day in 2012, representing a 14% decline. However, on a per capita basis, consumption has fallen by approximately 24%. Consequently, it appears that the majority of the decline in water demand in the City of Toronto over the period of 2005 to 2012 appears to be attributable to price increases. In other words, water management agencies looking to promote conservation should look at increasing prices rather than focusing on alternative strategies such as information campaigns or, for example, subsidies for installing low flow toilets.

7. Discussion

The results obtained in this paper demonstrate the effectiveness of increasing prices when facing an inelastic demand curve for water. This result has policy implications for all forms of government when it comes to finding ways to encourage consumers to conserve water. The City of Toronto appears to be leading the water conservation movement in Canada by combining the availability of water efficiency programs with price increases that make water efficiency more appealing.

Commercial users of water are expected to more responsive to changes in price because commercial users of water are likely more focused on the bottom line as compared to residential consumers. However, the demand curves for commercial water users are much more difficult to identify, as mentioned. Even so, it appears that non-residential water use drives increased consumption from Monday to Friday. Industrial users of water who use water for processing could be the reason for higher consumption during the workweek. The City of Toronto's industrial water rate program targets businesses with water consumption in excess of 6,000 cubic meters annually and gives them an opportunity to reduce the cost of their water bill in exchange for, in part, submitting a water conservation plan. The industrial water rate offers an almost 30% savings on the general water rate in 2013, offering savings of $76,525.40[9] for an industrial consumer with 100,000 cubic meters of use per year. The fact that the City of Toronto continues to offer this price-reducing program suggests that the gains from industrial consumers implementing water conservation plans outweigh any additional consumption though the income effect resulting from facing 30% lower prices. Further research is necessary to determine the impact of these types of water conservation programs.

8. Conclusion

This paper examines the influence of weather variation, infrastructure improvements and price in explaining the City of Toronto's decline in water consumption from 2005 to 2012. This is the first paper in Canada to study the determinants of water consumption and short run water demand using daily data sourced from the municipal water provider

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[9] Obtained from the City of Toronto's Industrial Water Rate Program website available online at http://www.toronto.ca/water (Accessed 7/1/2013)

for Canada’s largest city. Using an additional panel dataset allowed for separate demand curves to be identified for residential consumers and commercial consumers.

Variations in weather and infrastructure improvements alone are unable to explain the downward trend in water consumption, even though they are able to explain roughly 60% of the variation in water demand. Price elasticities of demand for water are estimated for residential and commercial consumers using a second dataset. Residential consumers in Toronto have inelastic demand for water with an estimated elasticity ranging between -0.52 and -0.54. Similarly, commercial consumers in Toronto appear to have inelastic demand for water, although their demand curves are more difficult to identify and the regression results are inconclusive. Based on the estimated price elasticity and given the 70% increase in the price of water in the City of Toronto between 2005 and 2012, the price increases are estimated to cause a 36.4% decline in water consumption. The City of Toronto experienced a 24% decline in per capita water consumption, meaning that the large decline in water consumption appears to be largely due to the rising price of water. This leads to the conclusion that price is still the most effective water conservation policy available to governments.

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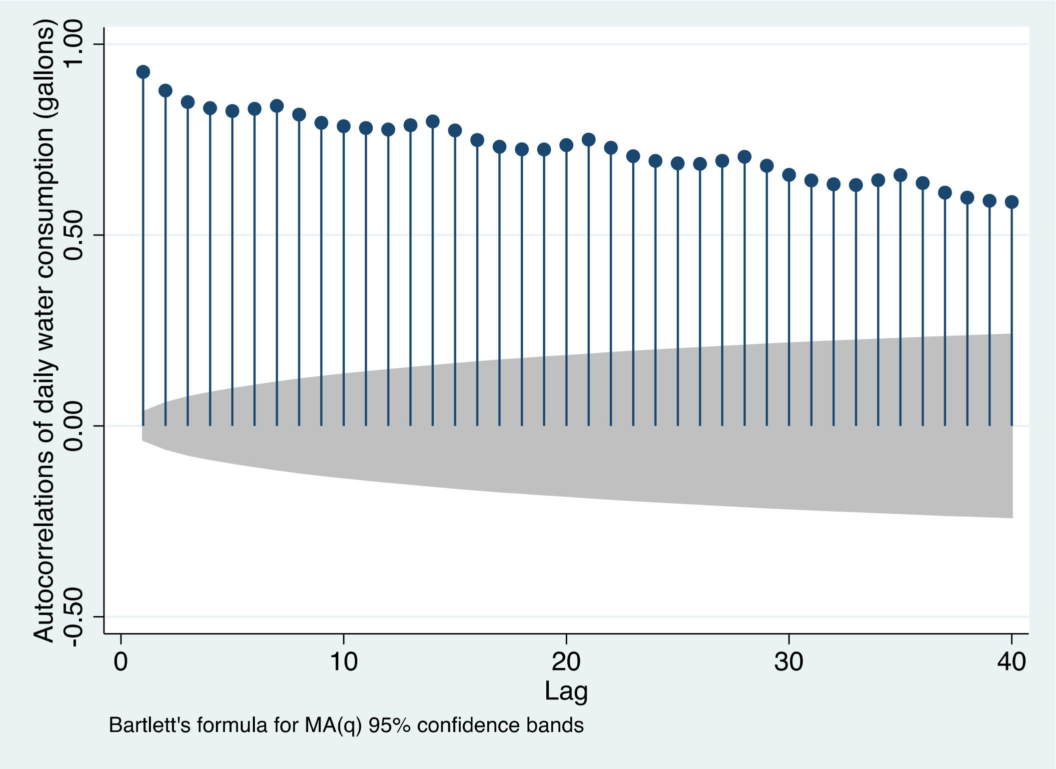
Appendix A: Time Series Properties of Daily Water Demand

There is significant value in being able to forecast municipal water demand in the short run. While previous Canadian literature has used weekly, monthly or annual data, there have been no Canadian studies to date that have forecasted municipal water demand on a daily basis. Projected population growth coupled with peak water use during the summer months requires that existing water infrastructure be upgraded to keep up with demand. This is true for other large cities experiencing population growth, such as Ottawa (Bougadis et al. 2005). In an effort to minimize the costs associated with the expansion of water infrastructure, forecasting models are utilized to understand when peaks in demand are expected.

One of the most important aspects of a forecasting model is ensuring that the data being modeled exhibit stationarity. A stationary process is one whose mean, variance and co-variance are constant across time and whose autocorrelations decay to zero as the displacement (or lags) increase. The following figure graphs the autocorrelations of Toronto’s daily water consumption.

Figure A1: Autocorrelations of daily water consumption



It is evident that there is significant persistence in the daily consumption data. The likely reason for this is that there are seasonal trends and a negative linear trend. However, before detrending the data it is necessary to ensure that the data is following a deterministic trend and not a stochastic trend, such as a unit root. Dickey and Fuller (1981) developed a test to determine if there is a unit root in time series data. The following table presents the results of the Dickey-Fuller test for unit root:

Table A1: Augmented Dickey-Fuller Test for Unit Root

Dickey-Fuller Test for Unit Root

N = 2555

		Interpolated Dickey-Fuller		
	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-20.09	-3.43	-2.86	-2.57

MacKinnon approximate p-value for Z(t) = 0.000

With the null hypothesis being unit root and the alternative hypothesis being no unit root, the null hypothesis is rejected and the data does not appear to follow a stochastic process. This being the case, it is possible to detrend the data by controlling for the seasonal variation and time trend. The autocorrelations and partial autocorrelations of the detrended data are provided below.

Figure A2: Autocorrelations of detrended daily water consumption

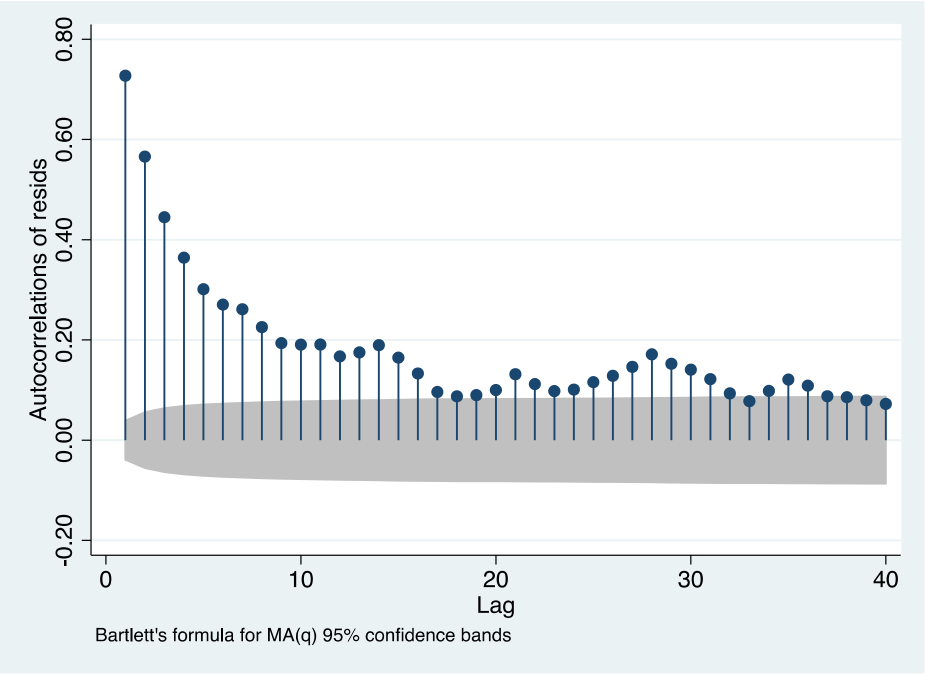
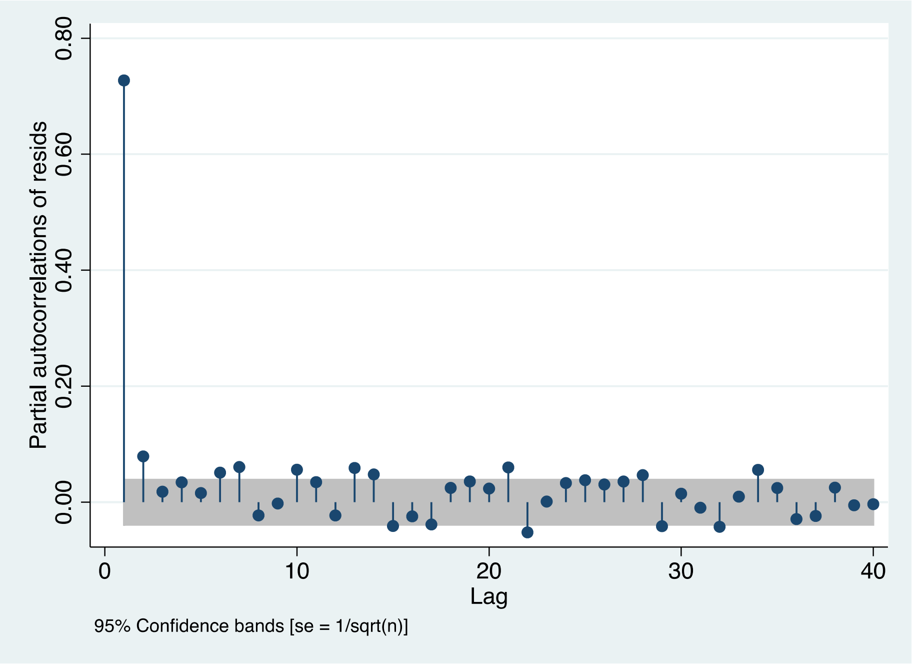


Figure A3: Partial autocorrelations of detrended daily water consumption



It is clear that the autocorrelations decay to zero at a more rapid pace after detrending the data. In addition, the partial autocorrelations jump to zero after the first lag. An autoregressive (AR) process of order "p" can be determined by examining the autocorrelations and partial autocorrelations of the data. An AR(p) model is the appropriate specification when the autocorrelations decay to zero with time and the partial autocorrelations cut off to zero after the p^{th} lag (Diebold 2008). In this case, the autocorrelations decay to zero with time and the partial autocorrelations cut off to zero after one lag. Based on this information, the appropriate model for the detrended daily water consumption is an autoregressive model of order one. The following table displays the results of the AR(1) regression:

Table A2: AR(1) estimates

ARIMA Regression Results

N = 2556
Log-likelihood = 44,662.2
Wald chi-squared = 6055.17 ***

Dependent variable: detrended daily consumption

	Coefficient	Std. Error	
Constant	-5817.433	699971.5	
AR Lag 1	0.727	0.009	***

*** p-value < 0.01; ** p-value < 0.05; * p-value < 0.10

Therefore almost 73% of the cyclical variation in the detrended daily water consumption can be explained by the previous day’s detrended water consumption.