An Econometric Estimation of Deadweight Loss in Pennsylvania's Water Market

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Abstract

Industrial water demand in the state of Pennsylvania is anticipated to increase in the near future due to the expansion of hydraulic fracturing of the Marcellus Shale. Pennsylvania's water markets are increasingly operated by investor-owned water monopolies, and have prices regulated by the Pennsylvania Utility Commission (PUC). The PUC's decisions on whether to approve or deny changes in the price of water can take up to nine months. This thesis estimates the quantity of deadweight loss attributable to this regulatory lag in Pennsylvania's water markets in a scenario of increasing demand. In this work, the model for a natural monopoly facing a price ceiling is defined, followed by an estimation of the relevant cost and revenue curves for a representative Pennsylvania water monopoly, after which residential and commercial water demand were estimated, with deadweight losses then being calculated. Demand is then increased such that market price would exceed the PUC-approved maximum price, which is then charged while the hearing and petitioning process occurs. This analysis calculates increases in estimated deadweight loss of 92.83% for the residential water market, and 40.46% for the commercial market. This finding indicates that if maintaining market efficiency is a goal for the PUC, this commission should aim to respond as dynamically as possible to changing market conditions when regulating monopoly water pricing.

Contents

1 Introduction

1.1 Market Background

Pennsylvania's water markets are regulated by the Pennsylvania Utility Commission (PUC), which has the right to regulate price charged for public utilities such as water and electricity.[1] In the case of water, the PUC does not regulate municipal providers which operate within their boundaries, [2] instead regulating the rates of private and investor-owned water utilities, in addition to munipial providers conducting business outside of their municipal boundaries. [3] In a ruling where the PUC approved a rate increase for United Water Bethel Inc., in Delaware County, PA, a PUC press release stated the organization's goals as "balanc[ing] the needs of consumers and utilities to ensure safe and reliable utility service at reasonable rates; protect the public interest; educate consumers to make independent and informed utility choices; further economic development; and foster new technologies and competitive markets in an environmentally sound manner." [4]

Pennsylvania's water markets have become increasing monopolistic by region, with many smaller water utilities being acquired by or merged into larger, investor-owned utility firms. [5] An analysis conducted by Torres and Paul (2005) attributes the incentives for consolidating water utilities to the cost-saving advantages gained from economies of scale.[6] Pennsylvania America Water, an investor-owned utility firms, describes, "our Regulated Businesses consist of locally managed utility subsidiaries that generally are subject to economic regulation by the states in which they operate. Our Regulated Businesses provide a high degree of financial stability because (i) high barriers to entry provide certain protections from competitive pressures; (ii) economic regulation promotes

[1] "The PUC Ratemaking Process and the Role of Consumers" (2012)
[2] "Water/Wastewater" (n.d.)
[3] "Before the Pennsylvania House Consumer Affairs Committee Testimony of Tanya J. McClosky Acting Consumer Advocate Regarding Overview Of The Regulated Utility Industry" (2013)
[4] "Press Releases: PUC Approves Lower Rate Increase than Requested for Water Co. in Delaware County" (2012)
[5] "Before the Pennsylvania House Consumer Affairs Committee Testimony of Tanya J. McClosky Acting Consumer Advocate Regarding Overview Of The Regulated Utility Industry" (2013)
[6] Shih et al. (2004)

predictability in financial planning and long-term performance through the rate-setting process; and (iii) our large customer base." [7] These high barriers for entry and the further merger of Pennsylvania water firms creates an effectively monopolistic market for water across the state, with large portions of the state water market now being operated by investor-owned firms. As such, the major water providers for the state of Pennsylvania will be subject to PUC regulation. In terms of rate adjustments, the PUC states that (including a 60 day notice period), a decision on a request for rate increases takes "about nine months." [8] The rates charged under PUC regulation are per unit of water sold, and for companies such as Pennsylvania American Water, a per unit price ceiling has been imposed on residential and commercial water sales. Residential water prices are capped per company at a fixed per-unit price, while commercial water pricing is also capped per company at a per-unit rate, but follows a decreasing block rate, [9] where the unit price decreases with the amount sold. [10]

1.2 Motivation

Hydraulic fracturing for natural gas in Pennsylvania has increased dramatically over the past few years, expanding from 114 drilled wells in 2007 to 1972 in 2011. [11] Fracking in the Marcellus Shale is expected to continue into the foreseeable future, and with each fracking well consuming an average of 4.4 million gallons of water, [12] and brings additional residents into the state for work, demand for water in Pennsylvania can be anticipated to increase in the future as well.

Given that for normal (especially, inelastic) goods in an unrestricted market, when demand increases the suppliers want to raise the price of that good, and in Pennsylvania there is a regulatory lag of approximately nine months for adjusting the approved prices facing major water utilities (during which the previously approved maximum price would be charged), there may be additional deadweight loss created in this water market during this time. In order to determine whether current PUC policies will result in higher deadweight losses during a time of steadily increasing water demand, this thesis will econometrically estimate the magnitude of a potential increase in deadweight loss resulting from this regulatory lag in Pennsylvania's water market.

[7] "American Water Works Company, Inc." (2013)
[8] "The PUC Ratemaking Process and the Role of Consumers" (2012)
[9] "Rates Information" (n.d.)
[10] Hanemannm, M.W. (1997)
[11] "The Social Costs of Fracking" (2013)
[12] "How Much Water Does It Take to Frack a Well?" (2013)

1.3 Procedure

In order to estimate the additional deadweight loss present in Pennsylvania's water market when there is a demand increase, this analysis will estimate the cost and revenue functions for a representative water monopoly, and plot these with respect to the imposed price ceiling and a water demand curve.

For this analysis, data from the U.S. Securities and Exchange Commission (SEC) 10-k filings of investor-owned water utilities will be used to econometrically estimate the variable cost function of this representative water monopoly, from which data to determine a marginal revenue curve will also be drawn. After estimating variable cost, average total cost, marginal cost, and marginal revenue from the available data, these curves will be plotted with respect to its price ceiling.

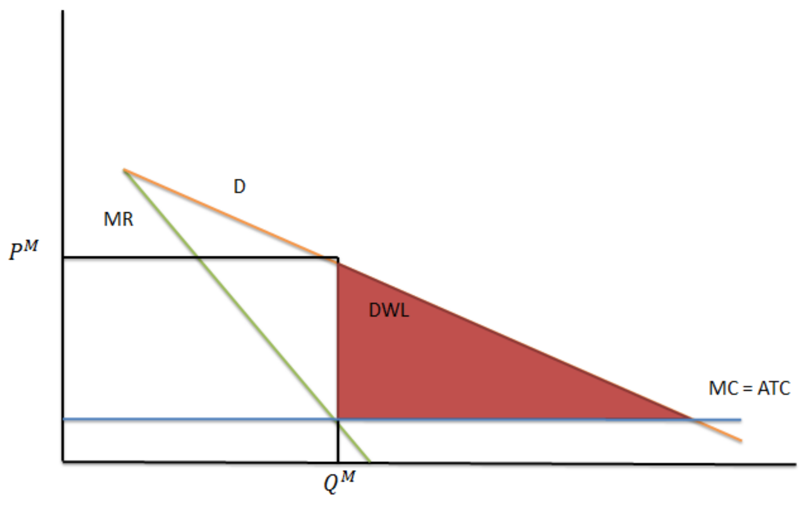
Demand for both commercial and residential water will be extrapolated from observed quantities sold and prices in the Pennsylvania water market. An estimate of current-state deadweight loss will first be computed, then he demand curves will then be shifted upwards to simulate an increase in water demand, and the deadweight loss due to a temporarily stagnant price ceiling can then be estimated. The difference between these two deadweight loss estimations for each market will then be compared.

2 Background Theory

To begin a proper analysis of monopoly behavior, the classic model for a natural monopoly must be established. To begin, we consider one actor (identified with the subscript i) who actively operates a water company in a given geographic market (such as a region of Pennsylvania). Firm i will select an output q_i. The costs faced by firm i are then determined to be $c(q_i)$. Regardless of functional form, the revenue faced by this firm will be $p(q_i)$, resulting in the objective function of $p(q_i)q_i - c(q_i)$, corresponding to the monopoly's costs subtracted from its revenue.

Monopolies generate deadweight loss, where surplus is neither allocated to consumers nor producers. [1] Deadweight loss is a market inefficiency, which does not benefit anyone in the market.

FIGURE 2.1: A Natural Monopoly



In the natural monopoly pictured, marginal cost (MC) is equal to the firm's average total cost (ATC), and the deadweight loss (DWL) produced through standard monopolistic

[1] "The Basics of Monopolies" (n.d.)

operation is represented by the shaded triangle formed between the demand curve and the intersection of demand with MC/ATC.

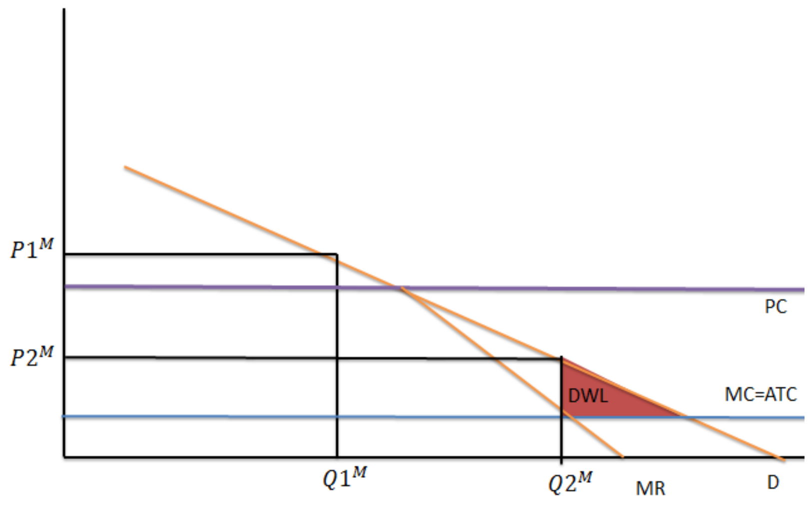
A comprehensive discussion of the definition of a natural monopoly can be found in Joskow (2005), who provides the technical definition: "a firm producing a single homogeneous product is a natural monopoly when it is less costly to produce any level of output of this product within a single firm than with two or more firms. In addition, this 'cost dominance' relationship must hold over the full range of market demand for this product."[2] In the case of water, Clark and Mondello (2011) discuss the occurrence of government-facilitated and regulated monopolistic markets due to both the advantages of economies of scale but also technical considerations including water treatment and the immense investment required in piping and related infrastructure.[3]

The mechanisms of government regulation of natural monopolies has been explored through both a microeconomic and game theoretical context, most notably through the combined work of Jean-Jacques Laffont and recent Nobel Prize winner Jean Tirole. Three of their papers (1986, 1990, 1993) provide an excellent theoretical analysis of the regulatory game and extent to which marginal cost is overreported to regulators, [4] pricing schemes and the roles of government watchdogs,[5] and asset pricing and competition,[6] respectively.

When a government levies a price ceiling (PC) below the monopolistic market price, deadweight loss can be decreased:

[2] Joskow, P.L. (2005)
[3] Clark & Mondello (2002)
[4] Laffont & Tirole (1986)
[5] Laffont & Tirole (1990)
[6] Laffont & Tirole (1994)

FIGURE 2.2: A Natural Monopoly with a Price Ceiling



However, it must be noted that the use of this price ceiling alters the structure of the marginal revenue faced by the firm. With a binding price ceiling, the levels of production for the firm prior to its output reaching market demanded quantities have a marginal revenue curve which is determined as a function of the price ceiling, not the market demand curve. This change in the marginal revenue curve faced by the monopoly has the interesting result of eliminating the revenue cannibalization effect observed when a monopolistic firm faces a downward sloping marginal revenue curve. An analogous economic case is when a monoposny faces a minimum wage, where the marginal cost becomes determined by the minimum wage up to the equilibrium market point.

One effect of this change is that when a price ceiling is imposed, marginal revenue is equated to the price ceiling until the price ceiling's intersection with demand, where the marginal revenue curve becomes downward sloping once more. The monopolist's production decision will occur where marginal cost is equal to marginal revenue, with the monopoly providing a greater quantity of that good to the market.

In the absence of a price ceiling, the optimal (profit-maximizing) production choice for Firm i is determined through taking the first-order conditions of the objective function and setting that equal to zero: $\frac{\delta\pi(Q*)}{\delta Q} = \frac{\delta p(q_i)q_i}{\delta Q} - \frac{\delta C(Q*)}{\delta Q} = 0$, which corresponds to producing at the intersection of the firm's marginal revenue and marginal cost curves. Taking the firm's first order condition and equating it to zero is the necessary condition for monopoly profit maximization, while the sufficient condition involves confirming that the second derivative of the firm's profit function with respect to output is negative: $\frac{\delta^2\pi(Q*)}{\delta Q^2} = \frac{\delta^2 R(Q*)}{\delta Q^2} - \frac{\delta^2 C(Q*)}{\delta Q^2} < 0$, indicating a local maximum of the objective function.

This process is altered when a price ceiling is implemented in a monopolistic market. The demand function faced by a monopolist with a price ceiling is:

$$p_D(q) = \begin{cases} p_c, & \text{if } q \leq q_c \\ p_r(q), & \text{if } q > q_c \end{cases}$$

where p_q is the demand curve without the price ceiling, and q_c is the quantity at which $p(q_c) < p_c$.

The standard (unconstrained) solution to the monopoly optimization problem is $\pi_c = p(q)q - c(q)$ which leads to the first order condition (with constant marginal cost) of $p'(q*)q * +p(q*) = c'(q*) = \gamma$ with the linear demand curve $p(q) = a - bq$, giving $p'(q) = -b$.

It then follows that:

$$\begin{aligned} -bq * +(a - bq*) &= \gamma \\ -2bq * +a &= \gamma \\ q* &= \frac{a-\gamma}{2b} \end{aligned}$$

The solution to the monopolist's optimization problem depends on what the market price is given this output level: $p(q*) = p\frac{a-\gamma}{2b}$ if on the demand curve ($p(q*) < p_c$), but if $p(q*) < p_c$, then this standard solution will not occur. If $p_c > \gamma$, then $MR > MC$ and the monopolist can produce any output level up to the downward sloping demand curve.

In the case of the Pennsylvania water market, the representative water monopoly faces two demand curves (and thus, two marginal revenue curves): one for residential water, and one for commercial water sales.

FIGURE 2.3: Natural Monopoly Supplying Residential Water

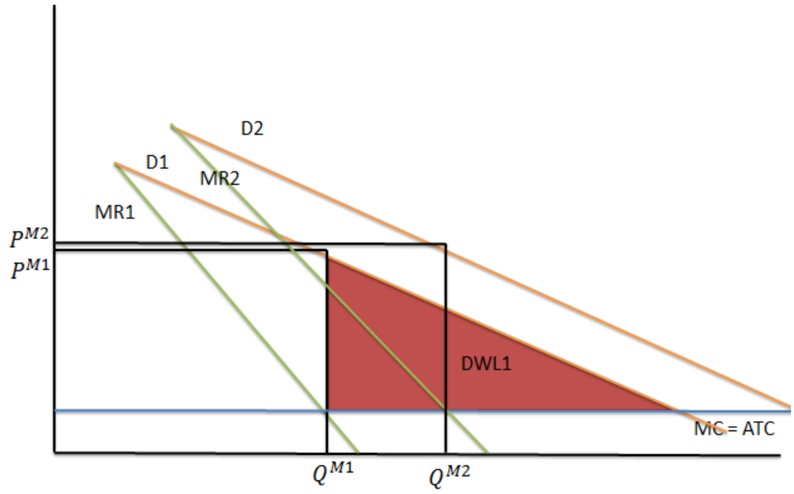
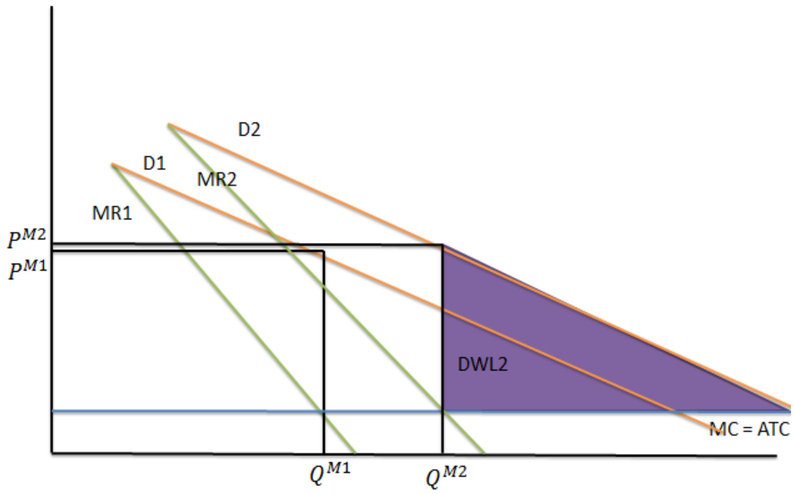


FIGURE 2.4: Natural Monopoly Supplying Commercial Water



For each demand curve in this market, there is a price ceiling which applies to each respective demand curve, making the market appear as the following:

FIGURE 2.5: Natural Monopoly Supplying Residential Water with Price Ceiling

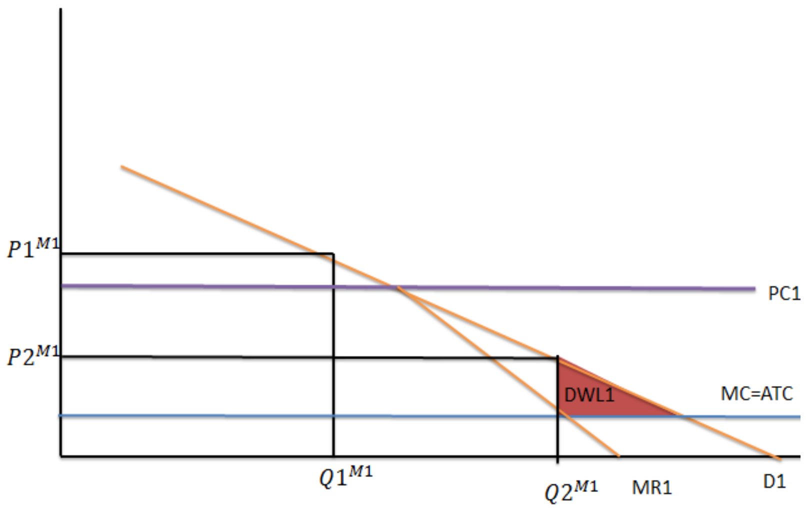
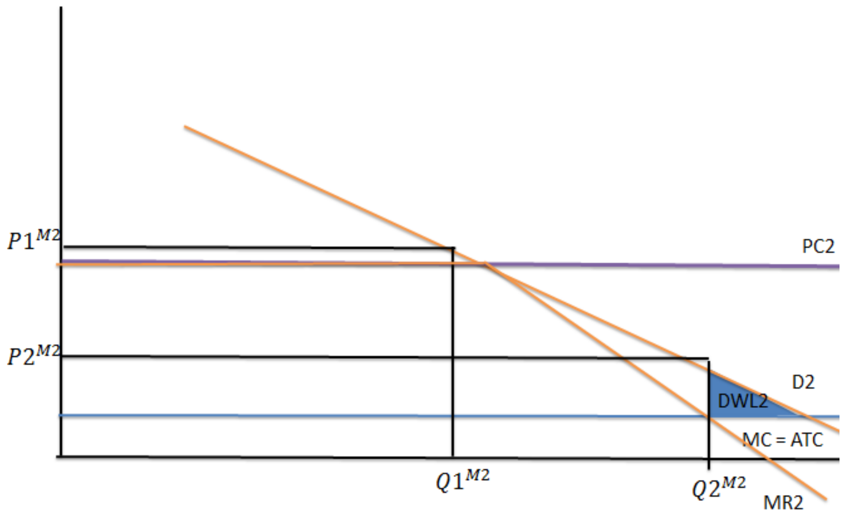


FIGURE 2.6: Natural Monopoly Supplying Commercial Water with Price Ceiling



As can be seen in both cases, the deadweight loss decreases with the imposition of a price ceiling below the monopoly price.

This thesis examines the change in deadweight resulting from the lag in adjustment the price for water in Pennsylvania under a scenario of increasing demand. Given that water demand is set to increase given the further expansion of hydraulic fracturing in the Marcellus Shale, the change in deadweight loss will be estimated for an increase in the demand for water, where due to regulatory lag, price is not adjusted relative to the this change in demand (forcing the monopolist to charge the previously-approved maximum price).

In order to perform this quantitative analysis, a representative monopoly's cost and revenue functions must first be estimated.

3 Estimating Variable Cost

3.1 Relevant Literature

The basic procedure used for estimating the variable costs of water utilities was based on a model created by Stewart (1993) in a paper for the UK water regulator Ofwat titled "Modelling Water Costs 1992-93: Further Research Into the Impact of Operating Conditions on Company Costs." While Stewart's methods are summarized and his models adapted in a few different papers, his original paper does not exist in a digital format and only seems to be located in the National Libraries of Scotland. I emailed Stewart personally requesting a copy, but according to his response he no longer has any copy of this paper (digital or physical). Two papers consulted for estimating variable cost functions for a water utility are "Comparing the Performance of Public and Private Water Companies in Asia and Pacific Region What a Stochastic Costs Frontier Shows" by Estache and Rossi (1999) [1] and "The use of a variable cost function in the regulation of the Italian water industry" by Antonioli and Filippini (2001). [2]

Estache and Rossi (1999) summarize Stewart's model (developed from a sample of UK water companies over the years 1992-1993) as:

LnCOSTS = 3.34 + 0.57LnSALES + 0.38LnNETWORK - 0.62STRUC + 0.13LnPUMP

Where "COSTS is the total operational cost in the water sector experessed in 1000 of pounds, SALES is the volume of water sold expressed in ML/d (mega litres per day), NETWORK is the length [of] the network in Km, STRUC is the volume of water sold on average to non-residential clients/total volume of water sold, PUMP is the average water pumping needed." [3]

[1] Estache Rossi (1999)
[2] Antonioli Filippini (2001)
[3] Estache, A., Rossi, M. (1999)

Estache and Rossi also note that all variables were statistically significant at a 90 percent confidence level and that the model has an R^2 value of 0.99.

Antonioli and Filippini (2001) use a model from Italy's water regulator, who adopted Stewart's model as:

$$COAP = 1.1 * VE^{0.67} * L^{0.32} * IT^{0.1} * e^{0.2*(UTDM/UTT)} + EE + AA$$

Where COAP is operating expenditures (in millions of lire per year), VE is volume of water delivered (in thousands of cubic meters per year), L is length of the distribution network (in km), UTDM is the volume of water delivered to households, IT is average pumping head, UTT is total users, EE is expenditures on electricity (in millions of lire per year), and AA is expenditures on water bought. [4]

These models were used as guides in constructing this paper's analysis of Pennsylvania water utilities.

3.2 Variable Cost Data Collection

Data regarding the costs, revenues, and related variables for the estimation of a representative water monopoly's variable cost function were collected through the Security and Exchange Commissions (SEC) website, where the 10-k filings of publicly-traded firms are available for viewing. After locating the 10-k filings for all publicly-traded water utilities, the ones which contained adequate data from which to estimate variable cost (namely, firms which provided data on their operating expenses) were selected. Data for the firms American Water Works Company (AWK), Middlesex Water Company (MSEX), Connecticut Water Service (CTWS), California Water Service Group (CWT), Artesian Resources Corporation (ARTNA), and San Jose Water Company (SJW) was compiled into a spreadsheet. The variables collected from their 10-k filings (if available) were total volume of water sold, total volume of water sold to industrial customers, operating expenses, operating revenues, miles of pipe, power used, total customers, and quantity of purchased water.

[4] Antonioli, B., Filippini, M. (2001)

A regression was run of the natural logarithms of these variables as recommended in the Estache and Rossi (1999) paper, however, the statistical software used (Stata) reported that there were insufficient observations to perform this regression.

To correct for this error, a regression was run without the variable for power (which served as a proxy for "PUMP"), and 24 observations were obtained with the following functional form:

$$LnExpenses = -.45 LnVolumeOfWater + 1.31 LnMilesofPipe + .26 LnShareIndustrial + 11.69$$

Table 3.1: Estache and Rossi (1999) Regression

lnExpenses	Coef.	Std. Err.	t	$P > \|t\|$
LnVolumeofWater	-.4536232	.3237249	-1.40	0.176
LnMilesofPipe	1.31069	.1467214	8.93	0.000
LnShareIndustrial	.2610971	.444991	0.59	0.564
Constant	11.6926	2.340471	5.00	0.000

Where Expenses is the recorded operating expenditures, MilesofPipe is the miles of water main used by the firm, and ShareIndustrial is the ratio of water supplied to industrial firms and total water supplied.

This regression was tested for multicollinearity as to ensure adequate independence of all variables, with the following results, indicating a lack of serious multicollinearity (typically determined as when the Variance Inflation Factor (VIF) is at or above 5):

Table 3.2: Estache and Rossi (1999) VIF

Variable	VIF	1/VIF
LnMilesofPipe	3.93	0.254638
LnVolumeofWater	3.72	0.268642
LnShareIndustrial	1.28	0.779062
Mean VIF	2.98	

An adaptation of Antonioli and Filippini's (2001) model was also tested (without the variables for pumping or purchased water, as these was either not reported or relevant for the firms observed) and provided the following:

$LnExpenses = .49LnVolWater + 2.78LnMilesofPipe - 0.09LnIndustrial - 1.84LnCustomers +$ 18.42

Table 3.3: Antonioli and Filippini (2001) Regression

lnExpenses	Coef.	Std. Err.	t	$P > \|t\|$
LnVolumeofWater	0.492129	.4284816	0.11	0.910
LnMilesofPipe	2.777763	.8250252	3.37	0.003
LnShareIndustrial	-.0932979	.0996193	-0.94	0.361
LnCustomers	-1.839915	1.0241	-1.80	0.088
constant	18.42485	4.008863	.60	0.000

However, this test proved to be extremely collinear with a mean VIF of 78.65.

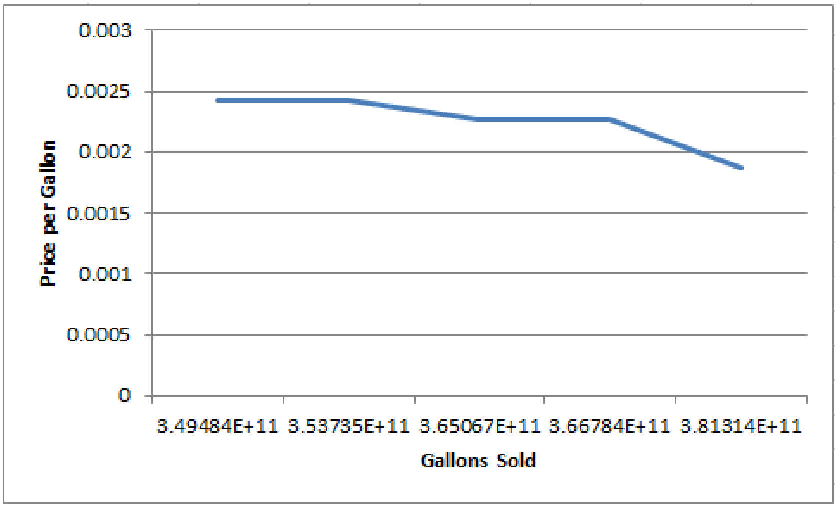
Table 3.4: Antonioli and Filippini (2001) VIF

Variable	VIF	1/VIF
LnCustomers	168.12	0.005948
LnMilesofPipe	137.68	0.007263
LnVolWater	7.23	0.138299
LnIndustrial	1.55	0.645247
Mean VIF	78.65	

As a result, the adaptation of the Estache and Rossi (1999) model was used to estimate the variable costs experienced by Pennsylvania American Water between the years 2013 and 2007. Pennsylvania American Water was chosen as the representative monopoly on which this analysis is based, because it was a Pennsylvania-operating water firm which provided 10-k data on costs re,venues, and quantities, in addition to having their prices available for viewing on line.

The following graph of variable cost was produced:

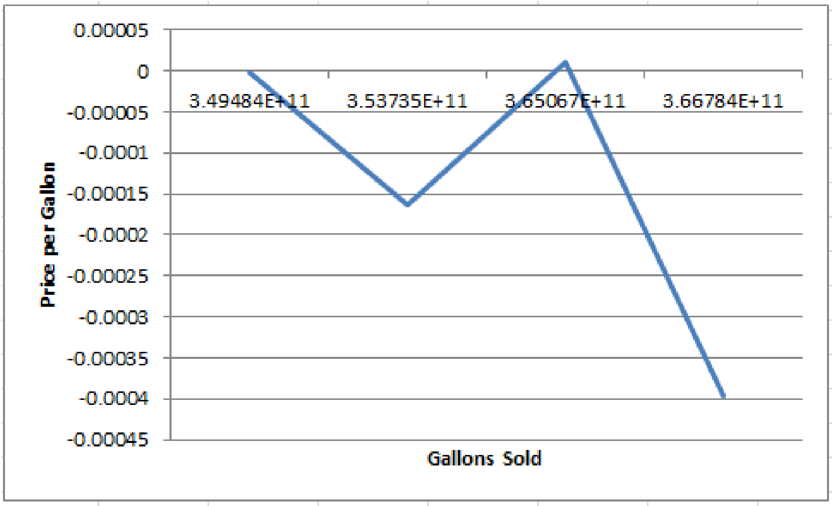
FIGURE 3.1: Graph of Variable Cost



As can be seen, the variable cost decreases in a roughly step-like fashion as quantity of water sold increases. This corresponds with conventional economic thinking, as economies of scale should decrease production costs past a certain level of quantity produced.

Using the variable cost estimated, marginal cost from increasing the quantity of water produced was then estimated using the standard formula $\frac{\delta TC}{\delta Q}$:

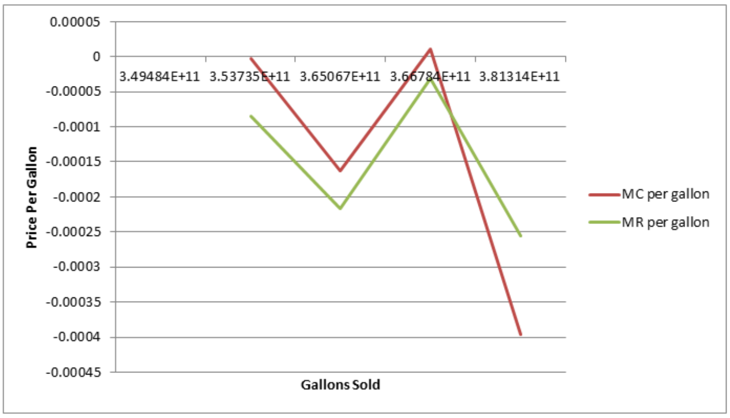
FIGURE 3.2: Graph of Marginal Cost



It is odd that the marginal cost function exists in a negative portion of the y-axis (indicating negative per-unit costs), however, when looking at the magnitude at which this function crosses below the x-axis, this behavior can likely be attributed to estimation error.

Marginal revenue was computed by taking the revenues recorded at each quantity and differencing them in the same fashion as was used to generate marginal cost: $\frac{\delta TR}{\delta Q}$. Marginal cost and marginal revenue were then plotted on the same graph:

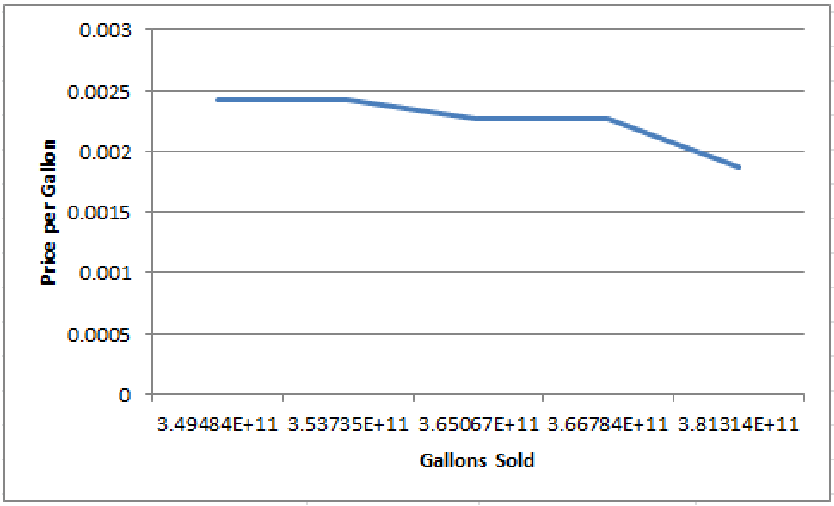
FIGURE 3.3: Graph of Marginal Cost and Marginal Revenue



Marginal revenue and marginal cost both have similar functional forms, with the negative portion of the marginal revenue curve also likely attributable to estimation error due to a small sample size. The quantity chosen by the monopolist for market production is determined by the intersection of the marginal revenue and marginal cost curves. While the curves graphed do not exactly intersect, the difference between the two curves is at its smallest at the quantity $3.654255 \cdot 10^{11}$ gallons and a price per gallon of \$0.000042. The midpoint of y-coordinates of the two curves at this quantity is \$-0.000011, which suggests (since negative prices are never charged) that the intersection between the curves at this point occurs at a per-unit price of approximately zero.

Average total cost (ATC) was computed by taking the estimation of variable cost at each quantity and dividing the variable cost by that quantity: $\frac{VC}{Q}$. It has a graph which is also decreasing slightly in a step-like manner, and exists at near-zero prices:

FIGURE 3.4: Graph of Average Total Cost



Having estimated variable cost, marginal cost, marginal revenue, and ATC for the Pennsylvania American Water Company, the quantity of water optimally produced in this model can be accurately determined to be $3.65067 \cdot 10^{11}$ gallons (at the approximate intersection between marginal revenue and marginal cost). In order to analyze other components of this model, water demand in Pennsylvania must now be estimated.

4 Demand Estimation

4.1 Estimating Demand Curves

A consumer's demand for a good is determined as a function of his or her income, and the prices of goods to be purchased: $q_d = F(p_1, p_2, ..., p_n, Y)$ where Y is income. In the case of demand for water, there are not any relevant substitutes for the good, allowing for demand to be modeled in a simple linear form: $p_d = m \cdot q_d + a$ where m is the slope and a is the intercept of this curve.

The demand curve for water in Pennsylvania must be extrapolated from observed data regarding quantities of water supplied and the prices at which they were sold. Data for water sold by Pennsylvania American Water is available in their 10-k filings, and the prices these quantities were sold are detailed on a page of the firm's website, [1] with the archives for each year being viewed using the internet archive `https://web.archive.org`. Despite these transactions occurring under the established price ceiling, it is possible to take the prices and quantities recorded at the observed transactions and extrapolate the form of a linear demand curves for water. Additionally, the PUC regulation has been standard practice for many years, consumer expectations have been formed under markets with the property of having regulated rates.

For simplicity of analysis, demand for both residential and industrial water is assumed to be a linear form, an assumption which is supported by the data, and also provides the ability to use a linear trend line to estimate the functional form of demand.

Graphs plotting the prices and quantities observed as well as an estimated linear approximation for each demand curve are shown for the residential and commercial markets as follows:

[1] "Rates Information" (n.d.)

FIGURE 4.1: Graph of Residential Water Demand

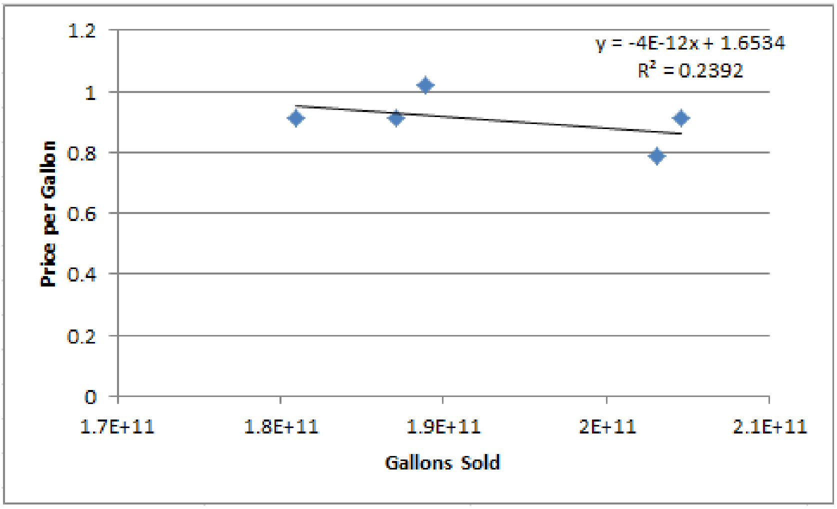
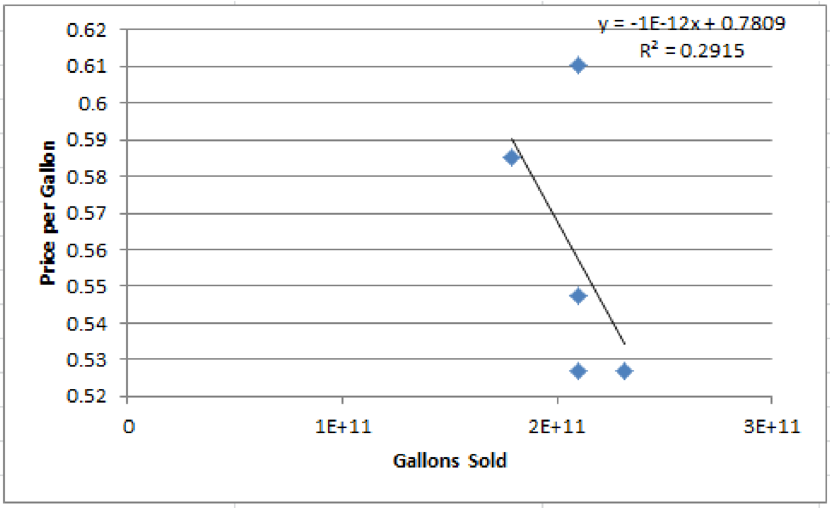


FIGURE 4.2: Graph of Commercial Water Demand



It can be seen from the data gathered that both demand curves are linear and downward sloping, indicating that this data corresponds with the assumed form.

4.2 Price Ceilings

The price ceilings faced by a water monopoly in Pennsylvania are determined on a per-company basis through a petitioning process. In this way, each firm ends up facing a price ceiling based on the PUC's decision regarding their individual request for a price given market demand. Since a change in demand alters the marginal revenue curve faced by a firm, it must be assumed that the requested price is one determined as a function of the firm's own optimization process (MC=MR) and what they believe is likely to be approved by the regulator. In the case of Pennsylvania American Water, the price ceiling faced differs by consumer market. For residential markets, the ceiling faced is \$1.0214 per gallon, and for commercial markets the price ceiling is \$0.9911 for the first 16,000 gallons per month, and \$0.7597 per gallon for all those after.

The residential and commercial per unit price ceilings are plotted below:

FIGURE 4.3: Graph of Residential Price Ceiling

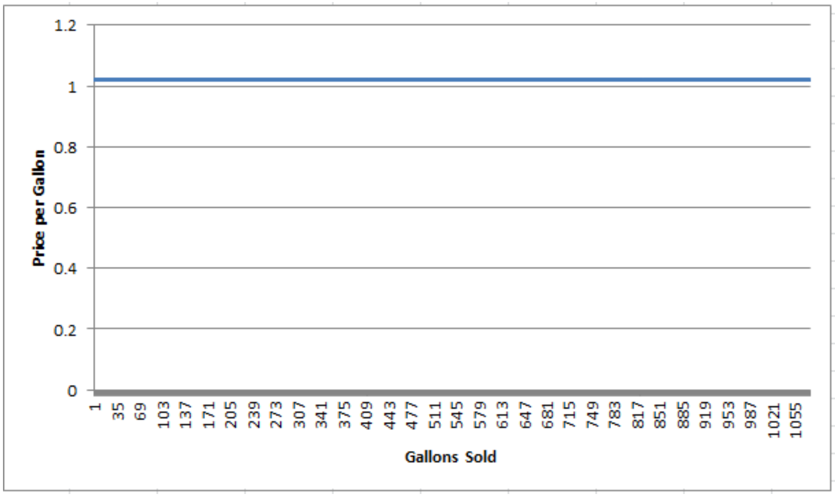
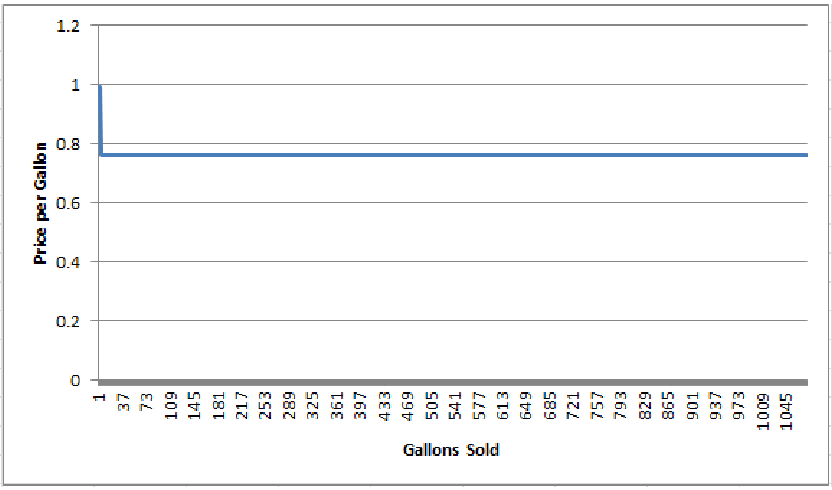


FIGURE 4.4: Graph of Commercial Price Ceiling



Now that data on demand and price ceilings has been obtained, this information can be integrated with firm cost function estimates so that an analysis of deadweight loss in this market may be conducted.

5 Estimating Deadweight Loss

5.1 Economic Theory

Since the market for water in Pennsylvania is divided into that for residential consumption and that for commercial use, a water monopoly faces two demand curves: one for each segment of this market. As a result, there are also two marginal revenue curves to which the firm optimizes its production and two price ceilings which are faced.

While in Pennsylvania the commercial price ceiling does adjust after the first 16,000 gallons per month, but given the large quantities at which this firm is making its marginal decisions, the ceiling will be displayed as flat at its price for above 16,000 gallons supplied.

If commercial demand were to increase such that the price ceiling for that market became binding, the deadweight loss in Pennsylvania's water market would include both the standard monopolistic losses but also any potential additional losses generated by the presence of the price ceiling.

The following section will estimate the existing deadweight loss in Pennsylvania's water market for a representative regional monopoly, will then increase commercial demand by a magnitude representative of expected growth, and calculate additional losses.

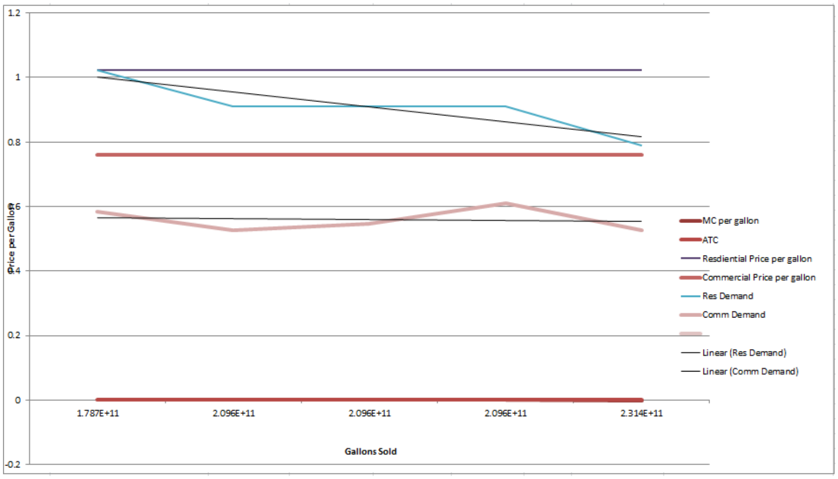
5.2 Empirical Analysis

A graph which includes the estimates of marginal cost, average total cost, residential water demand, commercial water demand, the price ceilings for each type of water sales, as well as the marginal revenue curves for both commercial and residential water was created and used to view the current state of deadweight losses Pennsylvania's water markets and estimate any potential changes due to a demand increase.

The values of marginal cost and average total cost are both approximately zero, allowing them to be considered equal, making the natural monopoly model described previously valid for this data.

Looking at the spreadsheet of data and the graphs produced from these numbers, the intersections between curves can be estimated, providing approximations which are used in a deadweight loss calculation.

FIGURE 5.1: Graph of Estimated Monopoly Curves, Demand Curves, and Price Ceilings



Since the demand curves for both residential and commercial water are observed to be below their respective price ceilings, the initial monopoly pricing of water will be determined with respect to the market demand curve and original marginal revenue curve faced by the firm, and not the implemented price ceilings.

In order to compare the potential increases in deadweight loss associated with demand increasing such that Pennsyvlania's water market price ceilings become binding, the status-quo deadweight losses (where the price ceilings are not taking effect) must first be calculated. Deadweight loss is calculated using the geometric formula for the area of a triangle ($\frac{1}{2}bh$), bounded between the intersection of demand and MC=ATC (estimated to be equal to zero), the monopoly quantity chosen for production (the intersection of MC and the MR curve), and the market price determined as a function of the demand curve. The calculations for the residential and commercial markets are shown as follows:

Residential Water Market Deadweight Loss:

The residential demand curve for water in Pennsylvania was estimated to be $(-4 \cdot 10^{-12})x + 1.6534$, which intersects the x-axis at a quantity of 413,350,000,000 gallons.

The intersection of marginal cost and marginal revenue was estimated to occur at $3.65 \cdot 10^{11}$ gallons, and the market price at this quantity can be determined as $(-4 \cdot 10^{-12})(3.65 \cdot 10^{11}) + 1.6534 = \$0.1934$.

This results in a final deadweight loss of $\frac{1}{2}[413,350,000,000 - 3.65 \cdot 10^{11}](0.1934) = \$4,675,445,000$.

Commercial Water Market Deadweight Loss:

The commercial demand curve was estimated to be of the form $(-1 \cdot 10^{-12})x + 0.7809$ and has an x-axis intercept of 778,090,000,000. Using the same intersection of MC and MR $(3.65 \cdot 10^{11})$, the market price is estimated to be $(-1 \cdot 10^{-12})(3.65 \cdot 10^{11}) + 0.7809 = \$0.4159$. This produces the resulting deadweight loss calculation of $\frac{1}{2}[778,090,000,000 - 3.65 \cdot 10^{11}](0.4159) = \$85,902,065,500$.

Now that these baseline values for deadweight loss in these markets have been calculated, they can be compared with the estimated deadweight losses found when demand increases such that the price demanded price would be above the approved posted price. In order to measure this effect, demand in the commercial and residential markets is increased by \$1 per gallon, representing an arbitrary positive increase in the price such that the price ceiling begins to take effect. In terms of demand's functional form this involves adding one to its intercept: $p_d = m \cdot q_d + (a + 1))$.

When the price ceilings take effect, not only is the price at which a transaction can be conducted altered, but so is the marginal revenue curve faced by the firm. The deadweight loss in this scenario is still determined by the formula for a triangle bounded between the intersection of demand and the x-axis, MC and MR, and the price at which the good is sold.

Since the marginal revenue curve constructed from observed values in the data is no longer relevant in this scenario, a new one is derived from the estimated market demand curve. Marginal revenue is defined as the derivative of total revenue with respect to quantity $(\frac{\delta TR}{Q})$, where total revenue is just the price multiplied by the quantity sold

$(TR = P \cdot Q)$. Price can be found by using the market demand curve $p_d = m \cdot q_d + (a+1))$ and substituting it into the total revenue equation for P.[1] Since marginal revenue becomes downward sloping where the demand curve intersects with the market price ceiling, it can be characterized as a piecewise function, where it is equal to the market price ceiling until the intersection of demand with the price ceiling, where it then becomes downward sloping. In this analysis, the slope of the marginal revenue curve is plotted beginning at that quantity and price, after which its intersection with the marginal cost curve (equal to zero in this case) is computed.

As observed in the data, the price charged for water will be equal to the PUC-approved value which applies as a price ceiling. In the data obtained for Pennsylvania American Water, prices are never observed to adjust downward, and only increase over time, supporting the claim that prices will remain at the approved maximum until the conclusion of a PUC petitioning process.

Deadweight losses for the residential and commercial water markets in this scenario where water demand increases such that the PUC price ceilings take effect are now computed as follows:

Residential Water Market Deadweight Loss With Increased Demand:

With the residential demand curve adjusted such that the price of water increases by one dollar, the new form of this curve becomes: $(-4 \cdot 10^{-12})x + 2.6534$ which has an x-intercept of 663,350,000,000. By equating this function to the value of the price ceiling ($1.0214), it is found that demand intersects the price ceiling at a quantity of 408,000,000,000 gallons.

Total revenue was computed by multiplying the demand curve by x, which has a derivative with the slope of $-8 \cdot 10^{-12}$, which when plotted as downward sloping from the intersection of demand and the price ceiling has the form $-8 \cdot 10^{-12}(x - 408,000,000,000) + 1.0214$. This marginal revenue function has an intercept of 535,675,000,000, which is where MR is equal to MC in this market. The posted price will then be charged by the firm for this quantity of water.

[1] Beggs (n.d.)

As a result, the deadweight losses experienced in this market are: $\frac{1}{2}[663,350,000,000 - 535,675,000,000](1.0214) = \$65,203,622,500$.

Commercial Water Market Deadweight Loss With Increased Demand:

After increasing the demand curve as described, the commercial market demand curve now becomes $(-1 \cdot 10^{-12})x + 1.7809$, which has an x-intercept of 1,778,090,000,000 gallons and intersects the market price ceiling of 0.7597 at 1,018,390,000,000 gallons.

The total revenue curve is determined by multiplying the demand curve by x, and marginal revenue is determined to have the slope of $-2 \cdot 10^{-12}$, which when plotted as downward sloping beginning at the intersection of demand and the price ceiling is $-2 \cdot 10^{-12}(x - 1.01839 \cdot 10^{12}) + 0.7597$. When taking the slope from this function and plotting the downward sloping MR curve from demand's intersection with the price ceiling, the intersection of this curve with MC=0 is found to occur at 1,398,240,000,000 gallons. The price charged is the posted price of 0.7597.

This leads to the deadweight loss calculation of $\frac{1}{2}[1,778,090,000,000 - 1,398,240,000,000](0.7597) = \$144,286,022,500$.

Comparing these deadweight losses with those found in the original market scenario, it is found that when demand increases such that the price ceilings take effect, deadweight loss increases notably in each market. In the residential market, the difference between the estimated deadweight loss values is \$60,528,177,500, amounting to an increase of 92.83%. For the commercial market, the difference is found to be \$58,383,957,000, or 40.46%. While these numbers are extremely large given the market being discussed, this is likely due to estimation error, and the percentage values provide a more insightful view into the magnitude of change experienced within each segment of the water market during this period of regulatory lag.

6 Conclusions, Limitations, Recommendations for Future Work

This thesis studied the effects of water market regulation on deadweight loss for a representative monopoly in the state of Pennsylvania in a scenario of increasing demand and fixed prices. The analysis was conducted by first estimating the relevant cost and revenue functions faced by a representative Pennsylvania water monopoly which would determine production decisions. Then, both commercial and residential water demand in the state were estimated and observed with respect to their approved prices. Existing deadweight loss in the Pennsylvania water market was estimated, and then water demand was increased in this model by an positive amount where demand would clearly exceed the established price ceilings for that firm. Deadweight loss was then calculated for this new scenario, with the firm charging the maximum approved price for water.

When comparing the estimations of deadweight loss found in each scenario, it was seen that an increase in demand such that the established price ceiling take effect results in an increase of deadweight losses of 92.82% for the residential market, and 40.46% for the commercial market. These results show that lags in adjusting regulated prices can create notable increases in deadweight loss when demand increases but prices cannot adjust dynamically. These increased losses are found to be of a greater magnitude for residential markets than commercial markets. While estimations of firm cost curves and water demand were limited by the amount of relevant data available for use, comparing the difference between these estimates provides evidence suggesting that a non-negligible increase in deadweight loss occurs in this scenario where demand increases but prices and regulation have not responded. This finding motivates the need for responsive shifts in market regulations during periods of changing market conditions if market efficiency is a concern for the PUC.

To overcome data limitations, future work this area could involve the collection and use of more specific firm-level and market demand data, a larger sample of cost and revenue data if it is available, as well as forecasts of future demand growth expected to be driven by industries such as those engaging in hydraulic fracturing within the state of Pennsylvania.

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