Spatio-economic Analysis of Water-related Appliance Retrofits: NYSERDA Case Study

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1 – Background

In part with the American Recovery and Reinvestment Act (ARRA) of 2009, the New York State Energy Research and Development Authority (NYSERDA) launched an $18.7 million program that offered rebates to residential customers in exchange for the purchase of high-efficiency household appliances. The program was known as "New York's Great Appliance Swap-Out". The program was launched on February 12, 2010, and replaced approximately 170,000 clothes washers, dishwashers, refrigerators, and freezers (**New York State Energy Research and Development Authority, 2010**).

In this case study, a spatio-economic model of water-related appliance retrofits was adapted to evaluate the rebates offered by the NYSERDA program. The goal of this case study is to evaluate how the NYSERDA rebates influenced cost-effectiveness of clothes washer and dishwasher retrofits at the county-level for typical New York homes, accounting for spatial factors such as prices of water and energy (**J. S. Vitter, "*Opportunities for Urban Water Systems to Deliver Demand-Side Benefits to the Electric Grid*", 2018**). The impact of the NYSERDA rebate is assessed in isolation, compared to a rebate associated with the avoided values of wholesale energy and water, and evaluated in conjunction with incentives related to internalized greenhouse gas costs and free installation. Results were estimated for homes using either an electric or natural gas hot water heater ($\eta_{ELECTRIC} = 92\%$; $\eta_{GAS} = 62\%$).

. Finally, the aforementioned avoided wholesale values of energy and water – along with the rebates presented by NYSERDA, annualized at a fixed discount rate and life of appliance – were calculated and used to determine a breakeven wholesale water rate for all counties across New York in which NYSERDA offering rebates would make sense. This breakeven wholesale

water rate was compared with typical levelized wholesale costs of constructing a new water supply project throughout the state of New York, to determine if the state of New York should construct new water supply projects, or conserve water by subsidizing water efficiency through the NYSERDA rebates, on a county-by-county basis.

2 – Methodology

A mathematical flow analysis (MFA) model linked to economic analysis was adapted from prior work (**Vitter, 2018**) to evaluate the impacts of the NYSERDA program using characteristic prices, costs, and efficiency standards corresponding to 2010. Inputs to the MFA model were updated to account for clothes washer and dishwasher efficiency standards circa 2010, which have since become more stringent.

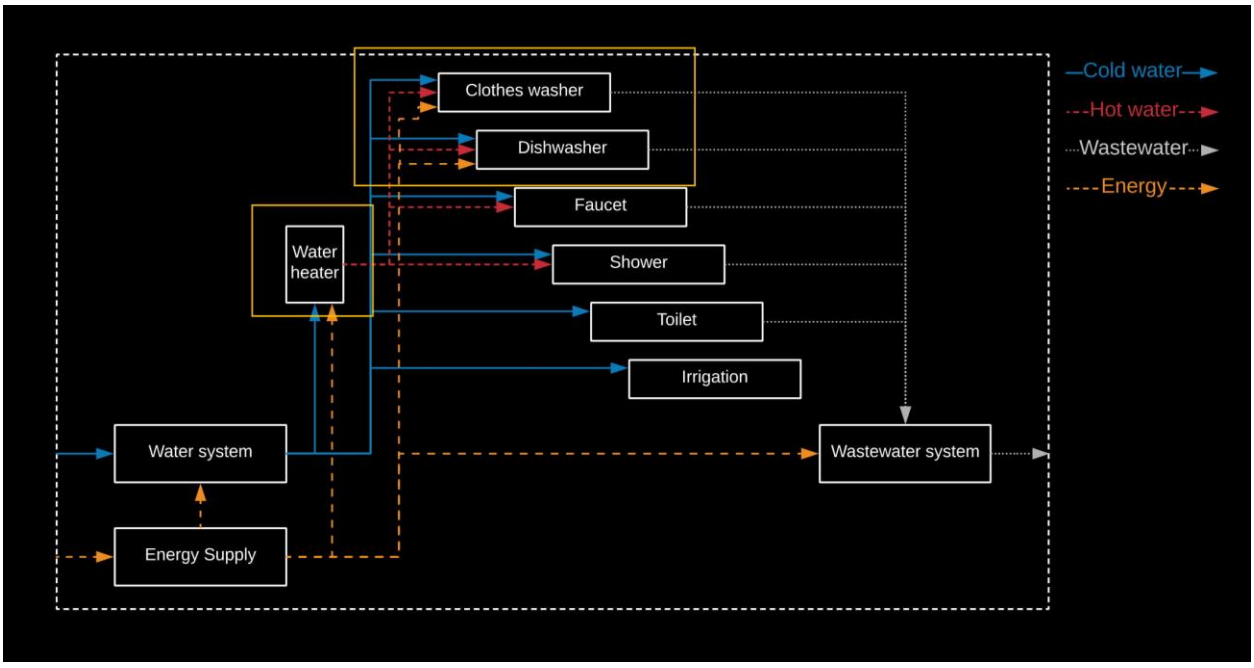

Figure (a): MFA model obtained from prior work. The pertinent appliances for this case study are boxed in orange.

Additionally, residential utility prices of electricity, natural gas, water, and wastewater have changed in New York since 2010. To accurately reflect the economics of NYSERDA appliance swaps, New York utility prices were estimated for 2010. Average residential utility rates for electricity and natural gas for New York state for 2010 were estimated by adjusting county-level 2016 rates (**Huggins, *"U.S. Electric Utility Companies and Rates: Look-up by Zip code (2016)",* 2016**) by a state-level factor. Relative to 2016, average electricity and natural gas prices in New York were 11.62% and 29.37% more expensive in 2010, respectively (**Hankey et. al, 2011**). For comparison, county-level rates were presented in terms of 2017-dollars.

Average water and wastewater rates were modeled with annual escalation rates of 5.34% and 5.98%, respectively, between 2010-2017 based on a national water rate database (**American Water Works Association, 2016 Water and Wastewater Rate Survey, 2016**). County-level rates estimated by prior work (**Vitter, 2018**) were adjusted backwards over seven years to account for rate escalation, then adjusted forward to put in terms of 2017-dollars (at an average annual inflation rate of 1.75%). The prices of carbon and methane ($/tonne), as well as the fugitive methane rate (%), were inherited from the base model (**Vitter, 2018**). Similarly, average state-level wholesale costs for electricity and natural gas were inherited from the base model.

Table 1: Breakdown of residential prices.

	NY Avg. in 2010 (Inflated to 2017-dollars)	*NY Avg. in 2016/2017 (Today)*	*% Change*
Electricity ($/kWh)	*0.2039*	*0.1802*	*-11.62*
Natural Gas ($/kcf)	*15.73*	*11.11*	*-29.37*
Water ($/kgal)	*Varies by County*	*Varies by County*	*+5.34*
Wastewater ($/kgal)	*Varies by County*	*Varies by County*	*+5.98*

New York's Great Appliance Swap-Out took into account retrofitting old appliances with ENERGY STAR and Consortium for Energy Efficiency-, or CEE-, rated appliances. In general, CEE-rated appliances consume less water and electricity compared to that of ENERGY STAR-rated appliances. Both ENERGY STAR and CEE data were available for clothes washers, while only CEE data was available for dishwashers. In the Great Appliance Swap-Out, less than 2% of all clothes washer retrofits involved upgrading to CEE clothes washers, contributing little impact to overall savings. Thus, CEE clothes washer data were ignored in this analysis. Since only CEE data was available for dishwasher retrofits, an analysis of CEE-rated dishwasher retrofits is included in this case study.

It is assumed that, for this analysis, the clothes washers and dishwashers in the New York dataset are set to the "typical" user category, using up to 500 cubic feet (3,740 gallons) per month, and are of standard sizes. Additionally, this analysis assumed that there were no additional electricity savings on the basis of direct machine electricity use.

2.1 – Clothes Washers

The amount of water used per cycle for a clothes washer, Q_{CW}, is the product of the capacity of the clothes washer, C_{CW} (ft^3), and the water factor, *WF* (gallons/cycle/ft^3) [water factor was renamed "integrated water factor" or *IWF*, in March 2018] [**ENERGY STAR, *"Clothes Washers Key Product Criteria",* 2018**]. For ENERGY STAR-rated clothes washers, an average capacity of 3.3 ft^3 was used, based on data found in existing literature and specifications dating back to 2010 or earlier (**ENERGY STAR, *"ENERGY STAR Qualified Clothes Washers",* 2010**). A water factor of 6.0 was used, based on 2011 efficiency standards for clothes washers provided by ENERGY STAR. The lower the WF, the less amount of water the appliance uses. It is important to note that 2010 and earlier ENERGY STAR efficiency standards had an upper-bound WF of 8.0; since this rebate program took place in both 2010 and 2011, either WF is permissible. For the sake of this analysis, a WF of 6.0 was utilized (**ENERGY STAR, *"Program Requirements Product Specification for Clothes Washers Eligibility",* 2011**). According to ENERGY STAR (**ENERGY STAR, *"Clothes Washers - 2007 Partner Resource Guide",* 2007**), the average family uses 13,500 gallons of water per year to wash clothes, washing on average 392 cycles per year. 13,500 gallons per year divided by 392 cycles per year outputs a Q_{cw} value of 35 gallons per cycle for a clothes washer under "Traditional Standards". Pertinent parameters for clothes washers can be found in Table 2 below.

Table 2: Parameters for clothes washers. The bold values are used as set parameters in the analysis.

	Traditional Standards	*ENERGY STAR Standards*
Capacity, C_{cw} (ft^3)	*3.3*	*3.3*
Water Factor, WF (gal/cycle/ft^3)	--	***≤ 6.0***
Q_{cw} (gal/cycle)	***35***	***19.8***

2.2 – Dishwashers

Unlike clothes washers, CEE-rated dishwashers only have one tier for efficiency standards. In fact, they are of the same standards set by ENERGY STAR. Additionally, ENERGY STAR specifications explicitly state the amount of water used per cycle, Q_{DW}. Q_{DW} for a traditional dishwasher was set at 9.5 gallons per cycle, according to a study done on dishwasher retrofits in California (**Koeller & Company, 2007**). Pre-2010 ENERGY STAR dishwasher specifications limited water consumption to 5.8 gallons per cycle (**ENERGY STAR, *"Program Requirements for Residential Water Heaters Partner Commitments Commitment",* 2009**).

2.3 – Rebates

NYSERDA offered rebates of $75 clothes washers during the program. When an older device was recycled, rates increased to $100. For dishwashers, NYSERDA offered either a $100 or $115 rebate, respectively, depending on appliance recycling. NYSERDA rebates are summarized in 2017-dollars in Table 3, assuming old appliances are recycled.

Table 3: Clothes washer and dishwasher rebates offered through NYSERDA's program.

Rebate with Recycling Appliance	*Rebate Amount (2017-Dollars) [$]*
ENERGY STAR-rated clothes washer	*112.07*
CEE-rated dishwasher	*128.88*

2.4 – Capital and Installation Costs

Capital and installation costs for installing appliances can vary greatly by model, efficiency, and region. Installation costs can greatly depend on whether a professional is hired to install the appliance in question, or if the customer chooses to install it him or herself. The average installation cost for a clothes washer in the New York state area was estimated as either $40 or $250, depending upon if professional installation was required (**Homewyse, *"Cost to Install a Clothes Washer",* 2018**). For dishwasher installation, total costs are estimated at $300 (**Homewyse, *"Cost to Install a Dishwasher",* 2018**). Capital costs can depend on the efficiency of the appliance, the make and model, and aesthetics, to name a few. In this model, the average ENERGY STAR-rated clothes washer is set at $650, while the CEE-rated dishwasher is set at $400. According to ENERGY STAR (**ENERGY STAR, "Clothes Washer Product Snapshot - May 2008", 2008**), the average price for an ENERGY STAR-rated clothes washer in 2008 was close to $1,000. In 2017, this price dropped to anywhere between $500 and $800, most likely due to technological advances in efficiency and cheaper production costs (**Home Depot, "Clothes Washers", 2017**). Therefore, it can be assumed that $650 is a reasonable price for an ENERGY STAR-rated clothes washer in 2010. The capital costs for CEE-rated dishwashers, however, were more difficult to assess. While NYSERDA listed the make and model of applicable CEE-rated

dishwashers, many of these dishwashers have been discontinued, rendering it difficult to research corresponding capital costs. Additionally, many home improvement stores, such as Home Depot, categorize CEE-rated dishwashers under ENERGY STAR dishwashers. The most popular CEE-rated dishwashers that could be found were anywhere from $350 to $600. Thus, $400 was used for the CEE-rated dishwasher (**Home Depot, "Dishwashers", 2017**). It is assumed that all capital and installation costs are in 2017-dollars. A breakdown of these costs can be found in Table 4 below.

Table 4: Breakdown of installation and capital costs for the clothes washer and dishwasher.

	Installation Cost, no Professional Required ($)	*Installation Cost, Professional Required ($)*	*Capital Cost ($)*
ENERGY STAR-rated clothes washer	*40.00*	*250.00*	*650.00*
CEE-rated dishwasher	–	*300.00*	*400.00*

3 – Results

The sensitivity of cost-effectiveness for clothes washer and dishwasher retrofits was quantified under the following parameters were for the clothes washer retrofit: the efficiency program (ENERGY STAR), installation costs (based on whether a professional was hired to replace the washer), and rebate based on a fixed value granted by NYSERDA. For the dishwasher retrofit, the same parameters were varied (however, only CEE data was given for dishwashers), with the exception of the installation cost (since only one installation cost was assigned to the dishwasher retrofit). Figures 1-3 below present these results on a county-by-county basis. Figures 4 and 5 below present age distributions of recycled appliances for each kind of retrofit.

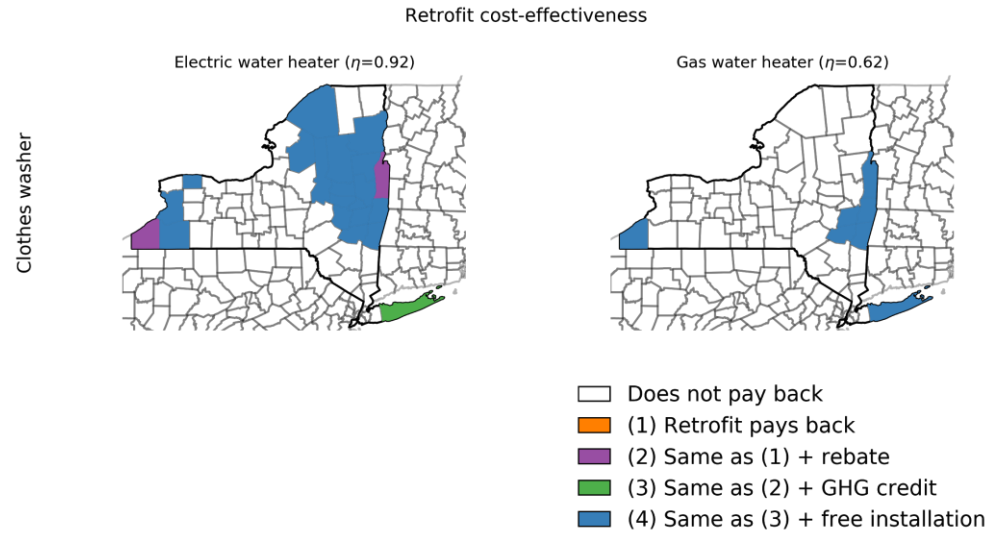

Figure 1: Retrofit cost-effectiveness for an ENERGY STAR-rated clothes washer, no professional installation involved, rebate based on fixed value granted by NYSERDA.

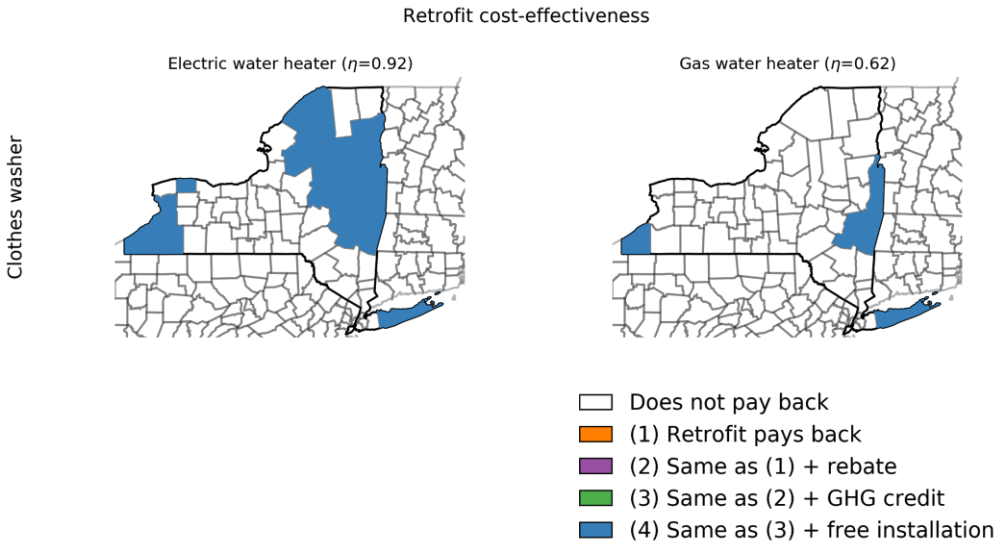

Figure 2: Retrofit cost-effectiveness for an ENERGY STAR-rated clothes washer, professional installation involved, rebate based on fixed value granted by NYSERDA.

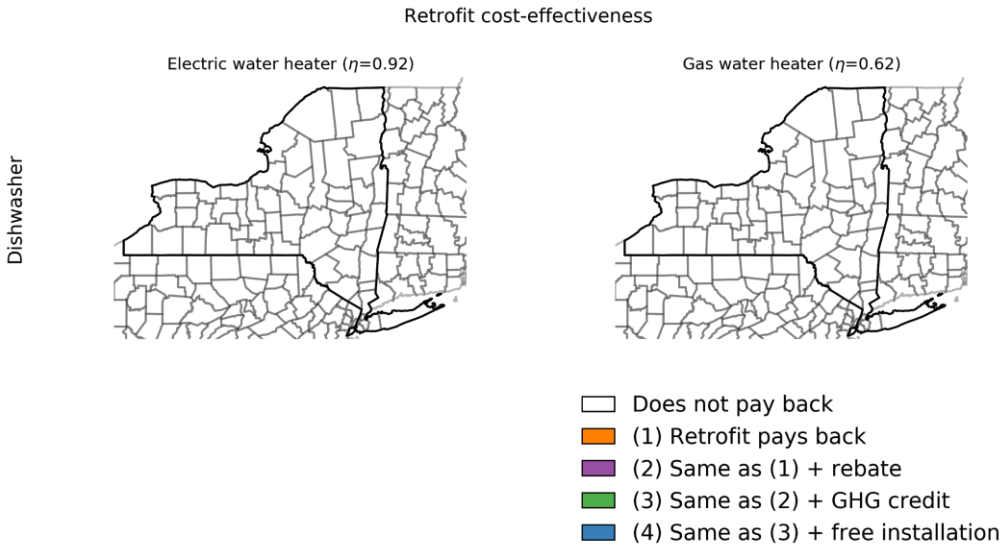

Figure 3: Retrofit cost-effectiveness for a CEE-rated dishwasher, professional installation involved, rebate based on fixed value granted by NYSERDA.

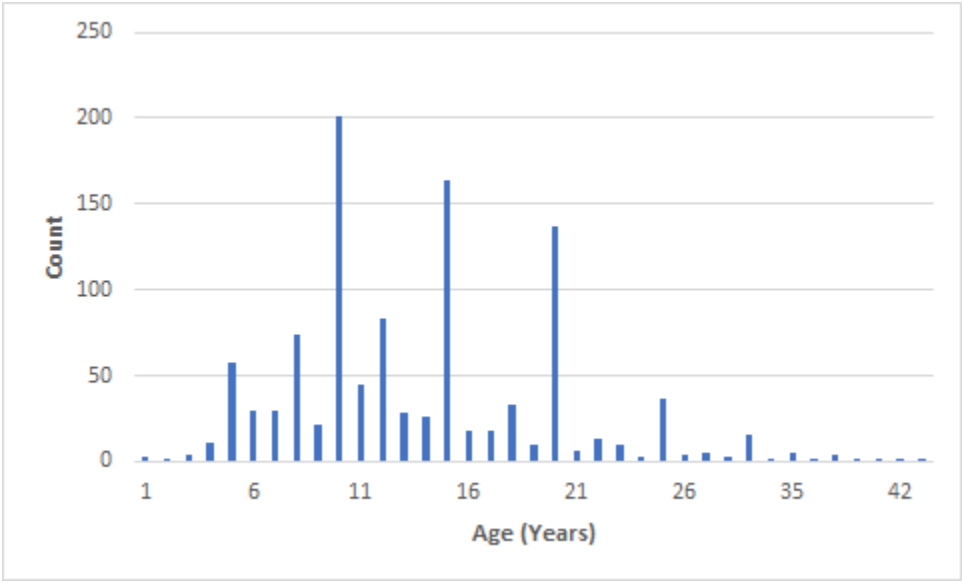

Figure 4: Distribution of age of recycled appliance for a CEE-rated dishwasher retrofit.

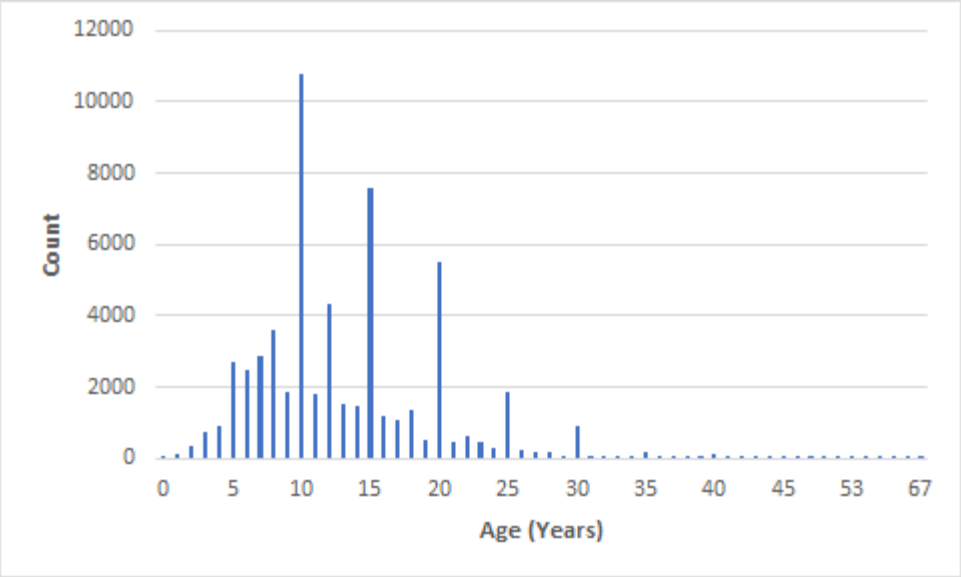

Figure 5: Distribution of age of recycled appliance for an ENERGY STAR-rated clothes washer retrofit.

4 – Discussion of Results

Based on the figures above, the most cost-effective scenario is retrofitting to an ENERGY STAR-rated clothes washer in which the customer installs it him or herself, and has an electric hot water heater (corresponding to the maps in Figure 1). In this scenario, retrofitting to an ENERGY STAR-rated clothes washer does not pay back in the long run for 41 of the 62 counties; meanwhile, the retrofit pays back with the NYSERDA rebate for 2 counties; pays back with the NYSERDA rebate and greenhouse gas credit for 1 county; and pays back with the NYSERDA rebate, greenhouse gas credit, and free installation for the remaining 18 counties. This corresponds to counties in the left map of Figure 1. The right map in Figure 1 depicts a customer owning a natural gas hot water heater, rather than an electric hot water heater. In this scenario, retrofitting to an ENERGY STAR-rated clothes washer does not pay back in the long run for 55 of the 62 counties;

meanwhile, the retrofit pays back with the NYSERDA rebate, greenhouse gas credit, and free installation for the remaining 7 counties.

Retrofitting to an ENERGY STAR-rated clothes washer with professional installation involved, with either an electric or natural gas hot water heater present (corresponding to the maps in Figure 2) produced similar results to that of Figure 1, but were not as cost-effective. With an electric hot water heater (left map), retrofitting to an ENERGY STAR-rated clothes washer does not pay back in the long run for 41 of the 62 counties; meanwhile, the retrofit pays back with the NYSERDA rebate, greenhouse gas credit, and free installation for the remaining 21 counties. With a natural gas hot water heater (right map), retrofitting to an ENERGY STAR-rated clothes washer does not pay back in the long run for 55 of the 62 counties; meanwhile, the retrofit pays back with the NYSERDA rebate, greenhouse gas credit, and free installation for the remaining 7 counties.

Retrofitting to a CEE-rated dishwasher with professional installation involved, with either an electric or natural gas hot water heater present (corresponding to the maps in Figure 3) produced trivial results. With an electric hot water heater (left map), retrofitting to a CEE-rated dishwasher does not pay back in the long run for all 62 counties. With a natural gas hot water heater (right map), retrofitting to a CEE-rated dishwasher does not pay back in the long run for all 62 counties.

The results above show that customers experience higher savings from retrofitting when an electric hot water heater is utilized. This makes sense, because while electric hot water heaters are more efficient than natural gas hot water heaters, the price of electricity is more than that of natural gas when compared on an equivalent price per kilowatt-hour ($0.1802/kWh for electricity, versus $11.11/kcf = $0.038/kWh for natural gas, in 2017-dollars). So, customers with electric hot water heaters experience higher savings due to a higher price of energy consumed.

It is evident that the more expensive the capital and installation costs for an appliance is, the smaller the cost-effectiveness of the appliance. Even though CEE-rated clothes washers were not analyzed in this research, comparing capitals costs between ENERGY STAR- and CEE-rated appliances can provide some insight on the relationship between efficiency and cost. As mentioned in Section 2, CEE-rated appliances are more efficient in their electricity and water consumption than that of ENERGY STAR-rated appliances. It was found that a CEE clothes washer retrofit was not as effective as an ENERGY STAR-rated clothes washer retrofit on a county-by-county basis. This is because CEE clothes washers and dishwashers tend to have higher capital costs than those of ENERGY STAR-rated clothes washers and dishwashers, due to the increased costs for developing new technologies to achieve maximum efficiency for the aforementioned appliances. Based on the model, purchasing an ENERGY STAR-rated clothes washer is more cost-effective than a CEE clothes washer, having to spend less upfront and gain more in the long run. Additionally, the rebate for a CEE-rated dishwasher is only applicable when the dishwasher is part of a three-appliance package of CEE-rated appliances, including a clothes washer and a refrigerator. The total valued rebate of this package is $500 ($560.35 in 2017-dollars) if none of the old appliances are recycled, and $555 ($621.98) if all of the appliances are recycled. It would be interesting to see the cost-effectiveness of retrofitting with ENERGY STAR dishwashers, although data for these were not available.

Figures 4 and 5 present age distributions of recycled appliance by retrofit scenario. The model initially assumed a lifetime of 12.6 years for both a dishwasher and clothes washer, based on initial parameters in prior work (**Vitter, 2018**). In observing the distribution of age of each recycled appliance, the mode for both the ENERGY STAR-rated clothes washer and CEE-rated dishwasher was a little above 10 years, supporting our initial intuition. Additionally, the average

age of recycled appliance for ENERGY STAR-rated clothes washer and CEE-rated dishwasher retrofits were 13.13 and 13.87 years old, respectively. However, these averages are skewed due to some of the recycled appliance being over 20 years old. Thus, setting the age of recycled appliance as 12.6 years old for both the clothes washer and dishwasher is just.

Another area of interest was calculating annualized values for avoided wholesale energy, *aVAWE*; avoided wholesale water, *aVAWW*; and the rebate for both clothes washers and dishwashers given by NYSERDA, *aNYSERDA* (all in $/year), for households with either electric or natural gas hot water heaters. These parameters were calculated to help determine a breakeven wholesale water rate for each county in New York that would make the NYSERDA rebate make sense, *WholesaleNYSERDA* ($/thousand gallons). Then, this breakeven wholesale water rate was compared with typical levelized wholesale costs of new water supply in New York, *WholesaleTypical* ($/thousand gallons). With these two parameters, the state of New York is presented with the following options: either expand the public water supply by building a new project (WholesaleTypical), or save water by subsidizing water efficiency via the NYSERDA rebates (WholesaleNYSERDA).

WholesaleTypical rates were gathered from the Onondaga County Water Authority, and range from $2.90-2.24 per thousand gallons, for a project using 200,000-2,700,000 gallons per month, respectively (**OCWA, *"Rate Schedule No. 7 – General Municipal Wholesale Service – Monthly",* 2017**). In this case study, it is assumed that these values are representative WholesaleTypical rates across the state of New York.

4.1 – Calculating aVAWE, aNYSERDA, aVAWW, and WholesaleNYSERDA

aVAWE was defined as the sum of the product of total saved electricity annually (EL_S, kWh/year) by wholesale rates for electricity (WS_{EL}, $/MWh), and the product of total saved natural gas annually (NG_S, MMBtu/year) by wholesale rates for natural gas (WS_{NG}, $/MMBtu). An equation for solving aVAWE is presented below.

$$aVAWE = \sum \left[\left(\frac{(EL_S * WS_{EL})}{1{,}000\ kWh/1\ MWh} \right) + \left(\frac{NG_S * WS_{NG}}{293.3\ kWh/1\ MMBtu} \right) \right]$$

aNYSERDA was calculated by annualizing the cost of the rebate presented by NYSERDA (for either an ENERGY STAR-rated clothes washer or CEE-rated clothes washer) over 12.6 years at discount rate of 5%. aVAWW was calculated by subtracting aVAWE from aNYSERDA, as it is assumed that aNYSERDA accounts for both energy and water savings. It is important to note that aVAWE and aVAWW each have two separate values – one for households with electric hot water heaters, and the other for households with natural gas hot water heaters. Meanwhile, aNYSERDA is independent of the type of hot water heater a household contains. WholesaleNYSERDA was calculated by dividing aVAWW by the total amount of water savings from the retrofit (gallons/year, converted into thousand gallons/year).

4.2 – WholesaleTypical versus WholesaleNYSERDA – ENERGY STAR-rated Clothes Washer and CEE-rated Dishwasher

The average WholesaleNYSERDA rates across all 62 counties based on the ENERGY STAR-rated clothes washer retrofit, for households with either an electric or natural gas hot water

heater, regardless of installation method (professional versus personal), were $1.34 and $1.78 per thousand gallons, respectively. Meanwhile, the average WholesaleNYSERDA rates across all 62 counties based on the CEE-rated dishwasher retrofit, for households with either an electric or natural gas hot water heater, with professional installation, were $22.16 and $24.54 per thousand gallons, respectively.

Table 5: Comparison of WholesaleTypical and WholesaleNYSERDA rates for both retrofits. The range for WholesaleTypical is based on a project consuming 200,000-2,700,000 gallons per month, respectively.

	Households Containing Electric Hot Water Heaters			*Households Containing Natural Gas Hot Water Heaters*		
	Minimum ($/kgal)	*Average ($/kgal)*	*Maximum ($/kgal)*	*Minimum ($/kgal)*	*Average ($/kgal)*	*Maximum ($/kgal)*
WholesaleTypical	–	*2.90-2.24*	–	–	*2.90-2.24*	–
WholesaleNYSERDA, ENERGY-STAR-rated Clothes Washer Retrofit	*1.25*	*1.34*	*1.47*	*1.70*	*1.78*	*2.16*
WholesaleNYSERDA, CEE-rated Dishwasher Retrofit	*21.74*	*22.16*	*22.85*	*24.21*	*24.54*	*26.61*

Based on the results in the preceding paragraph, as well as Table 5 above, it is ideal for the state of New York to try to save water by subsidizing water efficiency via the NYSERDA rebate

for an ENERGY STAR-rated clothes washer in the counties in which some sort of cost-effectiveness is present, since WholesaleNYSERDA rates are less than the aforementioned range of WholesaleTypical rates. However, building a new water supply project makes more sense in the counties in which an ENERGY STAR-rated clothes washer retrofit is not feasible, as WholesaleNYSERDA rates are more than the aforementioned range of WholesaleTypical rates. A CEE-rated dishwasher retrofit is proven to be not ideal in all 62 counties, as the WholesaleNYSERDA rates for all 62 counties are almost $18 per thousand gallons more than the aforementioned range of WholesaleTypical rates. Therefore, building a new water supply project would be more ideal for the state across all 62 counties.

An interesting observation is the increase in WholesaleNYSERDA rates for a house with a natural gas hot water heater. Since WholesaleNYSERDA is dependent on aVAWW, and aNYSERDA is independent of type of hot water heater, a house with a natural gas hot water heater has smaller aVAWE values. The smaller the aVAWE, the less total saved electricity and natural gas annually (EL_S and NG_S, respectively). This makes sense, as a natural gas hot water heater is less efficient than an electric hot water heater due to heat loss through venting.

5 – Conclusion and Recommendations for Future Work

The goals of this case study were twofold – evaluate how NYSERDA rebates influenced cost-effectiveness of clothes washer and dishwasher retrofits at the county-level for typical New York homes, and determine breakeven wholesale water rates on a county-by-county basis in which rebates offered by NYSERDA would make sense. According to the results, the ENERGY STAR-rated clothes washer retrofit proved to be more cost-effective than the CEE-rated dishwasher retrofit on a county-by-county basis, across the state of New York. Additionally, breakeven

wholesale water rates based on ENERGY STAR-rated clothes washer retrofits were proven to be reasonable when compared to the levelized wholesale cost of a new water supply project, while breakeven wholesale water rates based on CEE-rated dishwasher retrofits were proven to be ineffective.

Future work could involve utilizing the aforementioned MFA on data sets similar to that of the NYSERDA rebate program, as well as confirming whether the NYSERDA rebates considered both water and energy savings. Additionally, the MFA model could be expanded to include appliances such as refrigerators and freezers, the two other appliances that were retrofitted in the NYSERDA rebate program.

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