QUIDPRO

I. General Model Description

Seattle Public Utilities (SPU) uses economic and econometric modeling to better understand costs, benefits and trends in solid waste generation and management, and to measure results of programs to prevent waste and divert discards from disposal. One of these models is the QUIDPRO econometric model -- Quantitatively Understanding the Impacts of Diversion Programs for Recyclables and Organics.

QUIDPRO encompasses seven equations, statistically estimated using ordinary least squares (OLSQ) regression. These seven equations track monthly quantities for residential garbage, curbside recycling, curbside organics, apartment recycling, commercial garbage, self-haul garbage and self-haul yard waste. Solid waste materials managed on site by households or businesses, or self-hauled to out-of-Seattle transfer facilities, disposal sites or other dispositions are not tracked by QUIDPRO's equations.

Each QUIDPRO equation shows variations in one of the tracked monthly waste quantities as a function of a number of explanatory variables. Examples of explanatory variables include number of households, number of collection days per month, business and occupation (B&O) tax receipts, weather, season of the year, garbage collection fees, self-haul garbage disposal fees, recycling and organics collection program characteristics, and disposal bans.

Explanatory variables that have important impacts and explain significant variations in monthly waste quantities over time are identified through an iterative process. The ***first*** step uses the OLSQ statistical procedure in the GRETL (Gnu Regression, Econometric and Time Series Library) statistical package[1] to produce preliminary estimates for impacts of potential explanatory variables. These impact estimates are QUIDPRO equation coefficients that multiply monthly values for explanatory variables to yield impacts on waste quantity.

The ***second*** step is to test the statistical significance of these coefficients. This test basically compares a variable's estimated impact coefficient with that impact coefficient's standard error. One can think of this as comparing a sample average with its standard deviation. If the impact coefficient is very small relative to its standard error, then we are not very confident that we have a good estimate of the explanatory variable's impact. In fact we don't even have much confidence that we know whether the variable's impact is positive or negative. In this case the potential explanatory variable is removed from the list of candidate explanatory variables, and the OLSQ procedure re-estimates coefficients for the remaining variables.

Once the explanatory variables list is narrowed down to exclude all insignificant variables, the ***third*** step is to review summary statistics to determine if an estimated equation is a good fit for explaining changes over time in waste quantity. Goodness of fit is often judged by R-squared – a statistical measure of how well the fitted regression equation's monthly estimates match actual monthly waste quantities. R-squared is a number between 0 and 1 that indicates, in the case of a waste quantity, the portion of the monthly changes in that waste quantity that are explained by

[1] GRETL is open source software available for no charge at http://gretl.sourceforge.net/win32/ .

the changes in monthly explanatory variable quantities. R-squared equal to 1 means changes are all explained and 0 means none of the changes are explained. If R-squared is low, then we need to look for additional variables that might explain some of the “unexplained” variation in waste quantities and work through the explanatory variables identification process once again.

Appendix 1 shows GRETL outputs for each of the seven explanatory equations, as well as a graph for each equation showing actual waste quantity in comparison to estimated (i.e., fitted or “explained”) quantity . Output for each equation shows estimated coefficients for explanatory variables, coefficient standard errors and the test of statistical significance for each coefficient. GRETL output also lists R-squared, adjusted R-squared, F and P-value for F, Log-likelihood, rho, Durbin-Watson, and other measures of possible interest in evaluating the accuracy of an estimated equation for explaining actual movements in a waste quantity. We leave it to the interested reader to review most of these measures.

Here we discuss just one – rho, a measure for an estimated equation of autocorrelation (often referred to as serial correlation) in the difference between fitted (i.e., estimated) and actual waste quantities over time. These differences are the errors in our fitted equation’s attempt to replicate actual waste quantities. If there is autocorrelation, then the tests of statistical significance for estimated coefficients are no longer valid. This is because significant autocorrelation makes unadjusted standard errors inaccurate for estimating a coefficient’s standard error and thereby not reliable for determining whether a potential explanatory variable is statistically significant.

Fortunately, GRETL provides an adjustment for serial correlation, as well as for more complex correlations, called heteroskedasticity, within the sequence of error terms. The phrase “heteroskedasticity and autocorrelation consistent (HAC) standard errors” in GRETL output indicates that coefficient standard errors have been adjusted. These adjustments provide more accurate estimates for each coefficient’s standard error and improve reliability of the statistical significance tests for explanatory variables.

Besides testing for heteroskedasticity and autocorrelation, GRETL tests whether explanatory equations should have linear or non-linear form. Early in the development of QUIDPRO, tests of functional form were conducted on a data set that did not cover as many recent years as are included in data used for estimating the equations shown in Appendix 1. Based on these early tests, examination of various non-linear forms, and the complexities involved in adopting non-linear specifications, the simple linear equation is used for all QUIDPRO equations.

Equation specification for residential garbage illustrates the process and reasoning for choosing linear. Initial tests rejected the simple linear form for the residential garbage equation. However, nonlinear log and quadratic explanatory variable terms were mostly statistically insignificant. The double log constant elasticity specification yielded similar results. Regressing the log of residential garbage on linear explanatory variables, the log-linear specification, did show promise. However, it was not that much better at explaining garbage quantity variations than the simple linear form. At the same time, the simple linear form for curbside recycling was preferable to any log linear or nonlinear specification. Hence, the linear specification for garbage was chosen because it made coefficient estimates in the garbage and recycling equations, and their relationships, easier to interpret.

II. Results for Residential Recycling, Organics and Garbage Collection

Figure 1 portrays actual and estimated residential combined single-family (SF) and multi-family (MF) monthly collected waste generation and disposal per household per collection day through August 2014. Actual and estimated collections of garbage for disposal are shown beginning in January 1977.

Residential generation shown in Figure 1 is the sum of curbside recycling, apartment recycling, curbside organics and residential garbage disposal collections. Actual generation figures are shown beginning January 1989. By that date curbside recycling, apartment recycling and yard waste collections were available for all households, although households and apartment buildings had to sign up for yard waste collection. Prior to that date comprehensive data on household diversion are not available, making it difficult to track or estimate residential waste generation.

Once curbside diversion programs began, collection quantities for single family recycling, apartment recycling and subscription-based yard waste recycling, along with collection quantities for residential garbage, provide a fairly comprehensive picture of household waste generation trends. Garbage collection in Seattle is mandatory for all households and self-haul garbage quantities from households do not appear to be significant in total or to be increasing over time.

Estimated residential waste generation is shown beginning January 1990. By this date curbside recycling and yard waste collection programs had been in existence for at least a year, and collection quantities had mostly ramped up to their initial full-scale diversion levels.

Note that the quantities portrayed in Figure 1 are garbage, recycling and organics collection quantities divided by two important variables – number of collection days in a month and number of households (SF + MF) signed up for garbage collection for that month. Monthly collection tonnage is divided by the number of collection days in order to adjust for variations from month to month in the number of days that collection trucks provide service to household customers. Collection tonnage also is divided by household count in order to separate out the effect on total tonnage of growth in the number of households from the effects of other variables, such as household size, household income and weather, which determine the amounts of waste generated by each household. With these two normalizations, the four residential QUIDPRO equations provide estimates for a household's waste generation and disposal behavior in each month.

As can be seen by the closely aligned movements between actual and estimated in Figure 1, both generation and disposal are accurately tracked by QUIDPRO equations. This is confirmed in Appendix 1 GRETL OLSQ regression outputs for the four residential collections equations. Those show that R-squared = 0.998 for curbside recycling, 0.997 for multi-family recycling, 0.985 for organics collection and 0.998 residential garbage.

All four equations have significant seasonal effects, as measured by coefficients for monthly variations in per household per collection day quantities. As can be seen in Figure 1, residential garbage had significantly higher monthly variations prior to the advent of curbside yard waste collection in 1989. All four equations also have one or more significant weather related explanatory variables. For example, monthly total precipitation, monthly average temperature and monthly snow quantities all have statistically significant impacts on monthly residential garbage disposal per household per collection day. Organics collection for most months is significantly affected by the preceding month's precipitation.

All equations except apartment recycling have a significant collection fee variable. For residential garbage that variable is the relative marginal cost or price for garbage collection as measured by the ratio of marginal to average garbage collection fees. In 1977 this marginal cost was zero because Seattle charged a fixed fee for garbage unrelated to the garbage quantity that a household set out for pick up on collection day. Marginal cost jumped to 0.20 in 1981 when the City implemented pay as you throw (PAYT) based on a household's choice of garbage collection container size. It jumped again to 0.35 mid-1982 as Seattle moved to increase the incentive for customers to downsize their garbage collection container, but dropped back to 0.25 mid-1986 when the City increased collection costs for all container sizes without changing the incremental cost of using a larger container size. This was corrected mid-1987 and the marginal cost jumped back up to 0.33. Policymakers moved the marginal cost above 0.5 in 1989, to 0.65 in 1992, and then to above 0.75 in 1994 when linear rates were instituted.

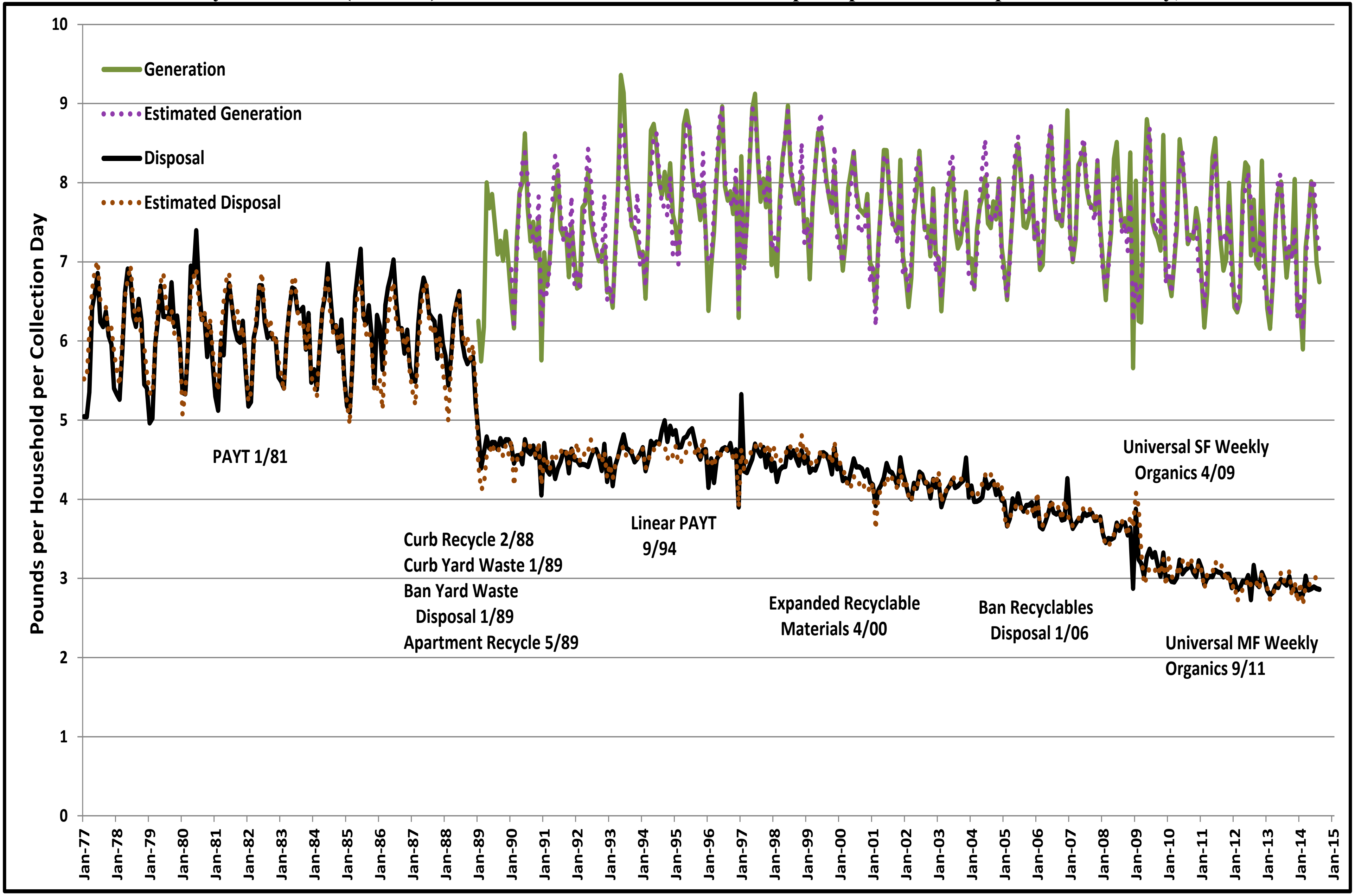
Relative marginal cost is only statistically significant for explaining residential garbage collection quantities during the months following implementation of single-family curbside recycling in February 1988. Prior to 1988 garbage collection fees did not have a statistically significant impact on garbage collection quantities, even though PAYT collection fees based on garbage container size were introduced in 1981. Until curbside diversion opportunities were implemented, PAYT's main effect was to reduce garbage container sizes used by single-family households without reducing the weight of garbage they put in their containers. This result of Seattle's initial PAYT fee structure was widely characterized in local and national media as the "Seattle Stomp".

Price elasticity for residential garbage disposal after 1988 with respect to relative marginal single-family garbage cost averaged -0.09. Assuming single-family garbage fees have no impact on the multi-family portion of residential garbage disposal, marginal price elasticity for single-family garbage disposal is -0.16 – i.e., a ten percent increase in relative marginal cost for single-family garbage collection reduces the single-family portion of residential garbage collection by 1.6%. Appendix 2 details how estimated effects of explanatory variables on overall residential garbage are used to deduce effects of those variables on just the single-family portion of residential garbage.

Cross price elasticity for single family curbside recycling with respect to relative marginal single-family garbage fees is 0.40. There is no own price elasticity for curbside recycling because this collection is provided at no additional charge as one of the services bundled with garbage collection.

The price elasticity for single family organics collection with respect to the real (i.e., inflation adjusted) price for yard waste extras is -0.07. The prices for curbside organics and single-family garbage collection were not statistically significant for the curbside organics equation. This is likely due to the yard waste disposal ban that was instituted conterminously with implementation

Figure 1
Seattle Monthly Residential (SF&MF) Collected Waste Generation and Disposal per Household per Collection Day, 1977-2014



Sound Resource Management Group – April 2015 of curbside yard waste collection January 1989, as well as the institution of mandatory organics collection service subscriptions for single-family households beginning April 2009.

There are no explanatory price variables for multi-family recycling. Most likely this is because apartment building households do not see a direct connection between their monthly rental payments and the fees their building owner has to pay for garbage collection.

Real household income is significant for both single- and multi-family recycling. Average income elasticity for these two household groups over the January 1990 through August 2014 months is 0.50 and 0.08, respectively.

The area's unemployment rate is also significant for multi-family recycling, reducing recycling by a few percent for every increase of one percentage point in the unemployment rate. Unemployment was not significant for the other three residential collection equations.

Household size is a significant explanatory variable for both residential garbage and single-family curbside recycling. Each additional person in a household accounts for 2.19 pounds of garbage per monthly collection day, or 47% of the average for residential household garbage over the January 1977 through August 2014 time period. Each additional person yielded 0.20 pounds of single-family recyclables per collection day during the months from January 1990 through August 2014, or just 7% of average collection day recyclables.

Economic events and City of Seattle regulatory requirements for collection were inextricably interrelated during 2008 through 2014. Most recyclables were banned from disposal beginning in 2006 with early warnings on the ban throughout 2005. The financial crash in 2008 and resulting economic recession were important economic occurrences. One of Seattle's two major newspapers ceased publication mid-March 2009. Mandatory single-family organics collection began April 2009 with mandatory multi-family following suit in September 2011. Waste prevention measures such as packaging reductions/light weighting and decreased printing and paper use also likely had increasing impacts in recent years.

Separating these highly interrelated and timing-correlated economic and regulatory events is quite difficult. What seemed to work well was to construct 5 indicator variables:[2]

- Early Ban Months -- 2005 thru 2007,
- Financial Crash Months – 2008,
- Newspaper Cessation & Mandatory SF Organics Months – 3/09 on,
- Later Ban & Waste Prevention Months – 2012 on, and,
- Mandatory MF Organics Months – 9/11 on.

Significant coefficients for these five indicator variables are shown in the GRETL output for residential garbage and for two or more of them in each of the other three residential collection equations. As an example of the influence of regulations and economic events, for residential garbage the recyclables ban warning in 2005 and implementation in 2006-07 reduced average garbage quantities by 9% each year 2005-2007. The financial crisis combined with the recyclables disposal ban reduced garbage in 2008 by 15%. Closure of the Post Intelligencer, continuation of the recyclables ban, and mandatory single-family organics collection reduced residential garbage during March 2009 - August 2014 by 40%. Continuation of the recyclables disposal ban along with waste prevention reduced residential garbage by between 3% and 4%, as did mandatory MF organics collection, during 2012 through 2014.

[2] An indicator variable has the value 1 during months when some event is occurring or some collection program characteristic is in place, and the value 0 otherwise. Its estimated coefficient indicates the impact on waste quantities of the event(s) or characteristic(s).

Table 1
Explanation for Changes over Time in Residential Collection Quantities
1987 to 1990 and 1990 to 2014

Time Frame for Averages	Average Pounds per Household per Collection Day: Garbage per SF+MF Household	Curbside Recycling per SF Household	Curbside Organics per SF Household	Apartment Recycling perMF Household
1977:01 to 1977:12	5.96	NA	NA	NA
1987:01 to 1987:12	6.18	NA	NA	NA
1990:01 to 1990:12	4.54	2.44	1.92	0.09
2013:09 to 2014:08	2.88	2.79	3.86	1.31
Comparison Years & Explanatory Variables	**Increases/(Decreases) - Total and Explained**			
1990 vs. 1987	(1.64)			
Curbside Recycling (incl. "old" recycling)	(1.50)			
Curbside Yard Waste	(1.16)			
Apartment Recycling	(0.04)			
2014 vs. 1990	(1.66)	0.35	1.94	1.22
Regulatory/Programmatic				
Mandatory SF Organics	(0.92)	NA	1.42	NA
PI Closure		(0.30)	NA	(0.02)
Recyclables Ban	(0.33)	0.12	NA	0.11
Biweekly Recycling, Carts, Materials	(0.28)	*	NA	NA
Mandatory MF Organics	(0.12)	NA	0.13	NA
Miscellaneous Waste Prevention	(0.12)	(0.27)	NA	*
Apartment Recycling Availability	NA	NA	NA	1.16
Economic				
Relative Marginal Garbage Collection Cost	(0.05)	0.28	*	NA
Real Price Organics Extras	NA	NA	(0.52)	NA
Real Household Income	*	0.46	*	0.02
Unemployment Rate	*	*	*	(0.02)
Demographic				
Household Size	0.11	0.01	*	*
Weather				
Precipitation	(0.00)	*	0.91	*
Temperature	0.02	*	0.02	*
Snow	0.03	0.02	*	*
Other/Unexplained	0.00	0.03	(0.02)	(0.04)

Notes: NA = not applicable; * = not statistically significant

Table 1 provides another way to view what matters most in explaining changes in collection quantities over time. The table details residential garbage decreases between 1987 and 1990. Garbage collection reduction between the start and end years of this period was associated with implementation of the three diversion programs introduced after 1987. It's interesting to note that the three diversion program collections in 1990 total more than the decrease in garbage collection between 1987 and 1990. This for the most part is because the new collection programs drew material from the previously popular drop-off and buy-back recycling depots, as well as a small private sector residential curbside collection service in the Freemont neighborhood. In other words, some of the new collection quantities were diverted from previous recycling efforts rather than just from residential garbage collection.

Comparison of annual collection quantities between 1990 and the twelve months ending August 2014 show the results of efforts by Seattle Public Utilities to continually reduce residential garbage disposal and increase diversion of recyclables and organics. Table 1 indicates the contributions of significant variables to the increases in curbside recycling, curbside organics and apartment recycling and the decreases in residential garbage.
As indicated in Table 1, residential garbage per household per collection day declined by 1.66 pounds, or 37%, between 1990 and 2014. Regulatory, programmatic and economic incentives/disincentives drove over 90% of this decrease. The closure of one of Seattle's two newspapers in 2009 also contributed to the decline in residential garbage, although the exact extent of the closure's impact is difficult to single out due to implementation of mandatory SF organics collection within a month of the newspaper closure in 2009. In any event, the overall decrease would have been even greater had demographic and weather variables not increased garbage disposal by 4%.

An important observation about SPU initiatives explaining over 90% of residential disposal decline over time is that cross-sectional studies sometimes conclude that demographic and general economic factors are more significant than local solid waste management authority initiatives in driving disposal reductions and diversion increases. This may be because cross-sectional studies pick up the often large influences of demographic, cultural and economic differences among different communities at a given point in time. These sorts of variables change very slowly over time, if at all. Thus, the time series analysis used to develop QUIDPRO's equations may do a better job of revealing the importance of local initiatives as influences on household and business decisions to divert or dispose.

Curbside organics collection grew the most between 1990 and 2014, increasing by 1.94 pounds, 101%, per SF household per collection day. For this collection program SPU initiatives explained more than half of the increase, with higher precipitation and temperatures in 2014 versus 1990 causing just under half.[3]

The story for curbside recycling is different than for the other three residential collection programs in that external factors provided impetus for most of the ups and downs that explain the net 0.35 pound increase per SF household per collection day between 1990 and 2014. The PI closure and the influence of waste prevention measures in packaging caused substantial decreases in curbside recycling collections. Household income, household size and weather were associated with increased collection to an extent that almost offset the decreases from newspaper closure and economy-wide waste prevention efforts. SPU's recyclables ban and increases in the relative marginal cost of garbage collection provided an increase in curbside of 0.40 pounds. This was enough to more than offset the net decrease caused by external influences.

The apartment recycling increase is mostly explained by the rolling out of the on-site recycling program from availability to less than 10% of multi-family households in 1990 to more than 97% by 2014. The ban on disposal of recyclables in garbage also aided the apartment recycling increase. These SPU initiatives explain virtually all the 14-fold increase in apartment recycling per household per collection day to 1.31 pounds by 2014.

[3] MF organics collection became mandatory September 2011. If MF organics increase relative to SF organics in curbside organics collections, it will become necessary to convert that equation to the per SF+MF household basis used for residential garbage.

III. Results for Commercial Garbage Collection

Figure 2 portrays actual and estimated monthly commercial garbage collection pounds per collection day per price and tax rate adjusted $1000 of business and occupation (B&O) tax receipts. Unlike household garbage which is well characterized on a per household basis, commercial garbage collection varies substantially according to size of the business customer. Hence normalization by a measure of sales activity such as B&O tax receipts provides a more accurate portrayal of garbage quantity for the average business customer than would normalization by number of businesses.

Figure 2 actuals for commercial garbage collection begin January 1990. Estimates begin January 1995. The later start date for estimates is due to the much more erratic movements in the actuals time series during 1990-1994. This makes it quite difficult to estimate a commercial garbage equation that works well throughout the entire 1990 through 2014 time period.

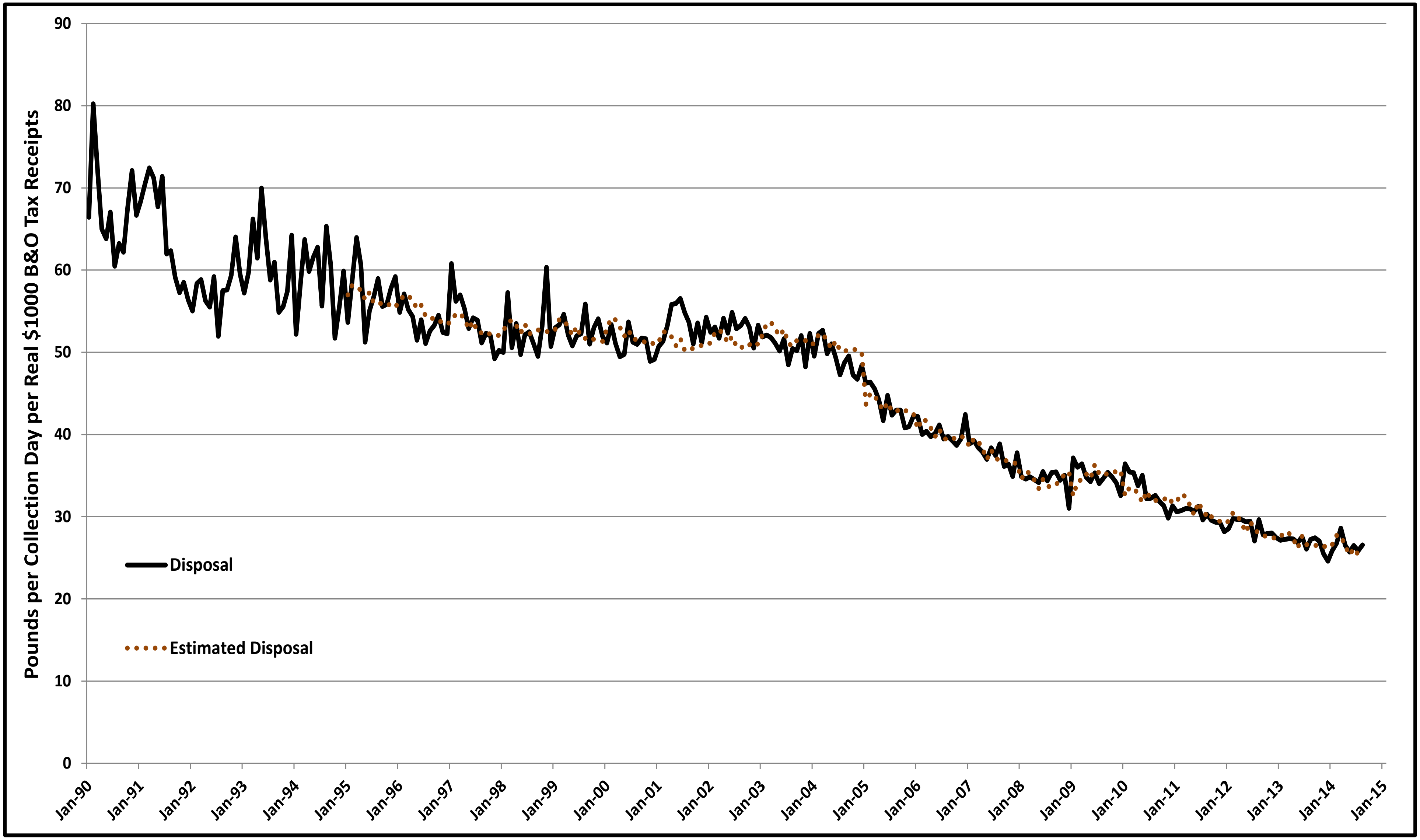
As can be seen by the closely aligned movements between actual and estimated disposal quantities in Figure 2, collection of commercial garbage for disposal is accurately tracked by its QUIDPRO equation. This is confirmed by R-squared = 0.998 for that equation as reported in Appendix 1 GRETL output.

Commercial garbage per $1000 of B&O tax receipts declined 52% between 1995 and the 12 months ending August 2014, from an average of 57.3 pounds to 26.4 pounds per collection day. As was the case for the decline in residential garbage per household discussed in the previous section, the decline in commercial garbage per $1000 of tax receipts was mainly driven by SPU initiatives, especially the recyclables disposal ban beginning in 2006. The exact extent to which the disposal ban contributed to this decline, however, is difficult to estimate due to the coterminous financial crash in 2008 and the following recession, the closure of one of Seattle's two major newspapers in 2009, and industry-wide waste prevention measures that may have gained in extent as the recession began to wind down. All of these would be expected to reduce commercial garbage disposal.

The real tip fee at Seattle transfer stations for garbage self-hauled in trucks was also a significant explanatory variable. When that tip fee goes up it tends to drive some self-haulers to make greater use of commercial collection services. When the real tip fee falls due to price inflation over time, on the other hand, some garbage quantities move back to self-hauling. Between 1995 and 2014 the real tip fee for self-hauled garbage actually declined by 4% due to price level inflation. The estimated cross-elasticity for commercial garbage collection with respect to real self-haul tip fees averaged 0.88 over this time period, indicating that commercial garbage collection quantities may be fairly sensitive to transfer station tip fees for self-hauled garbage.

Another finding is that the area wide unemployment rate is positively correlated with normalized commercial garbage collection quantities, holding other significant explanatory variables constant. The explanation may be that higher unemployment is associated with tighter budgetary controls at businesses, with the result that some waste prevention and diversion efforts get ramped down, resulting in higher disposal quantities. Or commercial waste generation may lag behind sales increases or decreases, resulting in normalized commercial garbage decreasing as unemployment goes down and increasing as unemployment turns up.

Figure 2
Seattle Monthly Commercial Collected Waste Disposal per Collection Day per Real $1000 B&O Tax Receipts, 1990-2014



IV. Results for Self-Haul Garbage & Yard Waste

A. Self-Haul Garbage

Figure 3 portrays actual and estimated monthly self-haul garbage disposal pounds per day per price and tax rate adjusted $1000 of business and occupation (B&O) tax receipts. Like commercial garbage collection, self-haul garbage is well-normalized by the B&O tax receipts measure of commercial business sales activity and by the number of days in a month that Seattle transfer stations are open.

As can be seen by the closely aligned movements between actual and estimated disposal quantities in Figure 3, self-hauled garbage delivered to Seattle transfer stations is accurately tracked by its QUIDPRO equation. This is confirmed by R-squared = 0.994 for that equation as reported in Appendix 1 GRETL output.

Self-haul garbage per $1000 of B&O tax receipts declined 48% between 1990 and the 12 months ending August 2014, from an average of 18.3 pounds to 9.6 pounds per day. As was the case for the decline in residential garbage per household and commercial garbage per real $1000 of tax receipts, the decline in self-haul garbage per real $1000 of tax receipts was mainly driven by initiatives implemented by SPU, especially the recyclables disposal ban beginning in 2006 and mandatory SF organics beginning spring 2009.

A caveat here is that the closure of Seattle's north transfer station in January 2014 for reconstruction may have driven some self-haul garbage to King County transfer stations. The closure did not as yet show up as a significant explanatory variable for the commercial garbage equation, so that outlet for the reduced self-haul activity is not an explanation. According to coefficient estimates detailed in Appendix 1, closure accounted for 35% of the 2014 versus 1990 decreases explained by the recyclables disposal ban, mandatory SF organics/newspaper closure, and the north transfer station closure. These decreases totaled 11.0 pounds per day per real $1000 of B&O tax receipts.

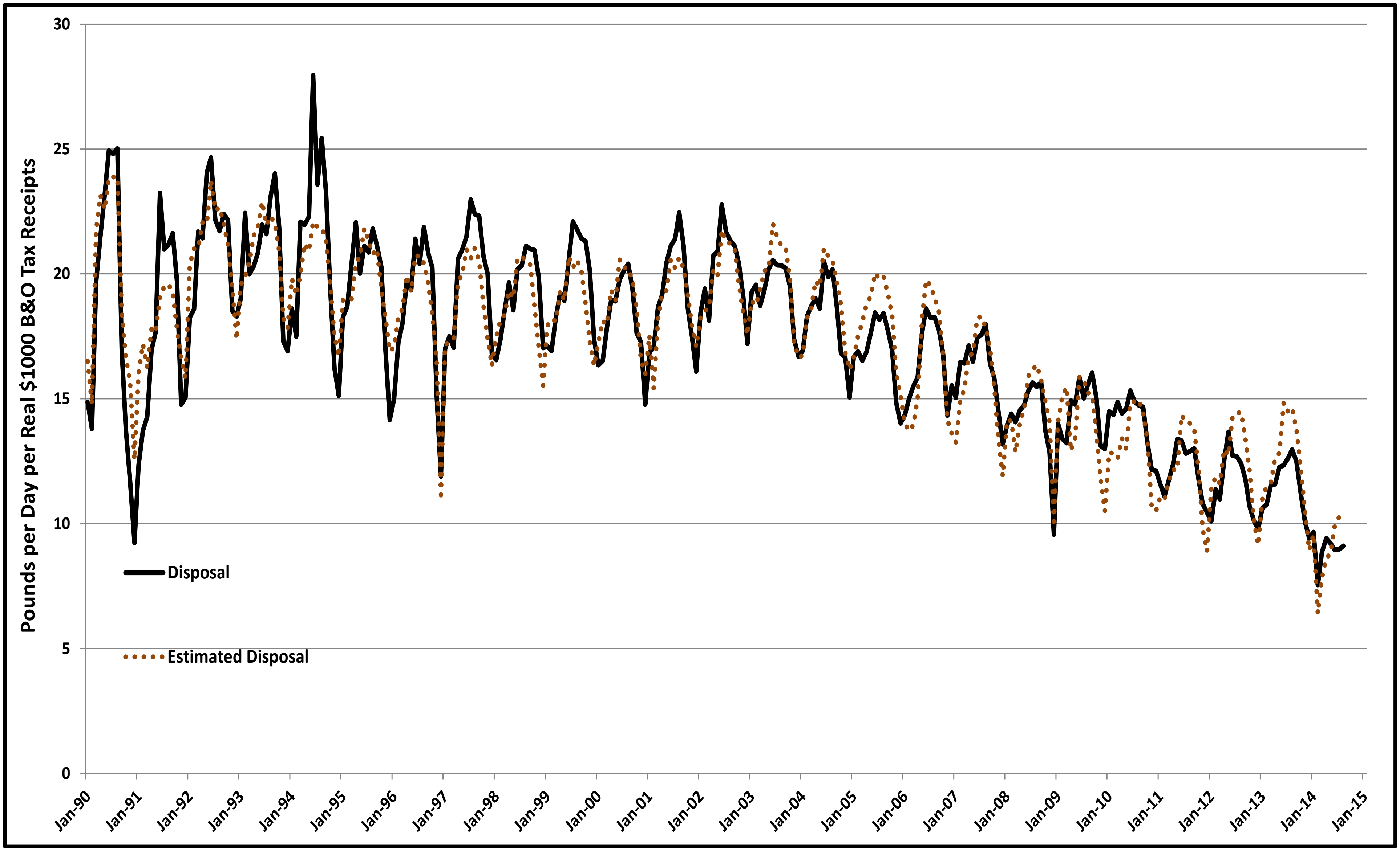
The decreases driven by these three SPU actions were offset somewhat by temperature increases and snowfall decreases, as well as by an increase in the unemployment rate, in the twelve months ending August 2014 compared to the year 1990. Seattle's low flat rate for self-haul garbage delivered in cars compared with King County's transfer stations' tip fee also provided an increase in self-haul garbage approximately equal to the increases related to weather differences and increased unemployment. Weather caused 0.3 pounds increase, unemployment 0.8 pounds increase and the comparative transfer station fees a 1.2 pound increase.

B. Self-Haul Yard Waste

Self-haul yard waste per day declined by 58% between 1990 and 2014. This decline is explained by the statistically significant variables in the self-haul yard waste QUIDPRO equation. The fitted equation has an R-squared of 0.985. These results are reported in Appendix 1. The appendix also shows the actual versus estimated (fitted) values graph, providing further verification of how well the self-haul equation matches the fluctuations and recent down trend of actual self-hauled yard waste deliveries to Seattle's transfer stations.

SPU initiatives – adding food waste to yard waste curbside collection, implementing mandatory SF curbside organics subscription, and later adding mandatory MF subscription, along with increases to the yard waste tip fee (estimated average elasticity = -0.71) -- more than account for the decline in yard waste self-hauling. Weather and income (estimated average elasticity = 0.97) induced increases in yard waste deliveries in 2014 versus 1990 would have offset nearly half these SPU initiatives. However, self-haul decreases induce by closure of the north transfer station in January 2014 in turn offset above 70% of the weather and household income induced increases, yielding the net 58% decline over this time period.

Figure 3
Seattle Monthly Self-Haul Waste Disposal per Day per Real $1000 B&O Tax Receipts, 1990-2014



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V. Appendix 1 – GRETL OLSQ Regression Output & Actual vs. Fitted Graphs

1. *Residential Garbage Equation*

Explanatory Variable Estimated Coefficients, based on observations 1977:01-2014:08 (T = 452 months)

Dependent variable: Monthly Residential Garbage Pounds per Collection Day per Household

Heteroskedasticity and autocorrelation consistent (HAC) coefficient standard errors

	Coefficient	*Std. Error*	*t-ratio*	*p-value*
Seasonality Indicator Variables				
Feb	-0.191719	0.0390644	-4.9078	<0.00001
Mar	0.408785	0.0898317	4.5506	<0.00001
Apr	0.866677	0.106882	8.1087	<0.00001
May	1.04882	0.120964	8.6705	<0.00001
Jun	1.08369	0.160185	6.7652	<0.00001
Jul	0.569355	0.163139	3.4900	0.00053
Aug	0.365861	0.163458	2.2383	0.02573
Sep	0.538105	0.138416	3.8876	0.00012
Oct	0.342825	0.107709	3.1829	0.00157
Nov	0.579359	0.0830758	6.9739	<0.00001
Dec	0.237669	0.0882386	2.6935	0.00735
Additional Seasonality Indicator Variables Prior to Yard Waste Disposal Ban				
MarYW	-0.637754	0.0835956	-7.6290	<0.00001
AprYW	-1.06331	0.0957056	-11.1102	<0.00001
MayYW	-1.30766	0.0948768	-13.7827	<0.00001
JunYW	-1.30049	0.11348	-11.4601	<0.00001
JulYW	-0.920966	0.102098	-9.0204	<0.00001
AugYW	-0.717253	0.0979304	-7.3241	<0.00001
SepYW	-0.810906	0.105176	-7.7100	<0.00001
OctYW	-0.611867	0.0958682	-6.3824	<0.00001
NovYW	-0.62885	0.0852616	-7.3755	<0.00001
DecYW	-0.321576	0.092804	-3.4651	0.00058
Monthly Weather Variables				
Total Precipitation	0.0217819	0.0045886	4.7470	<0.00001
Average Temperature	0.0185505	0.00563438	3.2924	0.00108
Cumulative Snowfall	-0.0351397	0.00998273	-3.5200	0.00048
Economic & Demographic Variables				
(MP/AP)*(SF/(SF+MF)	-0.879722	0.344592	-2.5529	0.01104
Household Size	2.19245	0.127177	17.2394	<0.00001
Economic & Regulatory Indicators				
Early Ban	-0.334695	0.0418723	-7.9932	<0.00001
Financial Crash	-0.541126	0.0353067	-15.3264	<0.00001
Newspaper Closure & Mandatory SF Organics	-1.2458	0.0551744	-22.5794	<0.00001
Later Ban & Waste Prevention Trends	-0.115149	0.0284549	-4.0467	0.00006
Mandatory MF Organics	-0.118316	0.0358557	-3.2998	0.00105
Collection Program & Other Indicators				
Curbside YW Available	-0.521982	0.164529	-3.1726	0.00162

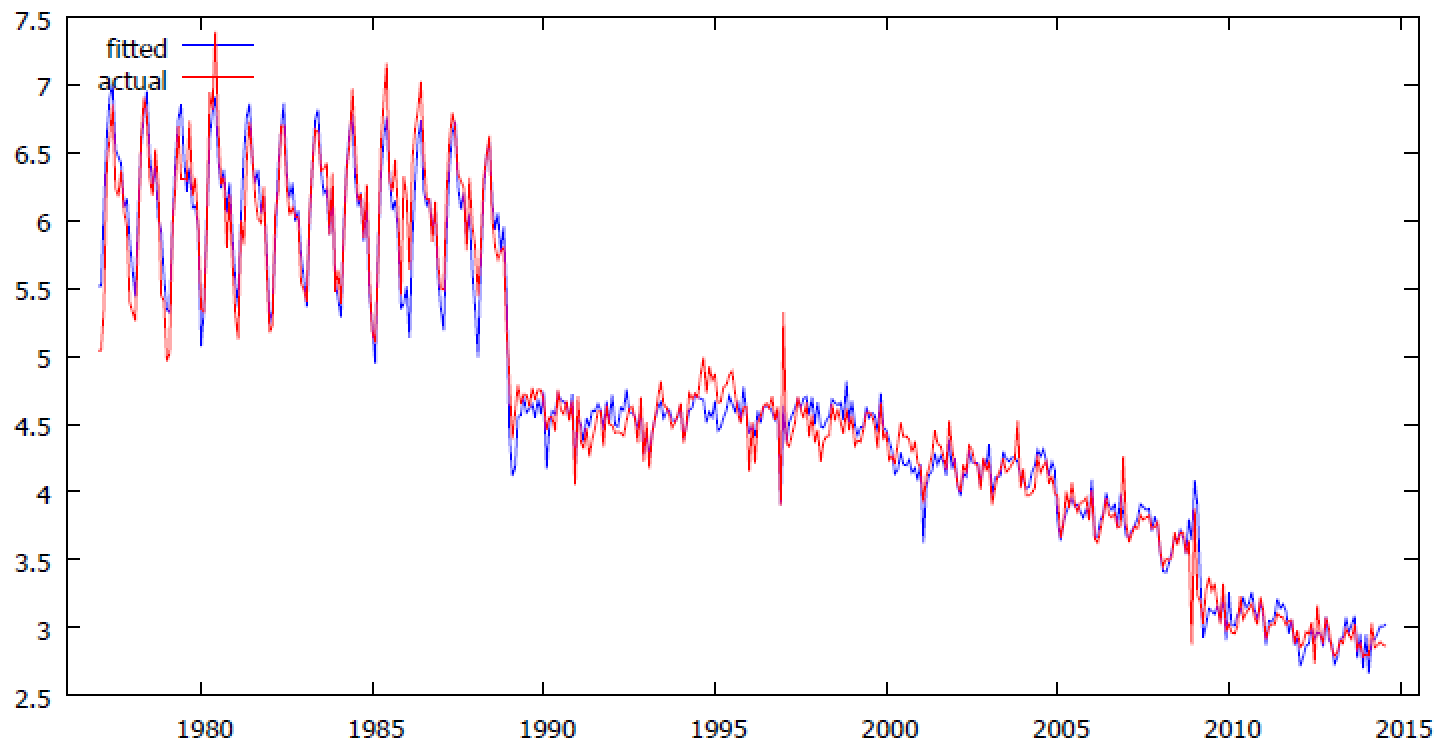
Recycling Biweekly, Carts, Added Materials	-0.279525	0.0458509	-6.0964	<0.00001

Mean of dependent variable	4.682545	Standard deviation of dependent variable	1.131718
Sum squared residuals	14.96035	Standard error of regression	0.188957
R-squared	0.998574	Adjusted R-squared	0.998465
F(33, 419)	10456.65	P-value(F)	0.000000
Log-likelihood	128.9108	Akaike criterion	-191.8215
Schwarz criterion	-56.06999	Hannan-Quinn	-138.3266
rho	0.519983	Durbin-Watson	0.945015

Acronyms in table: MP = marginal price for single-family garbage collection; AP = average price for single-family garbage collection; SF = single-family household count; MF = multi-family household count

Notes for table: (MP/AP)*(SF/(SF+MF) = 0, January 1977 thru January 1988, i.e., prior to implementation of curbside recycling. Neither this variable nor any other single-family garbage collection price variable formulation was statistically significant for the period prior to implementation of curbside recycling.

Actual & Estimated Residential Garbage Pounds per Collection Day per Household (SF + MF)



2. *Single Family Curbside Recycling Equation*

Explanatory Variable Estimated Coefficients, based on observations 1990:01-2014:08 (T = 296 months)

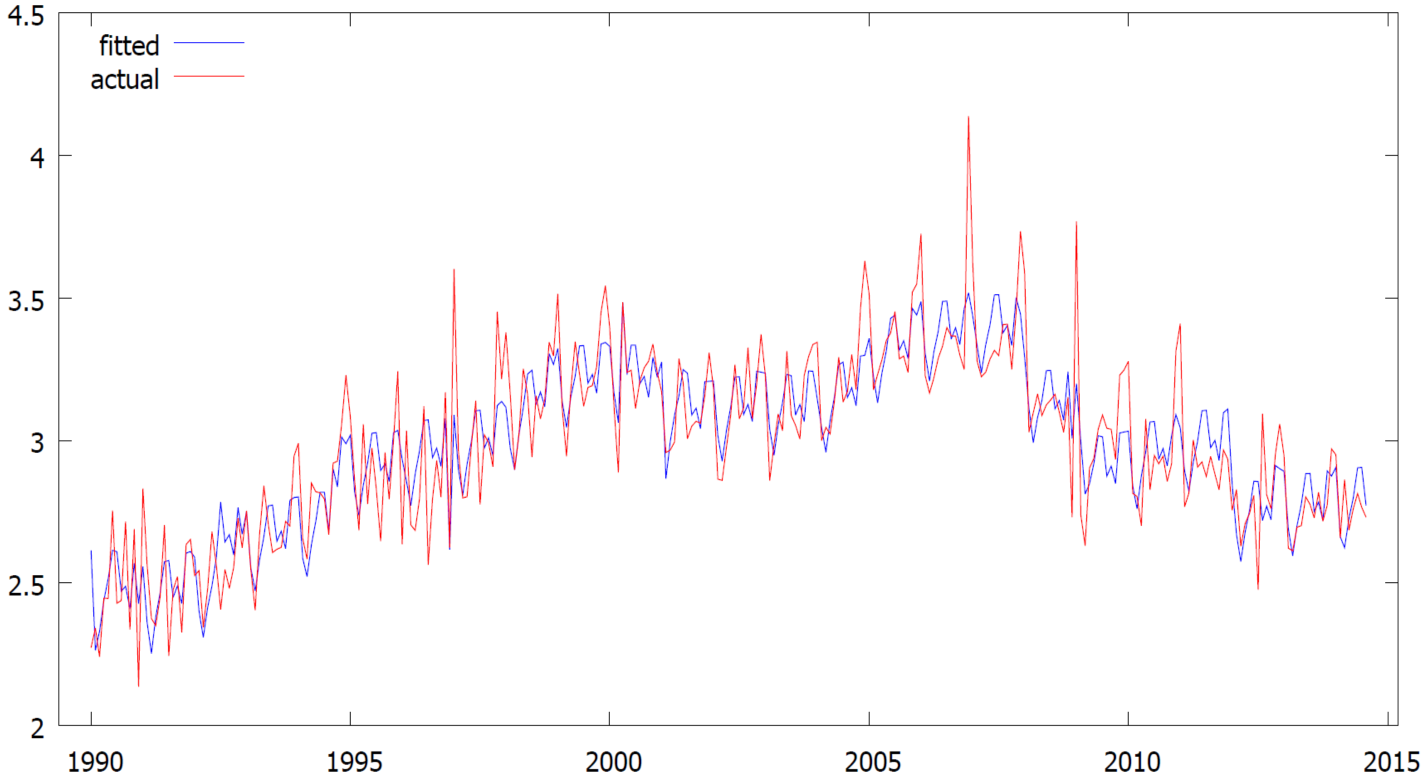
Dependent variable: Monthly Curbside Recycling Pounds per Collection Day per Single Family Household

Heteroskedasticity and autocorrelation consistent (HAC) coefficient standard errors

	Coefficient	*Std. Error*	*t-ratio*	*p-value*
Seasonality Indicator Variables				
Feb	-0.193112	0.0320967	-6.0166	<0.00001
Mar	-0.286262	0.026609	-10.7581	<0.00001
Apr	-0.181065	0.027705	-6.5355	<0.00001
May	-0.104012	0.028096	-3.7020	0.00026
Aug	-0.134104	0.0282326	-4.7500	<0.00001
Sep	-0.104167	0.0258747	-4.0258	0.00007
Oct	-0.170775	0.0242699	-7.0365	<0.00001
Monthly Weather Variables				
Snow	-0.0232682	0.00497537	-4.6767	<0.00001
Economic & Demographic Variables				
MRG2toAV	1.68144	0.198813	8.4574	<0.00001
R7HshldY	1.59519e-05	2.04955e-06	7.7832	<0.00001
HshldSiz	0.204428	0.0514226	3.9754	0.00009
Economic & Regulatory Indicators				
Early Ban	0.11559	0.0314431	3.6761	0.00028
Financial Crash	-0.0592892	0.0410792	-1.4433	0.15006
Newspaper Closure & Mandatory SF Organics	-0.181557	0.0412042	-4.4063	0.00002
Later Ban & Waste Prevention Trends	-0.273756	0.0448285	-6.1067	<0.00001
Collection Program & Other Indicators				
Start Month for Biweekly	0.327197	0.0268059	12.2062	<0.00001
Newspaper Strike	-0.0862854	0.0361611	-2.3861	0.01769

Mean of dependent variable	2.985636	Standard deviation dependent variable	0.316680
Sum squared residuals	6.240221	Standard error of regression	0.149554
R-squared	0.997661	Adjusted R-squared	0.997527
F(17, 279)	5.61e+15	P-value(F)	0.000000
Log-likelihood	151.1771	Akaike criterion	-268.3542
Schwarz criterion	-205.6181	Hannan-Quinn	-243.2359
rho	0.057213	Durbin-Watson	1.866750

Actual & Estimated Curbside Recycling Pounds per Collection Day per SF Household



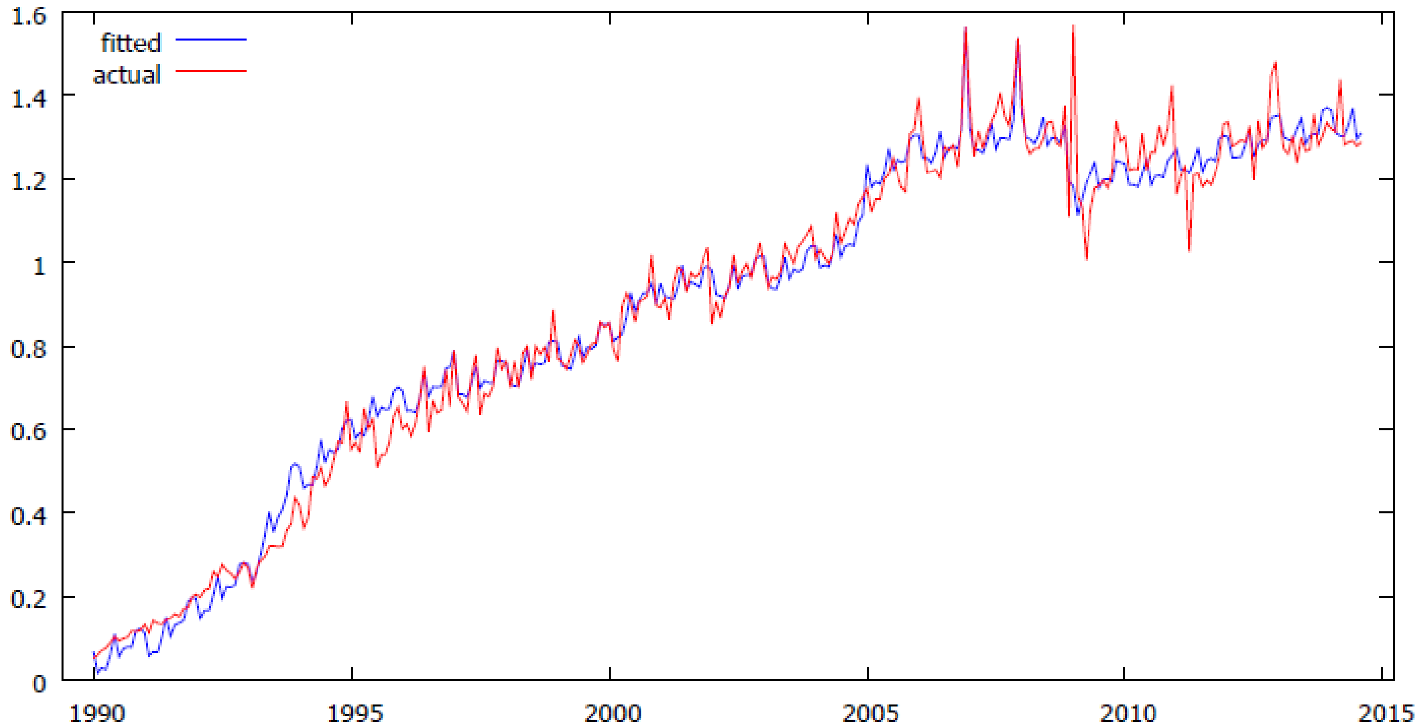
3. ***Multi-Family Recycling Equation***

Explanatory Variable Estimated Coefficients, based on observations 1990:01-2014:08 (T = 296 months)
Dependent variable: Monthly Apartment Recycling Pounds per Collection Day per Multi- Family Household
Heteroskedasticity and autocorrelation consistent (HAC) coefficient standard errors

	Coefficient	*Std. Error*	*t-ratio*	*p-value*
Seasonality Indicator Variables				
Feb	-0.0533897	0.00850034	-6.2809	<0.00001
Mar	-0.0599468	0.0121116	-4.9495	<0.00001
Apr	-0.0771652	0.0147408	-5.2348	<0.00001
May	-0.0451243	0.010573	-4.2679	0.00003
Jul	-0.0632404	0.0125434	-5.0417	<0.00001
Aug	-0.0444655	0.0105353	-4.2206	0.00003
Sep	-0.0427683	0.011537	-3.7071	0.00025
Oct	-0.0481333	0.00970242	-4.9610	<0.00001
Monthly Weather Variables				
Storm cleanup 1/1997	0.0529649	0.00814625	6.5018	<0.00001
Storm12/2006	0.238684	0.0140848	16.9462	<0.00001
Storm12/2007	0.194857	0.014264	13.6607	<0.00001
Economic & Demographic Variables				
Real Household Income	7.20593e-07	2.67422e-07	2.6946	0.00748
Unemployment Rate	-0.0160201	0.00371817	-4.3086	0.00002
Economic & Regulatory Indicators				
Early Ban	0.109696	0.0165528	6.6271	<0.00001
Financial Crash	0.12584	0.0138907	9.0592	<0.00001
Newspaper Closure & Mandatory SF Organics	0.0902601	0.0182618	4.9426	<0.00001
Collection Program & Other Indicators				
Recycling Available at Apartment Building	1.31478	0.0285361	46.0742	<0.00001
Newspaper Strike	-0.0838793	0.0192255	-4.3629	0.00002

Mean of dependent variable	0.892306	Standard deviation of dependent variable	0.398495
Sum squared residuals	0.929821	Standard error of regression	0.057833
R-squared	0.996709	Adjusted R-squared	0.996508
Log-likelihood	432.9363	Akaike criterion	-829.8726
Schwarz criterion	-763.4461	Hannan-Quinn	-803.2767
rho	0.326657	Durbin-Watson	1.346210

Actual & Estimated Multi-Family Recycling Pounds per Collection Day per MF Household



4. ***Curbside Organics Recycling Equation***

Explanatory Variable Estimated Coefficients, based on observations 1990:01-2014:08 (T = 296 months)

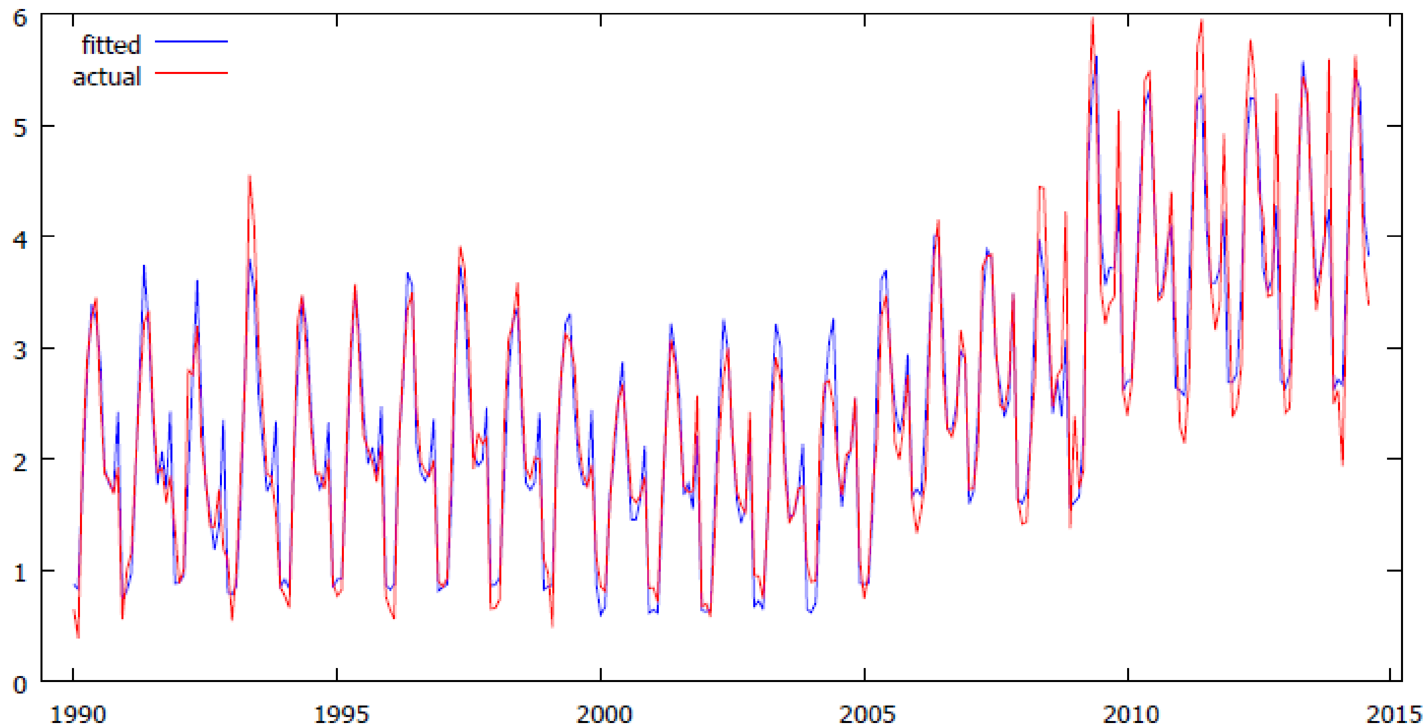
Dependent variable: Monthly Curbside Organics Pounds per Collection Day per Single Family Household

Heteroskedasticity and autocorrelation consistent (HAC) coefficient standard errors

	Coefficient	*Std. Error*	*t-ratio*	*p-value*
Seasonality Indicator Variables				
Mar	0.633876	0.135276	4.6858	<0.00001
Apr	1.56359	0.112007	13.9597	<0.00001
May	2.00547	0.158082	12.6863	<0.00001
Jun	1.66677	0.205035	8.1292	<0.00001
Jul	0.620713	0.160952	3.8565	0.00014
Aug	0.313121	0.0887179	3.5294	0.00049
Sep	0.375729	0.0772078	4.8665	<0.00001
Oct	0.661718	0.0639326	10.3502	<0.00001
Nov	1.46132	0.146066	10.0045	<0.00001
Monthly Weather Variables				
Effect in Indicated Month of Total Precipitation in Prior Month				
Mar	0.0707993	0.0257646	2.7479	0.00640
Apr	0.0505327	0.0194886	2.5929	0.01004
May	0.106548	0.0519413	2.0513	0.04121
Jun	0.21475	0.0922187	2.3287	0.02062
Jul	0.298807	0.0863952	3.4586	0.00063
Aug	0.278035	0.08969	3.0999	0.00214
Sep	0.180839	0.0333756	5.4183	<0.00001
Oct	0.083231	0.0184267	4.5169	<0.00001
Average Temperature	0.0203225	0.000941063	21.5952	<0.00001
Storm12/2006	1.24757	0.0790742	15.7773	<0.00001
Economic & Demographic Variables				
Real Price Organics Extra	-0.137765	0.030897	-4.4588	0.00001
Collection Program, Regulatory & Other Indicators				
Startup Months (3) for Switch from Weekly to Biweekly 4/00 (Biweekly Abandoned 4/09)	-0.541283	0.0962774	-5.6221	<0.00001
Biweekly Collection in 3 Winter Months (12,1,2) 12/04 – 2/09 (Abandoned 4/09)	0.20865	0.0854961	2.4405	0.01532
Food in Yard Waste 4/05	0.788448	0.0780413	10.1030	<0.00001
Mandatory Weekly SF 4/09	1.42235	0.113531	12.5282	<0.00001
Mandatory MF 9/11	0.13451	0.093687	1.4357	0.15224
Free Leaf Collection 10-11/04	0.346661	0.0690784	5.0184	<0.00001
Free Leaf Collection 11/07	0.513958	0.159325	3.2259	0.00141
Lawn Watering Ban Jun-Oct 92	-0.518233	0.101444	-5.1086	<0.00001

Mean of dependent variable	2.484089	Standard deviation of dependent variable	1.225964
Sum squared residuals	30.75581	Standard error of regression	0.338763
R-squared	0.986451	Adjusted R-squared	0.985086
Log-likelihood	-84.89227	Akaike criterion	225.7845
Schwarz criterion	329.1146	Hannan-Quinn	267.1559
rho	0.155768	Durbin-Watson	1.682321

Actual & Estimated Curbside Organics Pounds per Collection Day per SF Household



5. ***Commercial Garbage Equation***

Explanatory Variable Estimated Coefficients, based on observations 1995:01-2014:08 (T = 236 months)

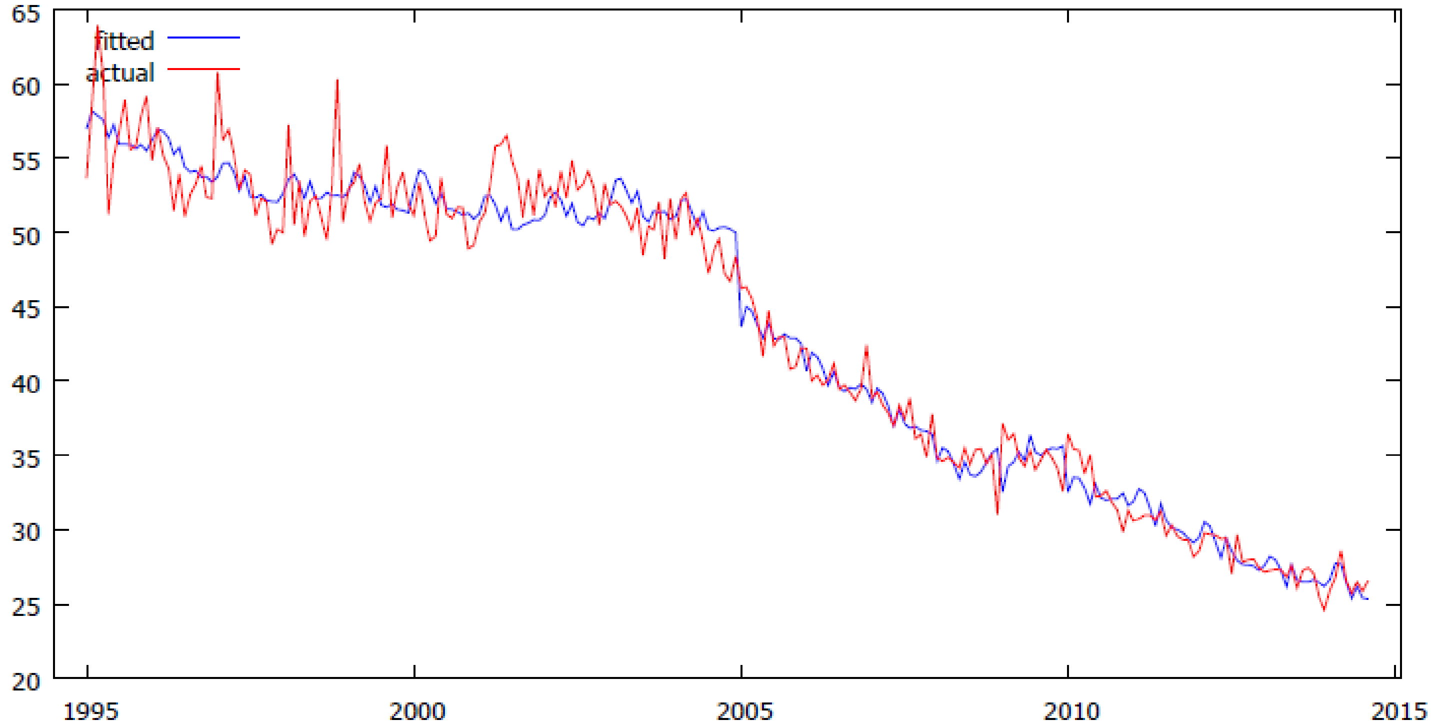
Dependent variable: Monthly Commercial Garbage Pounds per Collection Day per Real $1000 of B&O Tax Receipts (adjusted to 2014 tax rate)

Heteroskedasticity and autocorrelation consistent (HAC) coefficient standard errors

	Coefficient	*Std. Error*	*t-ratio*	*p-value*
Seasonality Indicator Variables				
Feb	1.06032	0.371936	2.8508	0.00477
Mar	1.30748	0.487717	2.6808	0.00789
Apr	1.18822	0.395603	3.0036	0.00297
Jun	0.884613	0.329628	2.6837	0.00783
Economic & Demographic Variables				
Real Household Income	0.00011194	2.20708e-05	5.0719	<0.00001
Unemployment Rate	0.898643	0.150938	5.9537	<0.00001
Real Price Self-Haul Garbage	0.355352	0.0217148	16.3645	<0.00001
Economic & Regulatory Indicators				
Recycling Ban Warning 2005	-6.3923	0.746154	-8.5670	<0.00001
Recycling Ban 2006	-8.33731	0.680354	-12.2544	<0.00001
Recycling Ban 2007	-12.8937	0.558529	-23.0850	<0.00001
Recycling Ban & Financial Crash 2008	-20.9039	0.601757	-34.7381	<0.00001
Recycling Ban & Financial Crash 2009	-24.6639	1.13023	-21.8221	<0.00001
Recycling Ban 2010 on	-31.2631	0.449847	-69.4973	<0.00001

Mean of dependent variable	43.46846	Standard deviation of dependent variable	10.45499
Sum of squared residuals	869.3105	Standard error of regression	1.974399
R-squared	0.998157	Adjusted R-squared	0.998058
F(13, 223)	12920.18	P-value(F)	0.000000
Log-likelihood	-488.7260	Akaike criterion	1003.452
Schwarz criterion	1048.482	Hannan-Quinn	1021.604
Rho	0.278371	Durbin-Watson	1.429657

Actual & Estimated Commercial Garbage Pounds per Collection Day per Real $1000 of B&O Tax Receipts (adjusted to 2014 tax rate)



6. ***Self-Haul Garbage Equation***

Explanatory Variable Estimated Coefficients, based on observations 1990:01-2014:08 (T = 296 months)

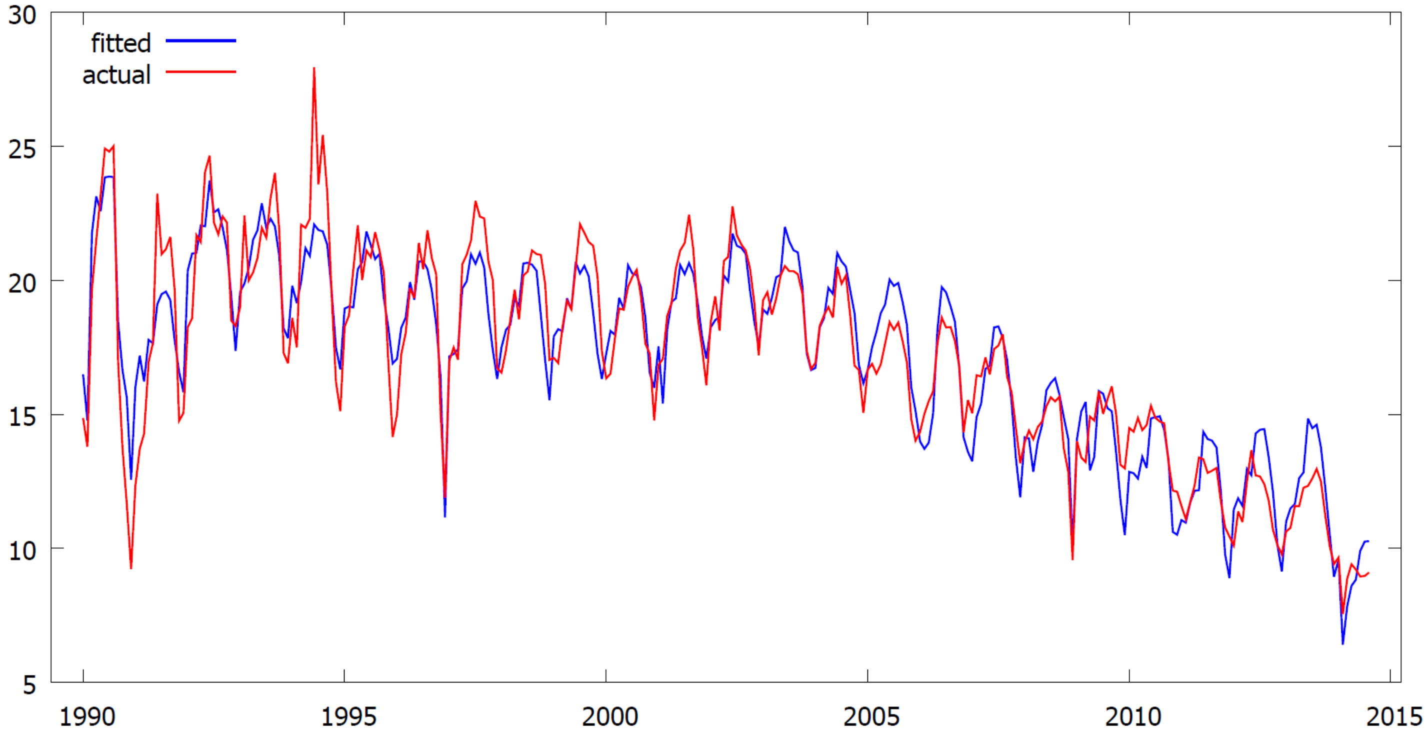
Dependent variable: Monthly Self-Haul Garbage Pounds per Day per Real $1000 of B&O Tax Receipts (adjusted to 2014 tax rate)

Heteroskedasticity and autocorrelation consistent (HAC) coefficient standard errors

	Coefficient	*Std. Error*	*t-ratio*	*p-value*
Seasonality Indicator Variables				
Apr	0.961776	0.201263	4.7787	<0.00001
Jun	0.719857	0.309226	2.3279	0.02062
Nov	-0.880393	0.331058	-2.6593	0.00828
Dec	-0.988818	0.310589	-3.1837	0.00162
Monthly Weather Variables				
Average Temperature	0.13527	0.01172	11.5418	<0.00001
Cumulative Snowfall	-0.220859	0.0417201	-5.2938	<0.00001
Economic & Demographic Variables				
Real Flat Rate for Cars in Seattle Minus Real Per Ton Fee at King County Transfer Stations	-0.108882	0.00819753	-13.2822	<0.00001
Unemployment Rate	0.695134	0.104075	6.6792	<0.00001
Economic & Regulatory Indicators				
Disposal Ban for Recyclables 1/06 on	-2.96031	0.44098	-6.7130	<0.00001
Mandatory SF Organics Collection	-4.18365	0.588133	-7.1134	<0.00001
King County CDL Disposal Ban 3/90-8/90 Prior to Seattle Ban	4.95185	0.694168	7.1335	<0.00001
King County 1st NE Transfer Station Closed 5/06-2/08	2.47342	0.518849	4.7671	<0.00001
Seattle North Transfer Station Closed 1/14 to Present	-3.81742	0.697907	-5.4698	<0.00001

Mean of dependent variable	17.21306	Standard deviation of dependent variable	3.862735
Sum of squared residuals	513.3585	Standard error of regression	1.346844
R-squared	0.994426	Adjusted R-squared	0.994190
F(13, 283)	2243.229	P-value(F)	9.2e-277
Log-likelihood	-501.4968	Akaike criterion	1028.994
Schwarz criterion	1076.968	Hannan-Quinn	1048.202
Rho	0.589033	Durbin-Watson	0.817204

Actual & Estimated Self-Haul Garbage Pounds per Day per Real $1000 of B&O Tax Receipts (adjusted to 2014 tax rate)



7. ***Self-Haul Yard Waste Equation***

Explanatory Variable Estimated Coefficients, based on observations 1990:01-2014:08 (T = 296 months)

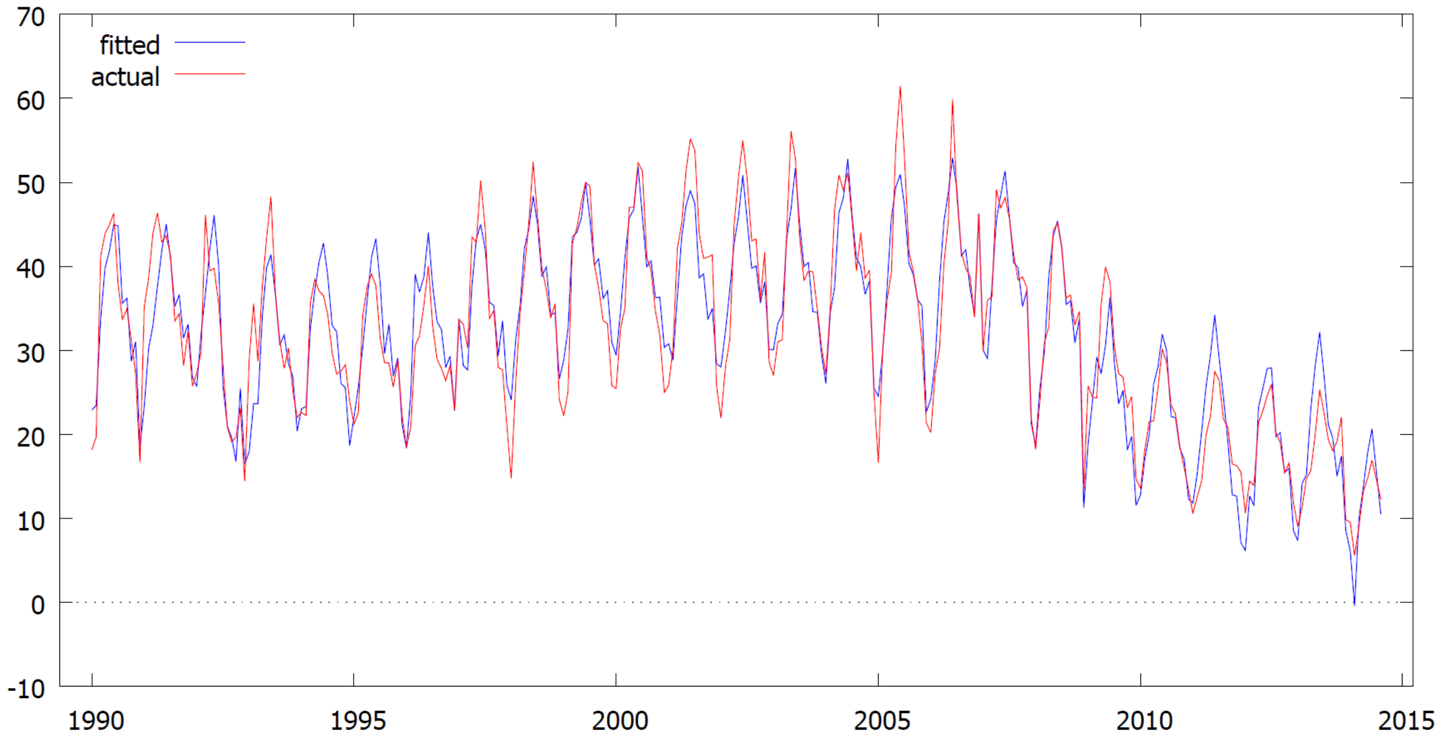
Dependent variable: Monthly Self-Haul Yard Waste Pounds per Day

Heteroskedasticity and autocorrelation consistent (HAC) coefficient standard errors

	Coefficient	*Std. Error*	*t-ratio*	*p-value*
Seasonality Indicator Variables				
Feb	3.24305	0.965147	3.3602	0.00089
Apr	10.0023	1.0441	9.5799	<0.00001
May	10.1722	0.976199	10.4202	<0.00001
Jun	11.1106	1.04688	10.6131	<0.00001
Aug	-2.6318	0.65414	-4.0233	0.00007
Nov	5.18356	0.784169	6.6103	<0.00001
Monthly Weather Variables				
Effect in Indicated Month of Total Precipitation in Prior Month				
March	1.76452	0.356252	4.9530	<0.00001
July	2.32988	0.564229	4.1293	0.00005
Total Precipitation	-0.294894	0.16344	-1.8043	0.07229
Average Temperature	0.493937	0.0583156	8.4701	<0.00001
Cumulative Snowfall	-0.465683	0.153721	-3.0294	0.00269
Storm12/1996	11.6508	2.94402	3.9575	0.00010
Cleanup 1/1997	10.8568	0.942837	11.5150	<0.00001
Storm12/2006	21.5619	1.43043	15.0737	<0.00001
Cleanup1/2007	9.39788	1.50663	6.2377	<0.00001
Economic & Demographic Variables				
Real Household Income	0.000325046	3.84311e-05	8.4579	<0.00001
Real Price Self-Haul Yard Waste	-0.289635	0.0513305	-5.6426	<0.00001
Economic & Regulatory Indicators				
Lawn Watering Ban Jun-Oct 1992	-9.38898	1.19011	-7.8892	<0.00001
Biweekly Collection in 3 Winter Months (12,1,2) 12/04 – 2/09 (Abandoned 4/09)	-5.85561	1.41044	-4.1516	0.00162
Mandatory Weekly SF 4/09	-9.79381	2.02407	-4.8387	0.00041
Mandatory MF 9/11	-6.85452	1.86523	-3.6749	0.00038
Curb Food Waste Added to Yard Waste Carts – phased in 4/05 thru 8/05, then available all subscribers	-2.8528	1.13025	-2.5241	0.01217
Financial Crash 2008	2.9691	0.995308	2.9831	0.00311
Seattle North Transfer Station Closed 1/14 to Present	-11.8417	1.74202	-6.7976	<0.00001

Mean of dependent variable	32.00397	Standard deviation of dependent variable	11.37667
Sum of squared residuals	4741.364	Standard error of regression	4.175103
R-squared	0.986110	Adjusted R-squared	0.984936
Log-likelihood	-830.5165	Akaike criterion	1709.033
Schwarz criterion	1797.602	Hannan-Quinn	1744.494
Rho	0.500819	Durbin-Watson	0.993635

Actual & Estimated Self-Haul Yard Waste Pounds per Day



VI. Appendix 2 – Specification of the Residential Garbage Equation

Monthly residential garbage collection quantities for the period January 1977 through August 2014 include garbage collections from both can and dumpster customers. The drivers of can household (primarily single-family and smaller apartment building households) and dumpster household (primarily larger apartment building households) garbage collection quantities are likely to be somewhat different. For example, a can household sees the impact of their garbage quantities on their monthly collection fees for the size garbage pickup container they have selected, whereas a dumpster household is not likely to have much influence over the amount of garbage fees included in their monthly rent. Thus, one must take some care in specifying the demand equation to be estimated over the monthly data for residential garbage collection quantity.

Let residential garbage collection per household per collection day be symbolized by GHD. If we define GC and GD as monthly garbage collection pounds in total from can and dumpster customers, respectively; HC and HD as number of can and dumpster service households, respectively; and D as number of collection days per month, then we can write the equation for GHD as follows:

(1) GHD = (GC + GD)/(D*(HC + HD)) = [(HC/(HC + HD))*(GC/(HC*D))] + [(HD/(HC + HD))*(GD/(HD*D))].

Now let the functions f(…) and g(…) represent per household demand for garbage removal per collection day for can and dumpster customers, respectively. Also let r_c = HC/(HC + HD), the proportion of customers that have can service. Then we can write the GHD equation as:

(2) GHD = r_c f(….) + (1- r_c)g(….), where the arguments of f and g are economic, weather, programmatic and demographic variables such as the average and/or marginal price of garbage collection service, the price of alternative waste collection services such as recycling or yard debris collection for can customers and recycling collection for dumpster customers, average income of can and dumpster households, household size, weather variables, yard size, disposal bans, mandatory recycling or organic collection, and monthly seasonality factors.

Equation (2) has the common sense interpretation that our available data on garbage collection pounds per household per day for can and dumpster households combined is just the weighted average of can (also sometimes referred to as "single-family") household and dumpster (also sometimes referred to as "apartment" or "multi-family") household pounds. If we can somehow further decompose equation (2) then the problems we have in identifying the separate influences of single-family and apartment households, as well as the separate drivers of those separate influences, on GHD might be simplified and perhaps resolved.

For example, in the case in which f and g are linear functions of their arguments (the explanatory variables for single-family and multi-family garbage disposal pounds), the GHD equation reduces to a series of terms including the following five types:

1. Constant = $r_c*A_{0c} + (1- r_c)*A_{0d} = A_{0d} + (A_{0c} - A_{0d})*r_c$, where A_0 is the intercept in each linear function denoted by the subscripts c and d for can and dumpster households, respectively. For monthly time series data this equation has the constant component A_{0d} and the variable component $r_c*(A_{0c} - A_{0d})$, because the proportion of can customers varies over time. If the intercepts for f and g are equal then the estimated coefficient on the can customer proportion variable will not be significantly different from zero.
2. A variable, say temperature T, that effects both can and dumpster household garbage will enter GHD as $r_c*A_{1c}*T+ (1- r_c)*A_{1d}*T = A_{1d}*T + (A_{1c} - A_{1d})* r_c*T$, where A_1 is the coefficient on temperature in each linear function f and g denoted by the subscripts c and d, respectively. If the effect of temperature on can and dumpster household production of garbage for collection is statistically the same (i.e., $A_{1c} = A_{1d}$), then a changing proportion of can versus dumpster households will not significantly affect the influence of temperature on GHD.

3. A variable, say marginal price of can collection service MP, that only effects can household garbage will enter equation (2) for GHD as r_c*A_{2c}*MP, where A_2 is the coefficient on marginal price in the linear function f.
4. A variable, say availability of apartment recycling service as measured by AR, that only effects dumpster household garbage will enter equation (2) for GHD as (1 - $r_{c)}$*A_{2d}*AR, where A_2 is the coefficient on apartment recycling service availability AR in the linear function g.
5. A variable, say income Y, which may be different for can and dumpster customers and may affect each group differently. In this case we need to multiply each household group's separate income levels by the separate proportionality factors given in 3 and 4 above.

This derivation explains why the proportion of can versus dumpster households might affect the coefficient estimates for some explanatory variables in the residential garbage equation. It needs to be factored in as a separate explanatory variable in its own right for what we would ordinarily call the "constant" term in the underlying can and dumpster household garbage equations as shown in 1 above. It also needs to be factored in as a multiplier of other variables that separately drive can and/or dumpster household garbage production as shown in 2 through 5 above.

Explanatory (right-hand) variables (the arguments of the f and g functions) that might drive can and dumpster household garbage disposal quantities include:

- Seasonal variables such as month of the year,
- Weather variables such as temperature or rainfall,
- Demographic variables such as household size and household income,
- Pricing variables such as the marginal price for a bigger garbage container, the average level of garbage fees, the average and marginal prices for yard waste collection, and the marginal price for water (if cheaper water drives additional usage of lawn and garden supplies that result in disposal items), and
- Programmatic variables such as the availability of curbside recycling or bans on disposal of recyclables or organics in garbage.

If this were a study to analyze differences in the behavior of individual households one would also posit the likely influence of yard size and house size on garbage disposal quantities. However, this is not a cross-sectional study. QUIDPRO's residential disposal equation explains aggregate disposal over time, not individual household disposal quantities at a single point in time. Furthermore, average yard size and home size likely change too slowly over time to have any statistically measurable impact on waste flows over the 38-year study period 1977 through August 2014. So these potentially important drivers of garbage disposal quantities are not considered in estimating the residential garbage disposal equation.

VII. Appendix 3 – Data Sources

In some ways estimating the QUIDPRO equations was less difficult than the task of assembling the database. Many of the explanatory variables of interest – e.g., number of households, household size and household income – are readily available on an annual snapshot basis from either local, state or federal agencies such as Puget Sound Regional Council, Washington Employment Security Department, Washington Office of Financial Management, US Census Bureau, and US Bureau of Labor Statistics. However, these same series are essentially non-existent on a monthly basis.

Because one of the objectives for QUIDPRO is to estimate and forecast collection quantities on a monthly basis, we had to resort to a variety of interpolation methods to produce monthly time series from annual snapshots. In some cases, such as household counts, where we could rely on SPU customer count data to provide guidance for filling in the blank months, the procedure was straightforward. In other cases, such as producing a monthly time series on household income, we had to interpolate quarterly or annual snapshots through simple straight-line approximations.

All waste quantity, pricing and programmatic variables are from one or another database or hard copy record available at SPU, except for King County transfer station disposal fees. Historical disposal fees for King County were provided by King County Department of Natural Resources. Current County transfer station fees are available on their website.

Weather variables are available online for the Seattle area (e.g., for a measurement station at Seattle-Tacoma International Airport) through the Western Regional Climate Center (http://www.wrcc.dri.edu/) with data for Washington Climate Summaries (http://www.wrcc.dri.edu/summary/climsmwa.html) and two Seattle area specific locations (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wa7470 and http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wa7473)

The demographic variables are computed from underlying data series from a variety of sources. Household size is based on estimates of occupied households and population in occupied households as reported on an annual basis by census tract by Puget Sound Regional Council (PSRC). These PSRC estimates are not re-estimated following each decennial census, so we had to benchmark them to the census counts with some help from Washington Office of Financial Management estimates for household counts that are benchmarked after each new census. Once we had an accurate annual series for years between the decennial censuses, we used simple linear interpolation to fill in the eleven missing months for each year.

Household income and the regional consumer price index are based on The Puget Sound Economic Forecaster quarterly estimates, which are in turn in part based on U.S. Department of Commerce Bureau of Economic Analysis datasets. The latter are available online at http://www.bea.gov/bea/regional/reis/drill.cfm. The Puget Sound Economic Forecaster is available on a subscription basis from www.economicforecaster.com.

The monthly unemployment rate is for the Seattle-Tacoma-Bellevue Metropolitan Statistical Area, not seasonally adjusted. The Bureau of Labor Statistics series identification number is LAUMT534266000000003 and the data series is available at http://www.bls.gov/data/.

Quarterly tax-rate-adjusted B&O tax receipts are provided by the City of Seattle Finance and Administrative Services Department.