Recreation Visits to Lake Mead and Glen Canyon National Recreation Areas: A Replication Study

RECREATION VISITS TO LAKE MEAD AND GLEN CANYON NATIONAL RECREATION AREAS: A REPLICATION STUDY

By

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As members of the Master's Committee, we certify that we have read the thesis prepared by *Xiaoting Wu*, titled *"Recreation Visits to Lake Mead and Glen Canyon National Recreation Areas: A Replication Study"* and recommend that it be accepted as fulfilling the dissertation requirement for the Master's Degree.

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Final approval and acceptance of this thesis is contingent upon the candidate's submission of the final copies of the thesis to the Graduate College.

I hereby certify that I have read this thesis prepared under my direction and recommend that it be accepted as fulfilling the Master's requirement.

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TABLE OF CONTENTS

Abstract

This thesis conducted a replication study of an earlier analysis of the relationship between lake volumes and monthly recreation visits to Lake Mead and Glen Canyon (Lake Powell) National Recreation Areas. The exact same data that were used in the original study were no longer available, but similar data were available from the same government agency sources used in the original study. For the years of the original study, 1996 to 2011, the basic results of the original study hold in the replication. These were that (i) lake volume was significantly and positively associated with visits, (ii) the effect of volume had different seasonal effects for Lake Powell, but not Lake Mead, and (iii) there were strong monthly seasonality in visitation patterns. The main results of the original study – the strong positive impact of lake volume on visits – was not robust when extending the period of analysis from 1979 to 2017. When additional economic variables were added to the regression model, a positive effect of lake volume was found for Lake Powell from 1996-2017, but not from 1979-2017, or 1979-1995. A significant positive relationship between volume and visits was not found for Lake Mead for 1979-1995, 1996-2017, or the entire period 1979-2017. Throughout out all regression specifications, gasoline price, which was omitted from the previous study, had a statistically significant negative effect on visits. This effect was robust across all time intervals and across both lakes.

Chapter 1 Introduction

According to a report prepared by Michigan State University for U.S. National Park Service in 2011, the U.S. National Park system contributed to over $30 billion in economic activity and more than 250,000 jobs nationwide. Thirteen billion of this went to communities within 60 miles of a U.S. National Park Service unit. This system includes national parks, national recreation areas, national monuments, national memorials, national parkways, and national historical sites and other units (Yue, 2013). Also, in a study conducted in 2017, the National Park Service found that 331 million park visitors spent $18.2 billion in local areas around national parks across the country (Thomas, 2018). This spending helped support 306,000 jobs.

Lake Mead National Recreation Area (NRA) and Glen Canyon National Recreation Area (home of Lake Powell) are two of the most visited sites in the National Park Service system. In 2018, there were 7.5 million visits to Lake Mead NRA (National Park Service, 2019) and 4.2 million visits to Glen Canyon NRA (Plumb, 2019). For comparison, there were 7.8 million visits to the Lincoln Memorial, 6.4 million visits to Grand Canyon National Park and 4.7 million visits to the Vietnam Veterans Memorial in 2018 (National Park Service, 2019). In 2018, Lake Mead NRA was the 6th most visited National Park Service site, while Glen Canyon NRA was ranked 20th among all sites (Table 1-10. Among sites in the Southwestern United States (southern California, Nevada, Arizona, and Utah), Lake Mead NRA ranked first, while Glen Canyon NRA ranked fourth in total visits in 2018.

Visitors to Lake Mead and Glen Canyon NRAs are important to the local economies. Lake Mead NRA is about 24 miles southeast of Las Vegas, Nevada and is in both Nevada and Arizona. Glen Canyon NRA is in both Utah and Arizona. Glen Canyon is in a more remote location, more than a 4-hour drive from Las Vegas and Salt Lake City, Utah and a more than 2-

hour drive from Flagstaff, Arizona. In 2018, visitors spent $411 million in and around Glen Canyon NRA, supporting more than 5,000 jobs. Visitors to Lake Mead NRA spend $336 million, supporting nearly 4,000 jobs (National Park Service, 2018).

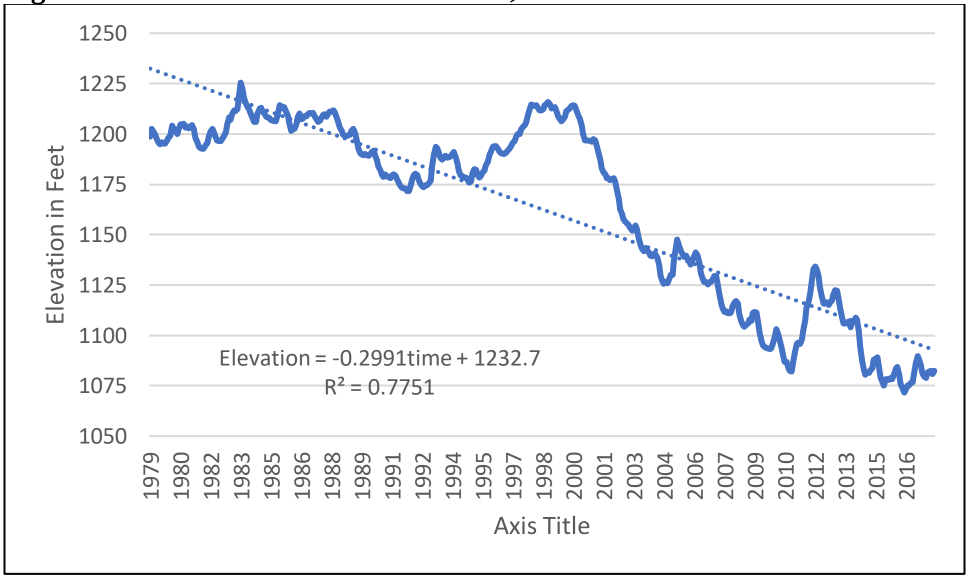
Table 1-1. Most Visited National Park Service Sites, 2018

Park	Rank	Recreation Visits	% of Total Visits
Golden Gate NRA	1	15,223,697	4.78%
Blue Ridge PKWY	2	14,690,418	4.62%
Great Smoky Mountains NP	3	11,421,200	3.59%
Gateway NRA	4	9,243,305	2.90%
Lincoln Memorial	5	7,804,683	2.45%
Lake Mead NRA	6	7,578,958	2.38%
George Washington MEM PKWY	7	7,288,623	2.29%
Grand Canyon NP	8	6,380,495	2.01%
Natchez Trace PKWY	9	6,362,439	2.00%
Vietnam Veterans MEM	10	4,719,148	1.48%
World War II Memorial	11	4,652,865	1.46%
Rocky Mountain NP	12	4,590,493	1.44%
Independence NHP	13	4,576,456	1.44%
Castle Clinton NM	14	4,533,564	1.42%
Chesapeake & Ohio Canal NHP	15	4,438,818	1.39%
Statue of Liberty NM	16	4,335,431	1.36%
Zion NP	17	4,320,033	1.36%
Gulf Islands NS	18	4,229,968	1.33%
San Francisco Maritime NHP	19	4,223,542	1.33%
Glen Canyon NRA	20	4,219,441	1.33%
Yellowstone NP	21	4,115,000	1.29%
Korean War Veterans Memorial	22	4,107,520	1.29%
Yosemite NP	23	4,009,436	1.26%
Cape Cod NS	24	3,926,462	1.23%
Martin Luther King, Jr. Memorial	25	3,567,434	1.12%

Source: National Park Service, Integrated Resource Management Applications (IRMA) Portal

Even though Lakes Mead and Powell have many visitors and significant visitor spending, there have been few studies that estimate the demand for visits. Frisvold, et al. estimated annual visits to Lake Mead and Glen Canyon NRAs in a study of visits to all National Park Service sites in the southwestern United States. They used elevations for Lakes Mead and Powell as intercept shifters in their regression analysis. Their model assumed that all other variables and regression coefficients were the same across NPS sites. Neher et al. (2013) estimated separate regressions for monthly (instead of annual) visits to Lake Mead and Glen Canyon NRAs. They were interested in how changes in lake volumes affected visits. Both studies found that higher lake levels or volumes increased visits.

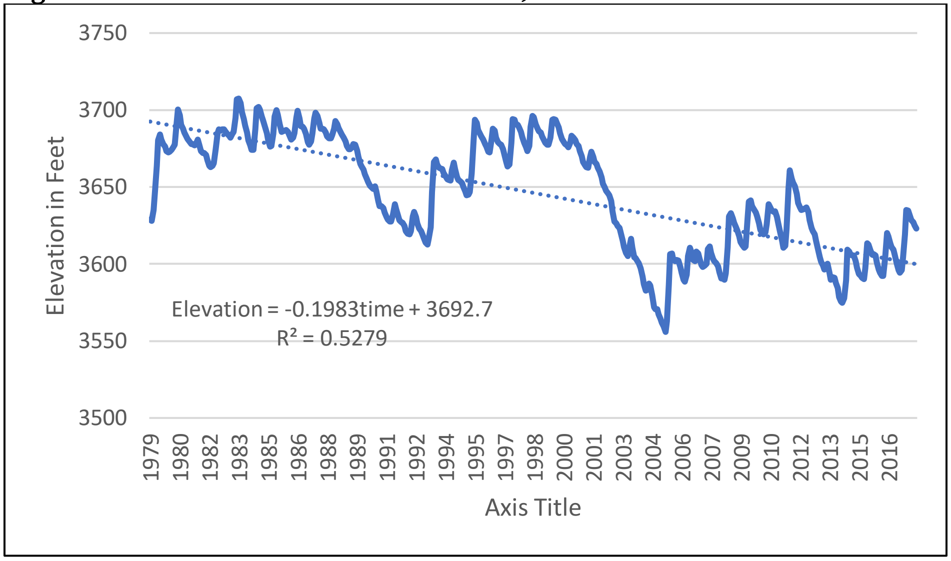
Figure 1-1. Lake Mead Elevation in Feet, 1979 – 2017.



Source: USBOR

The western United States has been in a prolonged drought and lake levels have been falling over time. Elevations at Lake Mead did not change much in the 1980s. They fell but recovered in the 1990s. Lake levels began to fall more steadily over the past 20 years (Figure 1). Elevations at Lake Powell fluctuate from month to month a lot (Figure 2). Levels trended down in the late 1980s and early 1990s, then recovered. Levels fell again between 2000 and 2005 but have recovered. They are still lower than high points of earlier decades.

Figure 1-2. Lake Powell Elevation in Feet, 1979 – 2017



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Some climate change studies predict that the levels of Lakes Mead and Powell could fall significantly (e.g. Christensen et al. 2004; Christensen and Lettenmaier 2006; Pierce et al, 2009). If visits are tied to lake levels, this could mean a fall in visits and visitor spending in the area.

Lake levels depend on snow melt from the Rocky Mountains. They also depend on policies to maintain elevations below a certain level. If the elevation of Lake Mead falls below 1075 feet this will trigger a Shortage Declaration for the Lower Colorado River. This means that deliveries of surface water to Central Arizona will be cut back. Most of the cuts will affect agriculture. Some studies have looked at the economic effects of lake level reductions and a Shortage Declaration on Arizona agriculture (USBOR, 2007; Bickel et al., 2019). To avoid a shortage declaration, the Bureau of Reclamation has programs to get water users to keep more water in Lake Mead instead of using it. By preventing a shortage, these program benefit Arizona agriculture. But if visits and visitor spending go up with lake levels, these programs may also help the local economies around the lakes.

Plan of the thesis

This thesis has three parts. Part one is a replication study of the Neher et al. (2013) article. There are three different kinds of replication (Duvendack, et al. 2017; Hamermesh, 2007). "Pure replication" means analyzing data all over again using the same dataset, the same regression model, and the same statistical methods as the original study. In "statistical replication", the new study examines the same population, regression model and statistical model, but the sample data used may be different from the original study. In "scientific replication" researchers may use different regression model specifications or different statistical methods. Neher et al. (2013) used publically available data on lake volumes from the Bureau of Reclamation and recreational visitation from the National Park Service. They report websites where these data were available at the time of their publication. These weblinks are no longer active, though. I could not obtain the exact same data that Neher et al. (2013) but collected data from Bureau of Reclamation and National Park Service websites that are currently available. These data are not exactly the same as Neher et al. (2013), but they are very close. Chapter 2 compares the descriptive statistics of the data I collected with the data used by Neher et al. (2013). Although, Neher et al. did test for autocorrelation in their models, but they only showed ordinary least squares (OLS) estimation, because they found there is nearly no change after correcting the autocorrelation. My analysis also fails to reject the hypothesis of no autocorrelation. My results no matter before or after correcting the autocorrelation are all like Neher et al.'s.

Part two of the thesis examines how the Neher et al. model performs out of sample. They originally estimated their models for 1996 to 2011. They also estimated their models for 1996 to 2006 then used those results to see how that model fit data from 2007 to 2011. They found that their 1996-2006 specification predicted values for 2007-2011 well. Data on lake volumes and visitation are available from 1979 to 2017. I examined how the Neher et al specification performed out of sample from 1979 to 1995 and from 2012 to 2017. Over this longer time period, their out of sample performance was much poorer than in their original study. Also, when estimating their model over different periods (1979-1995, 1996-2011, and 2012-2017) their regression coefficients were unstable and inconsistent across time. Greater lake volumes did not necessarily increase visits.

One reason for the poor performance of their model over a long-time horizon could be omitted variable bias. In their models, the only variables they use are lake volume, dummies for month, and interaction terms between volume and season. Other studies of park visits include variables to capture changes in the demand for visits. These include things like changes in population, income, the business cycle, and gasoline prices (Watson, 2013). In Neher et al., the only variables that change from one year to the next are volume. Depending how missing variables change with volume, this can create biases in the estimates of the regression coefficients for volume (Greene, 2002).

Part three introduces some demand side variables that have been used in other studies to the basic regression specification used by Neher et al. These include things like the price of gasoline, regional population, and measures of business cycle effects. Unfortunately, adding these variables did not improve the model's performance as expected. I also experimented with using a log-linear specification (Neher et al. used a linear specification). Again, results were often not consistent with expectations. Regression coefficients often changed signs and significance across different years. Autocorrelation continued to exist in the regression models. This can be due to model misspecification. This suggests more work is needed to correctly specify lake visitation models.

Chapter 2 Data and Model Specification for Replication

The study to be replicated is Neher et al. (2013). Their dependent variables of interest are recreational visits to Lake Mead NRA and Glen Canyon NRA. They used monthly recreational visit data to each site obtained from a National Park Service website. They ran two separate regressions for monthly visits to Lake Mead NRA and Glen Canyon NRA from 1996 to 2011 with 192 observations for each regression. Their regression specification was

(1) $\textit{Monthly Visits} = \alpha + \boldsymbol{\beta}'\mathbf{D} + \gamma \textit{Volume} + \delta(\textit{Volume} \times \textit{Shoulder}) + \eta(\textit{Volume} \times \textit{Summer}) + \varepsilon$

where **D** is a vector of dummy variables for the months of March through November. December to February were grouped together as the default period. *Volume* is the estimated volume of each lake obtained from a Bureau of Reclamation website. Shoulder is a dummy variable that equals 1 if the month is April, May, September or October and otherwise equals 0. *Summer* is a dummy variable that equals 1 if the month is June, July, or August and otherwise equals 0. The *Shoulder* and *Summer* variables are interacted with the *Volume.* Neher et al. argued that the effect of lake volume and visits might be different across different seasons. Neher et al estimated separate versions of equation (1) for Lake Mead NRA and Glen Canyon NRA (Lake Powell).

To replicate the study, data are needed that Neher et al, used for their study. Dummy variables for month and for *Summer* and *Shoulder* seasons are easy to construct. Neher et al. cite US Bureau of Reclamation. 2012. Upper Colorado Region Reservoir Operations, Lake Powell; [cited 15 Oct 2012]. Available from: http://www.usbr.gov/uc/crsp/] as the source for their lake volume data. When I tried to access this URL, I got the error message, “URL was rejected. Please consult with your administrator.” Searching on “Upper Colorado Region Reservoir Operations, Lake Powell” I found the site, “Upper Colorado Region Encompassing all or parts of Arizona, Colorado, Idaho, Nevada, New Mexico, Texas, Utah and Wyoming: Glen Canyon

Dam." At this site there is another option to search on "Historical Data." This site has data for different reservoirs in the Upper Colorado Basin, including Lake Powell. Searching on "monthly data" you can download data for Lake Powell volumes (storage) as of the first of each month. It is also possible to search on daily values for Lake Powell volumes. This Upper Basin site does not include any data for Lake Mead, which is in the Lower Colorado Basin. For the purposes of replication, I took daily readings and computed monthly average volumes.

At the site "Lower Colorado River Operations" it is possible to search on "Historical Reservoir Levels (updated monthly)" for Lake Mead. This site has data for the elevation of Lake Mead but not the volume. I was not able to find any website that reported the volume of Lake Mead by month. The National Park Service website "Storage Capacity of Lake Mead" discusses studies that estimate lake volume as a function of elevation. It reports Volume at a wide range of elevations.

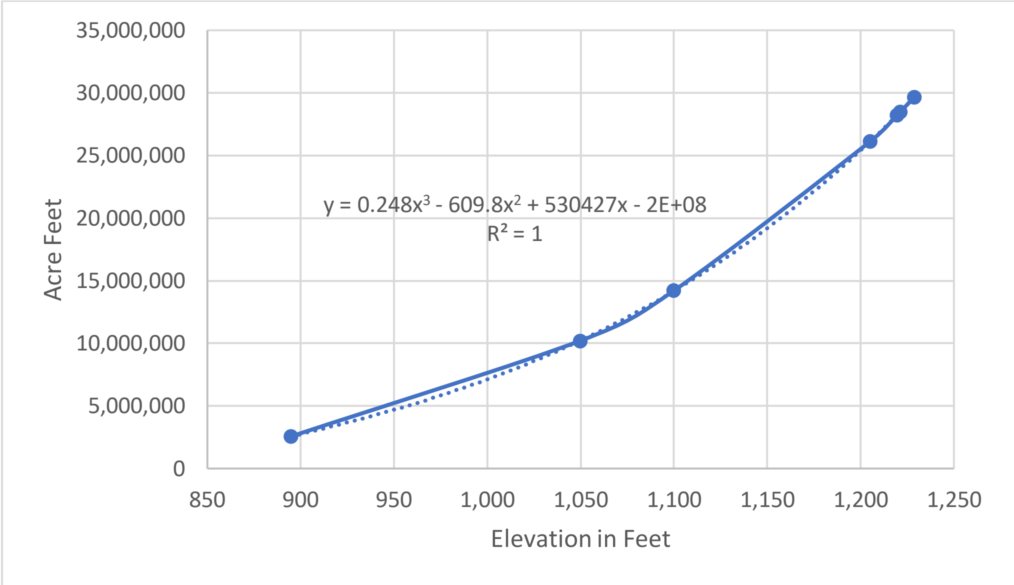
Table 2-1. Estimated Volume of Lake Mead at different Lake Elevations Source: National Park Service

Location	**Elevation**	**Volume (acre-feet)**
Maximum designed water-surface elevation	1,229	29,686,054
Crest of drum gates on spillway (raised)	1,221	28,507,783
Operational capacity	1,220	28,229,730
Permanent crest of spillway sill	1,205	26,150,596
Current lake level (February 2010)	1,100	14,210,242
Intake tower, upper gates	1,050	10,217,399
Intake tower, lower cylinder gate entrance liners	895	2,576,395

Source: USBOR

To estimate volumes of Lake Mead I first used the table above to run a regression of volume on elevation. Figure 2-1 shows that a quadratic equation fits the data well, with an R-square = 1).

Figure 2-1: Lake Mead Volume as a Function of Elevation



Source: USBOR

The coefficients of this regression equation and the lake level data from the Lower Colorado River Operations website were used to construct a monthly volume variable for Lake Mead. Neher et al. cite National Park Service. 2012. Visitor use statistics as the source of their recreational visitation data. From this site it is possible to download data on Recreational Visits by Month for Glen Canyon and Lake Mead NRAs.

Neher et al. report the minimum, median, and maximum values for the variables they use in their regressions. Table 2-2 compares these values with the data I obtained from the National Park Service (NPS) and Bureau of Reclamation (BOR) sites. The number of visits reported by the NPS in 2019 for both Glen Canyon and Lake Mead NRAs are larger than the numbers reported by Neher et al. This might be because NPS updates estimates over time. The Lake Powell volume numbers reported by Neher et al. and the numbers obtained by calculating monthly average from daily readings for BOR data reported in 2019 are very close. Minimum and maximum values are identical, while the median value reported is about 5% larger. There are greater differences in the descriptive statistics for Lake Mead. The variable I constructed for Lake Mead volume shows higher minimum, median, and maximum values than the values reported by Neher et al. The differences are greater in percentage terms at lower than higher volumes.

Table 2-2: Lake Mead and Lake Powell recreational visitation model explanatory variables

Variable	Neher et al. Minimum	This Study Minimum	Neher et al. Median	This Study Median	Neher et al. Maximum	This Study Maximum
Lake Powell Visitation	22,555	25,979	128,899	149,583	472,989	512,678
Lake Mead Visitation	210,232	253,465	542,941	654,602	1,047,848	1,165,154
Lake Powell Volume x Summer	0	0	0	0	23,748,777	23,748,776
Lake Mead Volume x Summer	0	0	0	0	24,894,088	27,150,128
Lake Powell Volume x shoulder	0	0	0	0	23,182,862	23,182,861
Lake Mead Volume x Shoulder	0	0	0	0	25,202,057	27,343,740
Lake Powell Volume	8,128,685	8,128,685	16,079,669	15,254,512	23,748,777	23,748,776
Lake Mead Volume	9,948,733	12,706,632	15,639,931	18,488,771	25,224,447	27,343,740

Figure 2-2 and Figure 2-3 compare the monthly distribution of visits to Glen Canyon and Lake Mead NRAs reported by Neher et al. and by the 2019 NPS website. The figures are not identical, but they are very close. The peak visit time for Lake Powell is always in summer months. Visits to Lake Powell drop to very low levels in November through February.

The next step in replication is to re-run separate regressions for Lake Mead and Glen Canyon NRAs using the dataset I constructed and the exact same regression specification (equation (1) above) as Neher et al. used. Results of this are reported in the next chapter, Chapter 3.

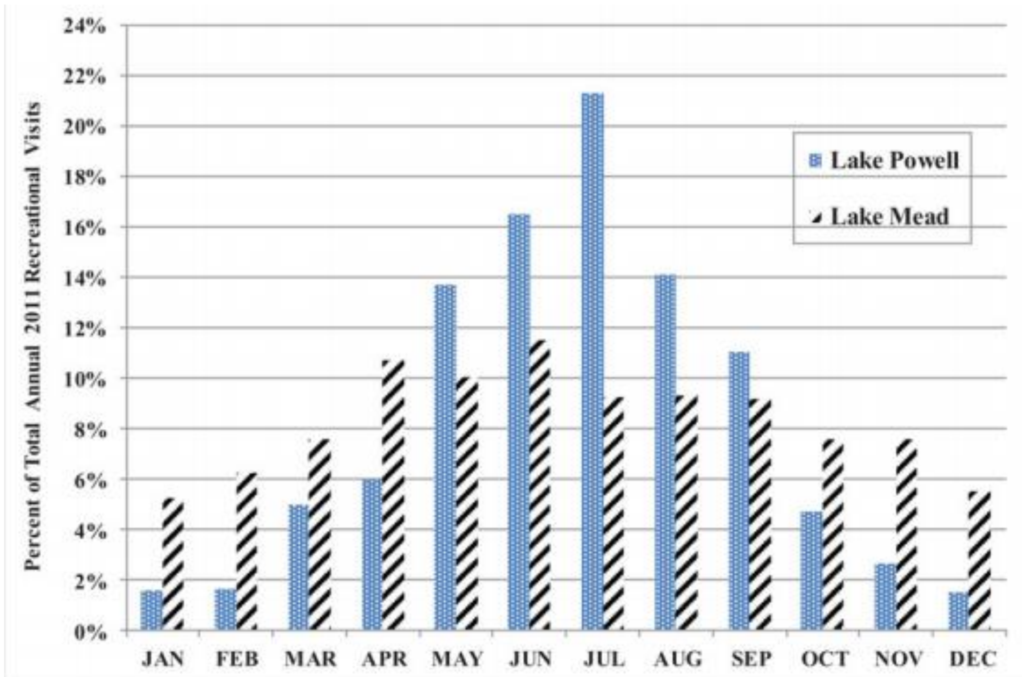


Figure 2-2: Monthly distribution of visits to Glen Canyon and Lake Mead NRAs reported by Neher et al.

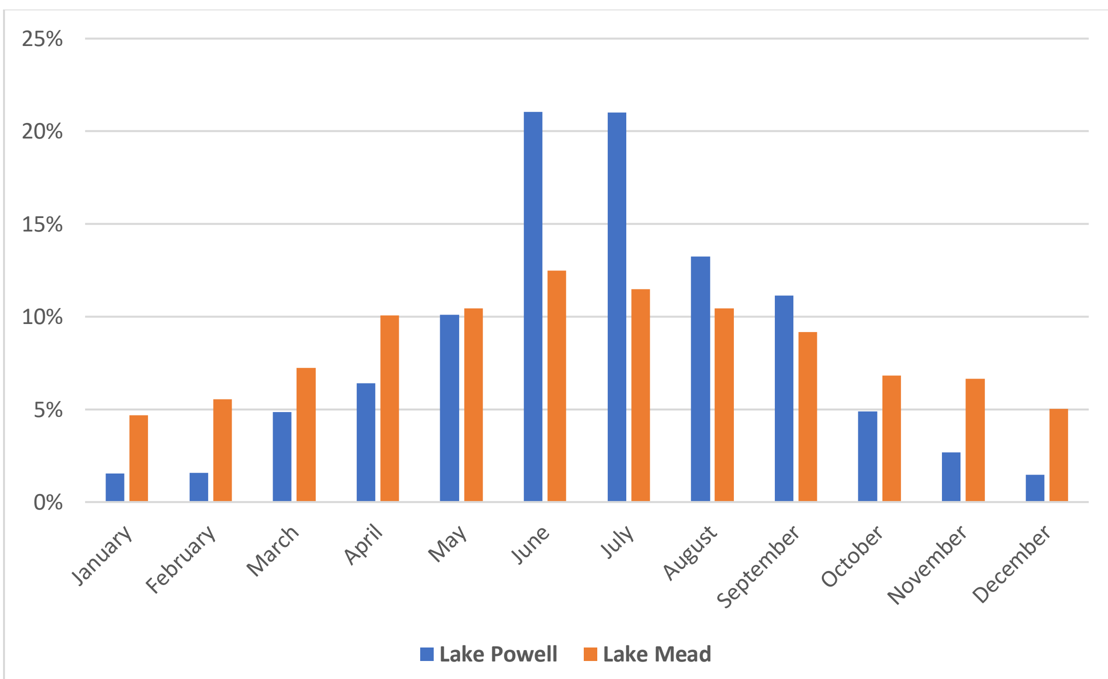


Figure 2-2: Monthly distribution of visits to Glen Canyon and Lake Mead NRAs using replication data

Chapter 3 Statistical Replication

This chapter conducts "statistical replication" of the Neher et al. study, using the same variables, regression functional form, and estimation techniques as the original study, but with different data Duvendack, et al. 2017; Hamermesh, 2007).

Table 3-1. Monthly Recreational Visits to Glen Canyon NRA (Lake Powell)

1996–2011 data	**Replication**		**Neher et al.**	
Variable	**Estimate**	**Standard error**	**Estimate**	**Standard error**
Intercept	18,641***	9,075	17,623***	9,450
Mar_Dum	60,219***	6,076	53,266***	6,327
Apr_Dum	59,051***	13,899	54,231***	14,473
May_Dum	140,472***	14,111	139,635***	14,694
Jun_Dum	158,365***	15,658	125,120***	16,305
Jul_Dum	186,125***	15,887	168,130***	16,543
Aug_Dum	144,042***	15,697	131,974***	16,346
Sep_Dum	126,626***	14,541	119,114***	15,142
Oct_Dum	49,972***	14,474	47,008***	15,072
Nov_Dum	31,092***	6,075	25,715***	6,327
Volume x Summer	0.00964***	0.00088	0.00895***	0.00092
Volume x Shoulder	0.00387***	0.00082	0.003***	0.00085
Volume	0.00131**	0.00055	0.00116**	0.00057
R-Square	0.9761		0.969	

∗Coefficient is statistically significant at 90% level of confidence; ∗∗ Significant at 95% level; ∗∗∗ Significant at 99% level.

Table 3-1 compares the original and replicated results for the Glen Canyon NRA (Lake Powell) regressions. Chapter 2 discussed how the data for replication was different from that data Neher originally used. The main variables came from the National Park Service and the Bureau of Reclamation in both cases and was not very different. The regression results are also very similar. The coefficients for lake volume and interaction terms are all very close. The ranking of the size of monthly effects (based on the month dummy coefficients) changes. But, the coefficients in the two models are all inside the upper and lower bounds of their standard errors. So, using currently available data, the results are qualitatively the same as the Neher et al. study.

Table 3-2. Monthly Recreational Visits to Lake Mead NRA

1996–2011 data	**Replication**		**Neher et al.**	
Variable	**Estimate**	**Standard error**	**Estimate**	**Standard error**
Intercept	219,878***	39,340	229,411***	34,206
Mar_Dum	115,006***	22,387	80,956***	23,341
Apr_Dum	281,229***	60,270	211,953***	53,826
May_Dum	328,848***	59,854	211,863***	53,321
Jun_Dum	495,251***	64,196	243,479***	56,705
Jul_Dum	456,184***	64,035	205,152***	56,439
Aug_Dum	477,291***	64,129	196,871***	56,454
Sep_Dum	262,787***	59,557	178,077***	52,820
Oct_Dum	168,988***	59,669	128,532**	52,881
Nov_Dum	57,548**	22,413	49,006*	23,356
Volume x Summer	-0.001496	0.00302	0.00406	0.002985
Volume x Shoulder	0.000121	0.00276	0.00044	0.002742
Volume	0.0117***	0.00185	0.01008***	0.001822
R-Square	0.8499		0.7126	

∗Coefficient is statistically significant at 90% level of confidence; ∗∗ Significant at 95% level; ∗∗∗ Significant at 99% level.

Table 3.2 compares the original and replicated regression of monthly visits of Lake Mead NRA. In this case, there is more of a difference between the two regressions. First, the fit in the replication model is better with an R-square of 0.85 compared to 0.71 in the original. There are also larger differences in the point estimates of the monthly dummy coefficients. Also, the values for the coefficients plus or minus one standard deviation do not always overlap. For example, for the month of July, the replication coefficient minus one standard deviation is 456,184 – 64,035 = 393,149, while in the original, the coefficient plus one standard deviation is 205,152 + 56,439 = 261,591. The coefficients for lake volume are very close. There is more difference in the point estimates of the lake volume and season interaction variables. For example, in replication, the point estimate for the volume and summer interaction moves from positive to negative. In both regressions, though, the volume and season interaction terms are not significantly different from zero at the 10% level of significance. So, the coefficients are basically both zero in both equations. In the replication, the main results from Neher et al still hold. The coefficient for volume is statistically significant and about 0.01. Volume and season interaction terms are not significant. The month dummy variables are more different, though. In the replication results, largest coefficients are for June, July, and August. In the original, the largest coefficients are for April, May, and June.

Neher et al. test for autocorrelation. They said both the Mead and Powell models showed statistically significant first-order autocorrelation, but they did not report the specific results of their tests, like D-W test results. They claimed after correcting the autocorrelation, the model still fits, and estimates were nearly unchanged in magnitude, and parameter t-values that were still highly statistically significant (Neher, 2013), so they only showed the estimates from OLS.

I used a Durbin-Watson test (Greene, 2002) to see if there was autocorrelation in the data and model. For the Lake Mead NRA regression, the Durbin-Watson statistic was 1.4611. The p-value for the test of positive autocorrelation was <0.0001, while the p-value for the test of negative autocorrelation was 0.9999. So, I reject the null hypothesis of no positive autocorrelation. For the Glen Canyon NRA (Lake Powell regression, the Durbin-Watson statistic was 1.7568. The p-value for the test of positive autocorrelation was <0.0383, while the p-value for the test of negative autocorrelation was 0.9617. So, I reject the null hypothesis of no positive autocorrelation at the 5% level of significance.

Table 3-3 compares the replicated regression equations with and without a correction for first order autocorrelation (AR (1). The regression coefficients are very close to each other across equations. The standard errors for the coefficients for the OLS regression are smaller in absolute value than in the AR (1) correction regression and smaller relative to the regression coefficients too. This is true in all cases except for the November dummy variable. Correcting for autocorrelation lowers the statistical significance of the coefficients, although they all remain highly significant as in Neher et al.'s original model.

Table 3-3. Monthly Recreational Visits to Glen Canyon NRA (Lake Powell)

1996–2011 data	Replication with AR(1) correction		Replication without AR(1) correction	
Variable	**Estimate**	**Standard error**	**Estimate**	**Standard error**
Intercept	18,266*	9,973	18,641**	9,075
Mar_Dum	59,805***	5,989	60,219***	6,076
Apr_Dum	59,045***	14,453	59,051***	13,899
May_Dum	140,496***	14,682	140,472***	14,111
Jun_Dum	160,587***	16,880	158,365***	15,658
Jul_Dum	188,396***	17,128	186,125***	15,887
Aug_Dum	146,273***	16,923	144,042***	15,697
Sep_Dum	126,637***	15,122	126,626***	14,541
Oct_Dum	50,007***	15,045	49,972***	14,474
Nov_Dum	31,237***	5,980	31,092***	6,075
Volume x Summer	0.009502***	0.000956	0.009638***	0.00088
Volume x Shoulder	0.003869***	0.000853	0.003873***	0.000817
Volume	0.001339**	0.000601	0.001312**	0.000546
AR (1)	-0.122*	0.0749	-	
R-Square	0.9764		0.969	

∗Coefficient is statistically significant at 90% level of confidence; ∗∗ Significant at 95% level; ∗∗∗ Significant at 99% level.

Table 3-4 compares the replicated regression equations with and without a correction for first order autocorrelation (AR(1)). The regression coefficients are very close to each other across equations. The standard errors for the coefficients for the OLS regression are smaller in absolute value than in the AR(1) correction regression and smaller relative to the regression coefficients too. This is true in all cases except for the March and November dummy variables. Correcting for autocorrelation lowers the statistical significance of the coefficients, although the coefficients that were statistically significant in Neher et al.'s original model are still significant at the 5% level, although their significance is lower than the OLS results report. The interaction terms for lake volume and the summer and shoulder seasons are not significant, but they weren't significant for Lake Mead in Neher et al. either.

Table 3-4. Monthly Recreational Visits to Lake Mead NRA

1996–2011 data	**Replication with AR(1) correction**		**Replication without AR(1) correction**	
Variable	**Estimate**	**Standard error**	**Estimate**	**Standard error**
Intercept	214,832***	48,050	219,878***	39,340
Mar_Dum	108,437***	21,335	115,006***	22,387
Apr_Dum	283,423***	64,033	281,229***	60,270
May_Dum	332,684***	63,714	328,848***	59,854
Jun_Dum	493,401***	74,422	495,251***	64,196
Jul_Dum	454,540***	74,238	456,184***	64,035
Aug_Dum	475,866***	74,335	477,291***	64,129
Sep_Dum	268,264***	63,378	262,787***	59,557
Oct_Dum	177,284***	63,298	168,988***	59,669
Nov_Dum	73,676***	21,176	57,548**	22,413
Volume x Summer	-0.001317	0.003535	-0.001496	0.00302
Volume x Shoulder	-0.000012	0.002942	0.000121	0.00276
Volume	0.0118***	0.002268	0.0117***	0.00185
AR(1)	-0.2698***	0.0733	-	
R-Square	0.8596		0.8499	

∗Coefficient is statistically significant at 90% level of confidence; ∗∗ Significant at 95% level; ∗∗∗ Significant at 99% level.

The results of the statistical replication are basically the same as in the original Neher et al. study. The ranking of the size of the monthly effects change slightly. But the inverted U pattern of more visits in spring and summer and fewer visits if the winter still holds. In both the original and the replication estimations, lake volumes have statistically significant and positive effect on visits. The lake volume / season interaction effects are significant for Lake Powell, but not for Lake Mead in both the replication and the original. I failed to reject the null hypothesis of positive autocorrelation for both regressions. Correcting for autocorrelation, does not change the Neher et al.'s basic findings.

Chapter 4 Out-of-Sample Model Performance

Neher et al only examined NRA visits from 1996 to 2011 even though monthly visitation data were publically available from the National Park Service going back to 1979. Visitation data are now also publically available for later years. This raises the question of how well the Neher et al model specification predicts visits out of sample. In this chapter, I examine how well their model fits data looking backward to 1979 to 1995 and how well their model predicts visits in recent years, 2012 to 2017.

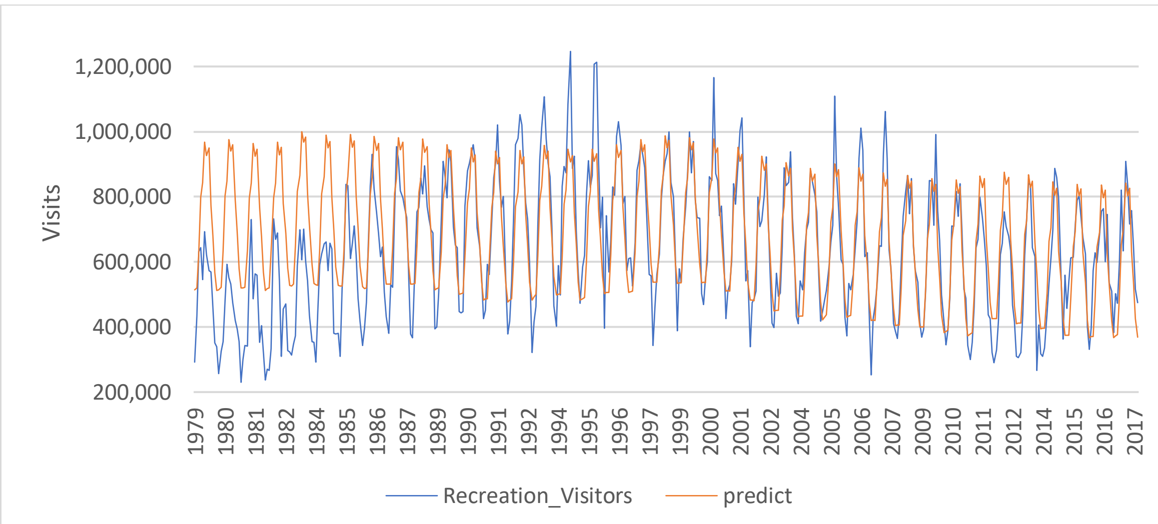


Figure 4-1. Predicted ("predict") versus actual ("Recreation_Visitors) monthly visits to Lake Mead NRA

Figure 4-1 compares the predicted values of visits using their model specification and regression coefficients from their original study with actual visits from 1979 to 2017. The Neher et al. model over-predicts visits (predicted > actual) in the 1980s but under-predicts visits (predicted < actual) in the early 1990s (Figure 4-1). There does not appear to be any systematic bias in later years, from 2008-2017. For earlier years, results are similar for Glen Canyon NRA (Figure 4-2). The Neher et al. model over-predicts visits in the 1980s and under-predicts them in the early 1990s. The Neher et al. model does much worse at predicting visits in recent years.

From 2012 to 2017, there has been a large increase in visits to Glen Canyon NRA that the model failed to predict.

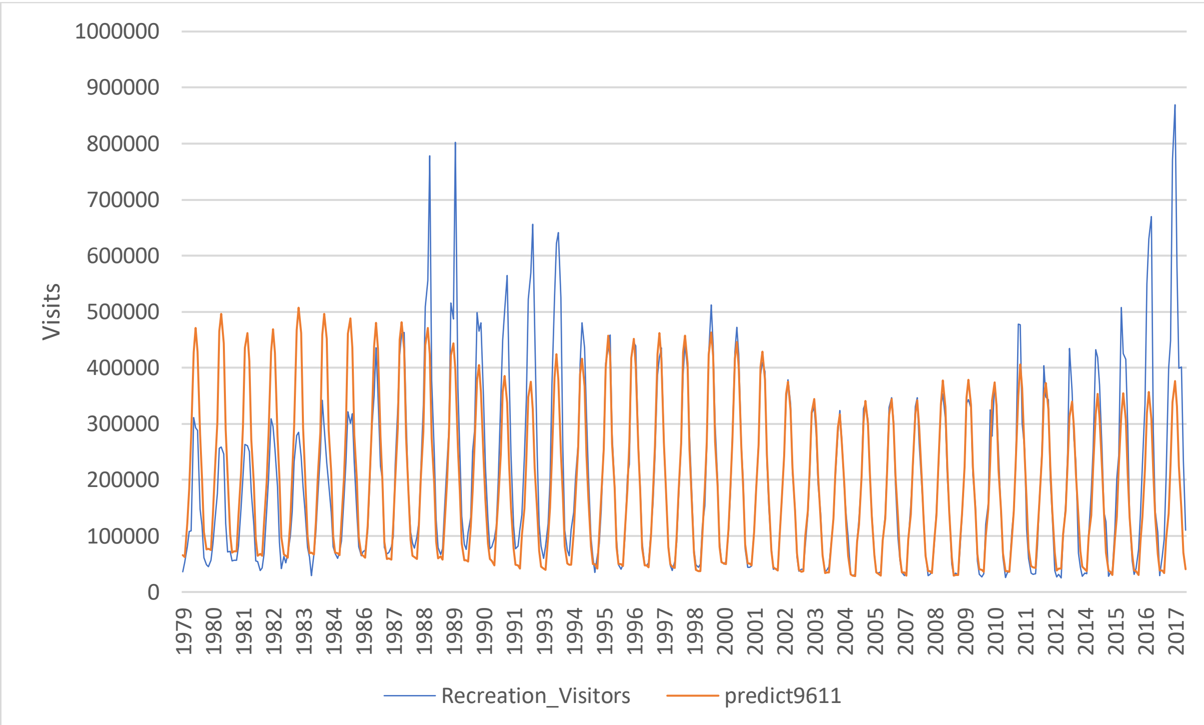


Figure 4-2. Predicted ("predict9611") versus actual ("Recreation_Visitors) monthly visits to Glen Canyon NRA

Table 4-1 shows results for separate regressions of visits to Lake Mead NRA in two different periods, 1979-1995 and 1996-2017. The dummy variable coefficients are not stable and change a lot between regressions. Lake volume does not have a significant, positive effect on visits in early years. Although lake volume does have a significant, positive in later years. Table 4-2 makes a similar comparison for Glen Canyon NRA. Again, month dummy variable coefficients are very different across the two time periods. In both regressions, lake volume only has a significant effect on visits during the summer. But the coefficient is negative in the 1979-1995 regression.

One reason the Neher et al. regressions may have predicted poorly in the 1979-1995 period might be if there was some structural break in the data so that regression coefficients were different in the 1979-1995 period than in later years. I conducted a Chow test of whether the regression coefficients estimated from data for 1979-1995 were the same as for 1996-2017. For Lake Mead the F-statistic was 16.2 and for Glen Canyon it was 8.9. The critical value of the F-statistic for 12 degrees of freedom was 3.36. So, I reject the hypothesis that the coefficients are the same across the two periods for both lakes.

Table 4-1. Re-estimation of Neher et al. regression model of monthly visits to Lake Mead extended back to 1979 and forward to 2017

	1979-1995			1996-2017		
Variable	**Estimate**	**Standard Error**	**P value**	**Estimate**	**Standard Error**	**P value**
Intercept	866954**	403414	0.0329	264494***	41884	<.0001
Mar_Dum	156151***	25232	<.0001	106929***	19170	<.0001
Apr_Dum	588055*	303712	0.0543	236063***	53031	<.0001
May_Dum	638668**	303214	0.0365	283739***	52865	<.0001
Jun_Dum	1259676***	381758	0.0012	364758***	62859	<.0001
Jul_Dum	1292216***	381511	0.0009	340785***	62752	<.0001
Aug_Dum	1218227***	381034	0.0016	329026***	62839	<.0001
Sep_Dum	525037*	302356	0.0841	247911***	52563	<.0001
Oct_Dum	454713	301404	0.133	131199**	52315	0.0128
Nov_Dum	111936**	24991	<.0001	66403***	19065	0.0006
Summer x Volume	-0.0357**	0.0153	0.0204	0.004538	0.003215	0.1594
Shoulder x Volume	-0.0105	0.0121	0.3852	0.001692	0.0026	0.5157
Volume	-0.0183	0.0161	0.2586	0.009501***	0.002126	<.0001
AR1	-0.7069***	0.0539	<.0001	-0.3483***	0.06	<.0001
R square	0.8191			0.8336		

∗Coefficient is statistically significant at 90% level of confidence; ∗∗ Significant at 95% level; ∗∗∗ Significant at 99% level.

Table 4-2. Re-estimation of Neher et al. regression model of monthly visits to Glen Canyon NRA extended back to 1979 and forward to 2017

	1979-1995			1996-2017		
Variable	**Estimate**	**Standard Error**	**P value**	**Estimate**	**Standard Error**	**P value**
Intercept	171716**	86154	0.0477	8892	31995	0.7813
Mar_Dum	31043**	12957	0.0176	62366***	9132	<.0001
Apr_Dum	189557***	63048	0.003	96877***	25701	0.0002
May_Dum	279943***	64724	<.0001	176432***	26866	<.0001
Jun_Dum	590366***	89447	<.0001	298262***	37088	<.0001
Jul_Dum	618834***	91087	<.0001	317477***	37897	<.0001
Aug_Dum	639872***	90150	<.0001	268409***	37162	<.0001
Sep_Dum	311704***	66773	<.0001	161949***	27884	<.0001
Oct_Dum	204503***	65936	0.0022	77666***	27035	0.0044
Nov_Dum	27314**	13091	0.0383	36868***	9350	0.0001
Summer x Volume	-0.0124***	0.00434	0.0047	0.003759*	0.002207	0.0897
Shoulder x Volume	-0.004336	0.003224	0.1802	0.002427	0.001607	0.1323
Volume	-0.005313	0.004425	0.2313	0.00235	0.002053	0.2535
AR1	-0.7266***	0.05	<.0001	-0.7778***	0.0404	<.0001
R square	0.9047			0.9306		

*Coefficient is statistically significant at 90% level of confidence; ** Significant at 95% level; *** Significant at 99% level.

Neher et al originally plotted visits on lake volumes, looking at differences across seasons. They divided seasons into summer (June to August), winter (November to March), and shoulder (April, May, September and October). Figure 4-3 shows the results of this for visits to Glen Canyon NRA and Lake Powell volumes, using data from 1996 to 2011. One can see clear differences in the data for the different seasons. Points for winter visits are all lower than points for shoulder visits, while points for shoulder visits are all below points for summer visits (Figure 4-3). You can also see that the plotted trend line of visits on volume is steeper for the shoulder than for the winter and steeper for the summer than the shoulder. The results for Lake Mead aren't as clear (Figure 4-4). There are many points for shoulder visits that are greater than for summer visits. Neher did not display a separate trend line, for each season. But, in their original regression model, the interaction terms for volume and season were not significant.

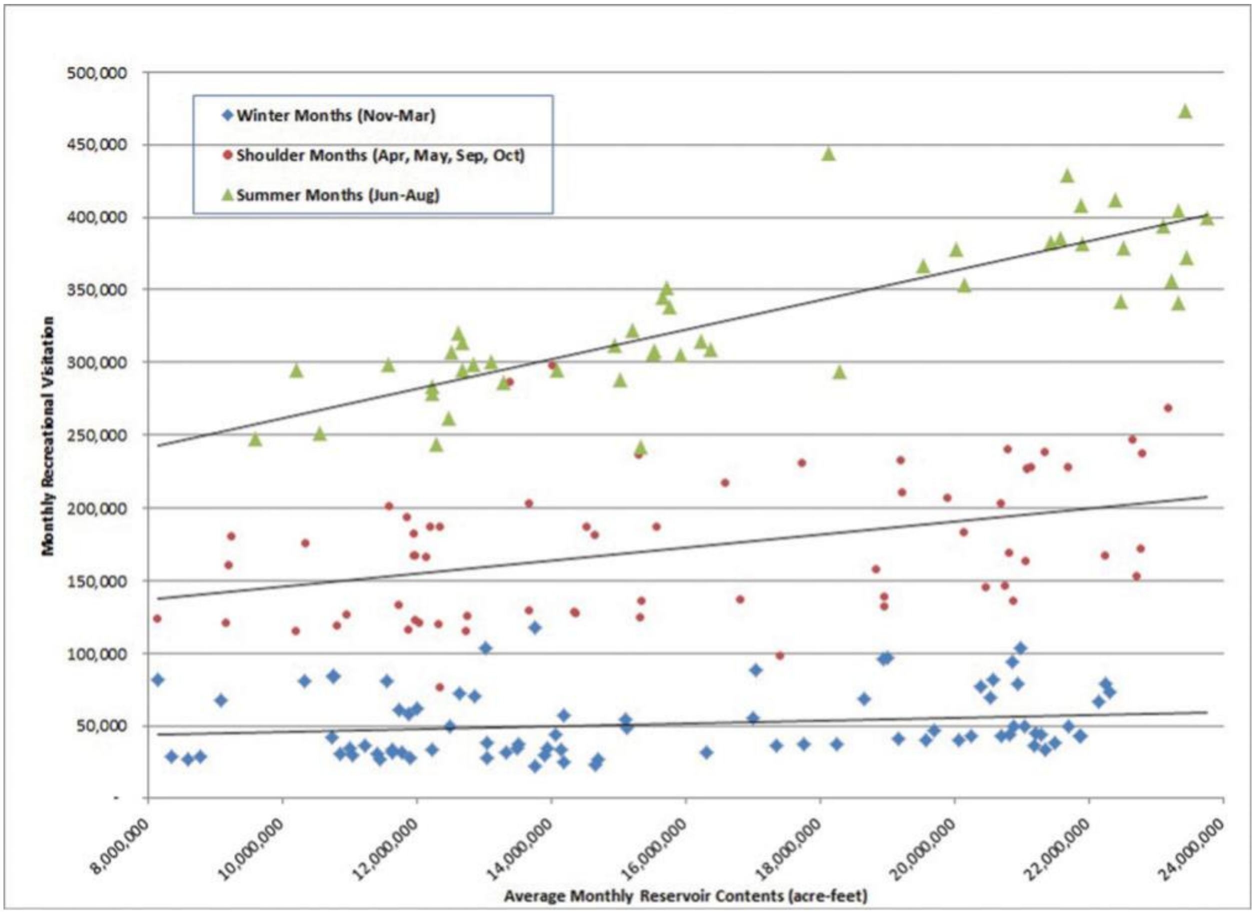


Figure 4-3. Monthly Visits to Glen Canyon NRA as a function of Lake Powell volume. Source: Neher et al.

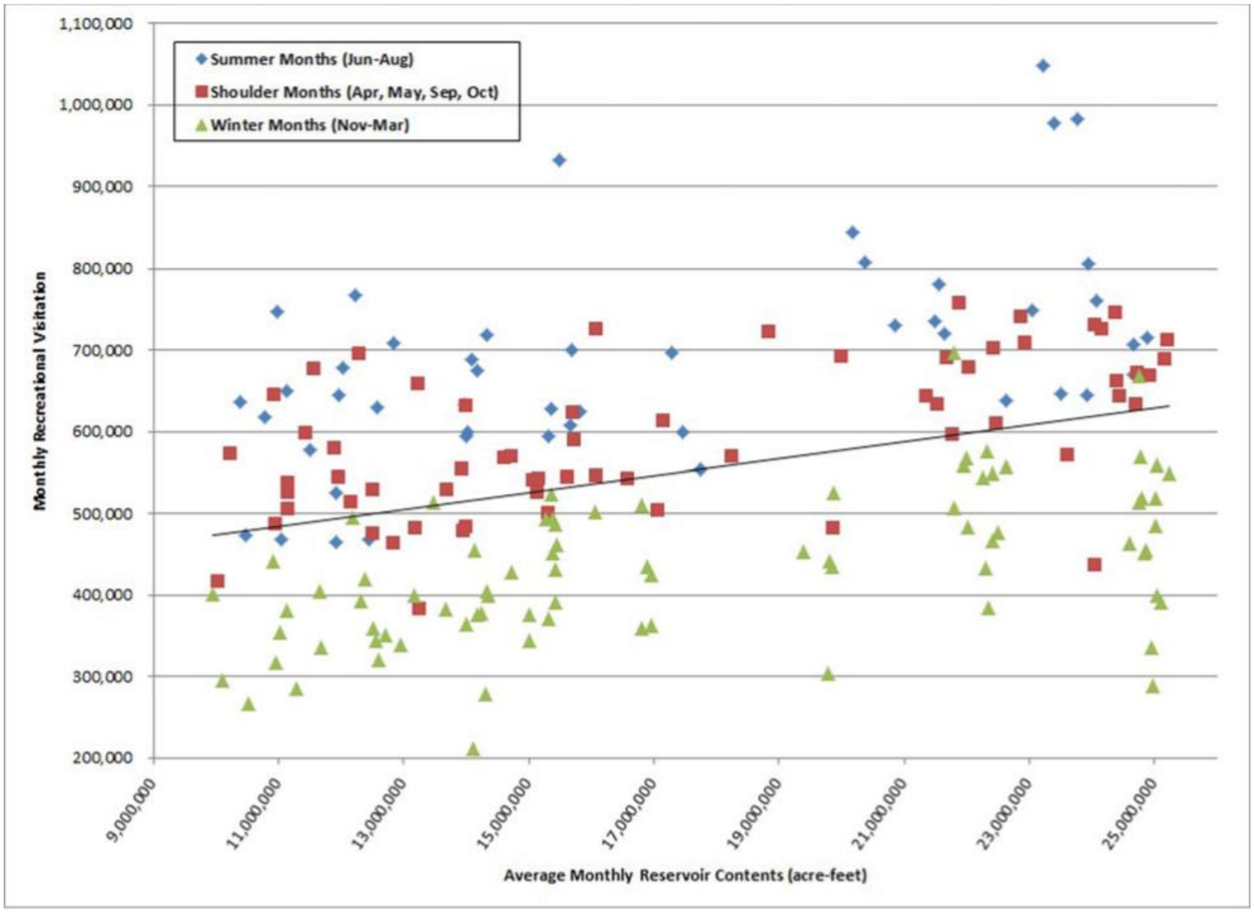


Figure 4-4. Monthly Visits to Lake Mead NRA as a function of Lake Mead volume. Source; Neher et al.

Figures 4-5 (for Lake Mead) and 4-6 (for Glen Canyon), repeat this scatter plot analysis using data for a larger sample period, 1979-2017. For Glen Canyon (Fig 4-5), over the longer sample period, there is now more overlap in the number of visits in shoulder and summer months. The slope of the plot of visits on volume is now also negative for summer months. For Lake Mead (Fig 4-6) there is overlap between monthly visits across all three seasons. At lower volumes, visits in shoulder and summer overlap and visits in shoulder and winter overlap. At higher volumes visits in all three seasons overlap. As with Glen Canyon, the slope of the plot of visits on volume has a negative slope for summer months.

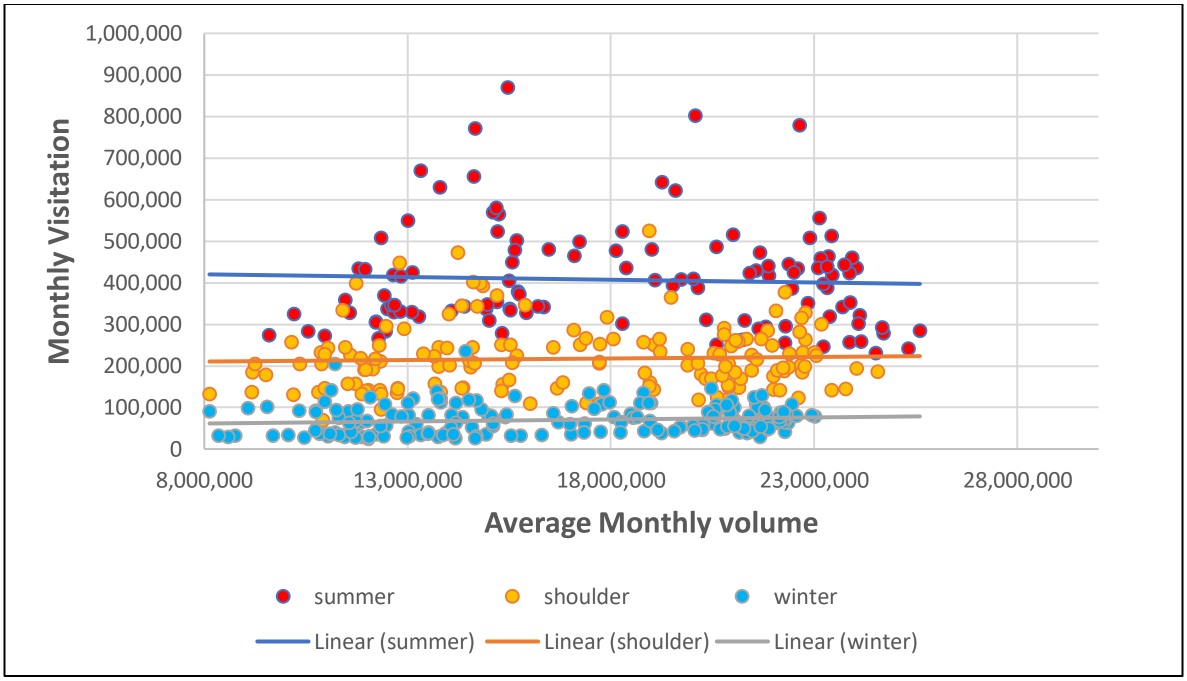


Figure 4-5. Monthly Visits to Glen Canyon NRA as a function of Lake Powell volume (measured in acre feet), 1996-2017 data

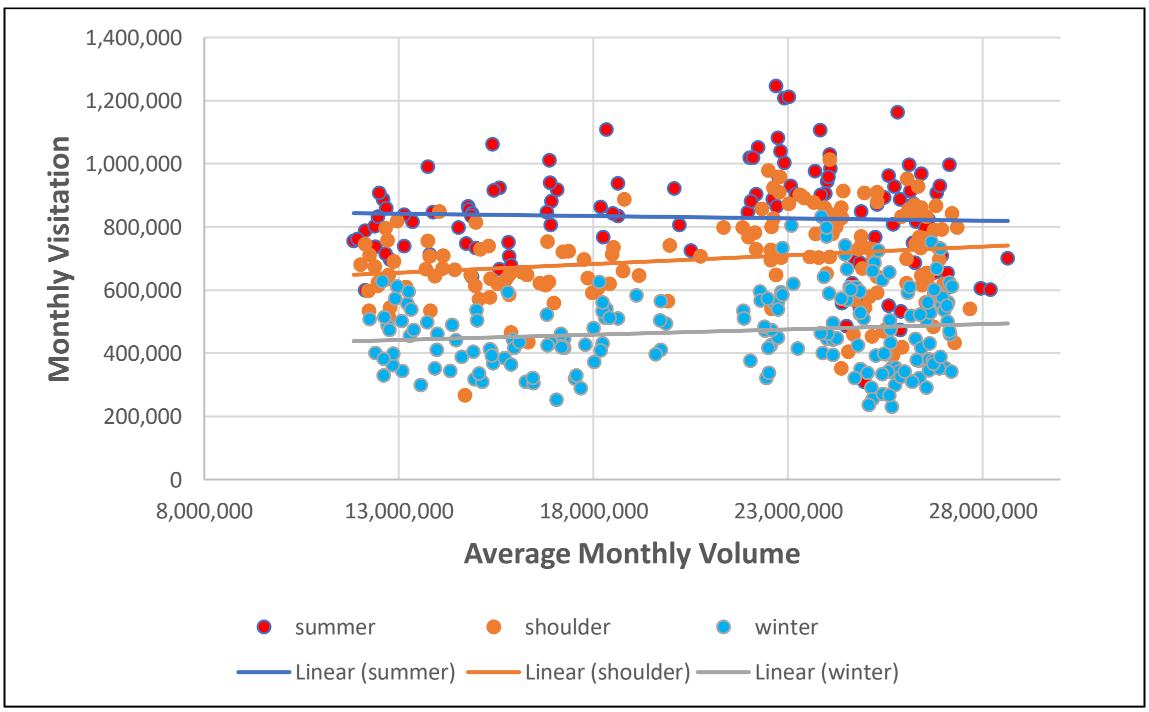


Figure 4-6. Monthly Visits to Lake Mead NRA as a function of Lake Mead volume (measured in acre feet), 1996-2017 data

The results of this chapter show that the out of sample prediction performance of the Neher et al model specification is poor for both Lake Mead and Glen Canyon NRAs for 1979-1995. The out of sample performance for Glen Canyon NRA is also poor for 2012-2017. The specification tends to over-predict visits in earlier years and under-predict visits in later years. Estimates of regression coefficients are not consistent across different periods. Some results were unexpected, with lake volumes having a negative effect on visits in the early period for both lakes. Autocorrelation was also present in all the regressions. This was two even when the data were broken up into different time periods. Autocorrelation could also be a sign of misspecification in the original model, omitted variables, or both (Greene, 2002).

Omitted variables bias might be problem with the Neher et al. regression model specification. The lake volume variables are the only variables that change from one year to the next. The month dummies capture seasonal fluctuations in visits within a year. But they don't account for any changes from one year to the next or account for any long-run trends over time. Omitted variables can cause autocorrelation in errors, which the regressions have. There are also theoretical reasons to think important variable have been omitted. The Neher et al. have no variables to measure changes in the demand for visits over time. Past studies have found that variables that affect demand, like gasoline prices, population growth, or changes in the business cycle can affect the demand for national park visits. Chapter 5 will discuss some of these studies and variables. It will also examine how adding some of these variables affects the lake visitation models.

Chapter 5 The Role of Demand Side Variables

A number of studies have examined cross-section time series data for multiple NPS sites to predict monthly or annual visits. They focus on the role of park attributes, such as age, size, or distance from population centers. They also consider factors that affect recreation demand and park visits specifically. These include measures of population, income and the cost of travel, measured in terms of exchange rates or the price of gasoline. In a study of monthly visits to 353 NPS sites, Macintosh and Wilmot (2011) included measures of real personal disposable income. They found a significant negative association and argued that park visits might be an inferior good. Poudyal et al. (2013) experimented with different measures of recession to explain visits at high-volume NPS sites. All the recession measures they used (in different specification) had significant negative effects on visits. They found that survey-based measures, such as consumer confidence performed better that secondary data variables, such as the business cycle index. Henrickson et al. (2013) examined spatial relationships among high-volume NPS sites. In their regression, population had a positive effect, while distance from population centers had a negative effect. Median per capita income had a significant, negative effect. Frisvold et al. (2012) examined annual visits to NPS sites in the Southwestern United States. There model included regional population, and market potential index that was a measure of income in metropolitan and micro-politan areas of the Southwest inversely weighted by distance from park. It also included a travel-weighted exchange rate index, arguing that higher U.S. exchange rates discourage foreign visits to the United States and encourage visits of U.S. residents abroad. So, for U.S. residents, park visits and trips abroad were assumed to be substitutes. They included Lake Mead and Glen Canyon in their regression model with a variable for lake surface area that only applied to these sites. Other sites in their study did not have lakes. They found that lake area had a positive effect on visits. Population and the market potential index also had positive effects. The exchange rate had a negative effect.

I experimented with including some of the demand side variable used in other studies. The variable *POPULATION* was the combined population of the states Arizona, Nevada, and Utah. Lake Mead is on the Arizona / Nevada border, while Glen Canyon is on the Arizona / Utah border. Population estimates were obtained from the Federal Reserve Bank of St. Louis (FRED) database. These annual data were converted to monthly values using linear interpolation. The monthly real trade-weighted exchange rate variable *TWER* (1997 =100) and the price of gasoline also came from the FRED database. The price of gasoline *GASPRICE* used data for the Depart of Energy West Coast district, which includes Arizona, Nevada, California, Washington and Oregon. The nominal price of gasoline was deflated using the monthly Consumer Price Index for All Items in the West (also from FRED). *UNEMP* is the monthly unemployment rate for the Western Region, again from FRED.

The following regression model was fit for monthly recreation visits to Lake Mead and Glen Canyon NRAs.

$$\text{(1)} \quad \textit{Monthly Visits} = \alpha + \boldsymbol{\beta}'\mathbf{D} + \gamma \textit{Volume} + \delta(\textit{Volume} \times \textit{Shoulder}) + \eta(\textit{Volume} \times \textit{Summer}) + \zeta\, \textit{POPULATION} + \upsilon\, \textit{GASPRICE} + \theta\, \textit{UNEMP} + \mu\, \textit{TWER} + \varepsilon$$

Where **D** is a vector of monthly dummy variables and *Volume*, *Shoulder,* and *Summer* are the same variables used by Neher et al.

Table 5-1 shows regression results for monthly visits to Glen Canyon NRA from 1979 to 2017. The demand side variable coefficients all have the expected sign and all except *UNEMP* are statistically significant. None of the volume variables used by Neher et al. are significant, though.

Table 5-1. Monthly Recreational Visits to Glen Canyon NRA (Lake Powell)

Lake Powell	**1979-2017**	
Variable	**Estimate**	**Standard Error**
Intercept	182,819**	80,368
Mar_Dum	54,836***	8,158
Apr_Dum	125,132***	24,977
May_Dum	210,556***	25,939
Jun_Dum	368,597***	34,774
Jul_Dum	387,344***	35,334
Aug_Dum	369,636***	34,824
Sep_Dum	211,463***	26,539
Oct_Dum	115,382***	25,822
Nov_Dum	36,398***	8,130
Volume x Summer	-0.000649	0.001847
Volume x Shoulder	0.000412	0.001371
volume	0.001128	0.002606
Population	20.4701**	8.3166
GASPRICE	-164,287***	41,666
UNEMP	-6,200	4,656
TWER	-1,654**	704.8526
AR1	-0.7007***	0.0344
R square	0.9117	

∗Coefficient is statistically significant at 90% level of confidence; ∗∗ Significant at 95% level; ∗∗∗ Significant at 99% level.

Table 5-2 splits the sample into two periods as in Chapter 4. Gasoline price is negative and significant in both regressions. Volume and interaction terms are all significant and positive in the later period, but only the volume and summer interaction are significant in the early period. The coefficient is also negative. The demand side variables have expected signs but POPULATION and UNEMP are only statistically significant in the later regression.

Table 5-2. Monthly Recreational Visits to Glen Canyon NRA (Lake Powell)

Lake Powell	**1979-1995**		**1996-2017**	
Variable	**Estimate**	**Standard Error**	**Estimate**	**Standard Error**
Intercept	66,467	207444	-234,416*	128,725
Mar_Dum	32,924**	12996	72,553***	9,448
Apr_Dum	206,967***	61804	108,930***	25,327
May_Dum	297,121***	63391	188,530***	26,424
Jun_Dum	621,523***	85055	302,469***	35,280
Jul_Dum	646,767***	86598	316,977***	35,849
Aug_Dum	668,695***	85650	268,099***	35,137
Sep_Dum	323,640***	65327	162,776***	27,170
Oct_Dum	216,792***	64618	75,195***	26,357
Nov_Dum	26,091**	13119	35,065***	9,407
Volume x Summer	-0.014***	0.004122	0.004*	0.002067
Volume x Shoulder	-0.005023	0.003162	0.00269*	0.001554
volume	0.00047	0.003623	0.00785***	0.001969
POPULATION	45.2351	38.6104	45.349***	7.0404
GASPRICE	-184,457**	77142	-128,728***	40,601
UNEMP	-2,703	7375	-12,586***	3,853
TWER	-1,863	1919	-1,275	922.1043

∗Coefficient is statistically significant at 90% level of confidence; ∗∗ Significant at 95% level; ∗∗∗ Significant at 99% level.

Table 5-3 shows regression results for Lake Mead for 1979 to 2017. The summer volume interaction term is significant by negative. GASPRICE is the only statistically significant demand side variable.

Table 5-3. Monthly Recreational Visits to Lake Mead NRA

Lake Mead	1979-2017		
Variable	**Estimate**	**Standard Error**	**P value**
Intercept	485,175***	177,544	0.0065
Mar_Dum	144,789***	16,003	<.0001
Apr_Dum	323,733***	50,725	<.0001
May_Dum	379,893***	51,049	<.0001
Jun_Dum	577,533***	62,638	<.0001
Jul_Dum	573,413***	62,495	<.0001
Aug_Dum	531,266***	62,396	<.0001
Sep_Dum	297,243***	50,691	<.0001
Oct_Dum	194,703***	50,108	0.0001
Nov_Dum	93,616***	15,797	<.0001
Volume x Summer	-0.006149**	0.002776	0.0273
Volume x Shoulder	-0.000104	0.002186	0.9622
Volume	0.004062	0.005156	0.4312
POPULATION	11.7595	16.7148	0.4821
GASPRICE	-327,397***	55,181	<.0001
UNEMP	-2,686	4,921	0.5854
TWER	492.9759	1,052	0.6395
AR1	-0.4512***	0.0429	<.0001
R square	0.8193		

∗Coefficient is statistically significant at 90% level of confidence; ∗∗ Significant at 95% level; ∗∗∗ Significant at 99% level.

Table 5-4 shows regression results for Lake Mead, splitting the sample into two periods. GASPRICE is again statistically significant with the expected negative sign. UNEMP also has the expected negative sign and is significant in both periods. Volume variables are insignificant in the later period. In the earlier period volume is positive, but the interaction terms with volume are negative.

Table 5-4. Monthly Recreational Visits to Lake Mead NRA

Lake Mead	**1979-1995**		**1996-2017**	
Variable	**Estimate**	**Standard Error**	**Estimate**	**Standard Error**
Intercept	-215,586	359,829	1,109,532***	217,417
Mar_Dum	188,882***	23,299	122,198***	19,029
Apr_Dum	748,758***	233,167	256,177***	49,374
May_Dum	798,511***	232,476	303,525***	49,350
Jun_Dum	1,514,304***	246,772	402,213***	56,275
Jul_Dum	1,538,175***	246,710	375,353***	56,016
Aug_Dum	1,455,807***	246,545	362,829***	55,957
Sep_Dum	650,755***	232,368	261,061***	48,852
Oct_Dum	572,350**	232,077	138,772***	48,552
Nov_Dum	96,699***	22,582	62,907***	18,659
Volume x Summer	-0.0448***	0.009889	0.0032	0.00281
Volume x Shoulder	-0.0155**	0.009305	0.00149	0.002393
volume	0.0173*	0.008841	-0.0017	0.004349
POPULATION	74.3223*	39.1725	-17.109	15.3131
GASPRICE	-282,405***	74,620	-167,810***	53,438
UNEMP	-11,555*	6,301	-1,136***	3,809
TWER	655.384	1,739	-2,076*	1,136
AR1	-0.162**	0.0764	-0.2067***	0.0634
R square	0.8759		0.8508	

*Coefficient is statistically significant at 90% level of confidence; ** Significant at 95% level; *** Significant at 99% level.

I also experimented with a log-linear regression equation. The only variable that had a consistent, significant and expected (negative) sign was the log of the price of gasoline.

Chapter 6 Conclusions

This thesis first carried out a statistical replication study of the original Neher et al. study of visits to Lake Mead and Lake Powell NRAs. The original data used by Neher et al. is no longer publically available in the same form as their original study. Instead I used the closest available data from the same government sources that Neher et al. used.

Neher et al. estimated the effects of seasonal effects and lake volumes on monthly visits for the years 1996 to 2011. Although my regression coefficients were not exactly the same, the basic results using the new dataset were basically the same as Neher et al. Lake volume positively affected visits, while volume and season interaction terms were significant for Glen Canyon, but not Lake Mead.

Next, I looked at how well the Neher et al. model predicted out of sample, looking back in time from 1979-1995 and forward, 2012-2017. Their model predicted poorly for both lakes in the earlier period and poorly for Lake Powell in the later period too. I found evidence of a structural break in the data and rejected the null hypothesis that coefficients from 1979-1995 were the same as those from 1996-2017.

A number of earlier studies found that demand side variables such as the unemployment rate, regional population, the exchange rate, or gasoline prices affected demand for visits to National Park Service sites. The only explanatory variable that had a consistent, expected and significant effect in various regression specifications was the price of gasoline. The price of gasoline negatively affected visits. The strong positive relationship between lake volumes and visits that Neher et al found for 1996 to 2011 was not consistent at all when expanding analysis backward or forward in time. Adding demand side variables did not change this.

Future research might consider different types of park visits. For example, some types of visits might be more associated with boating than with hiking. It is not obvious from NPS data that visits could be split out this way. But it may be that lake volumes only affect water-based recreation visits, but not other kinds of visits.

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