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ESTIMATING THE MARGINAL COST OF DAM REMOVAL

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SUMMARY

This paper reports the results from linear regression models that estimate the cost of dam removal as a function of the dam's height and length. The models indicate that, on average, each vertical foot contributes between $22,331 and $30,620 to the cost of removal. These estimates are in line with the only other study we are aware of that estimates cost per foot. Although the models fail to account for potentially important variables, they may be useful for providing rough estimates of the variable portion of dam removal cost.

DATA AND METHODS

Data for removal cost, height and length of removed dams and year removed were derived from American Rivers' (AR) database of *Dams Removed in the United States 1912-2016* (American Rivers 2016). Of the 1,370 removed dams in the database, there were 205 valid observations that included data for the necessary variables. Removal cost was adjusted to constant 2016 USD using regional Consumer Price Index data (Bureau of Labor Statistics 2017). We dropped one dam that was removed five years prior to any other removals. Additionally, visual inspection of scatterplots revealed two outliers (Figures 1A and 1B). One, the San Clemente Dam in CA, is several orders of magnitude larger and more costly than all other dams. The other, Dewey Dam in CO, is extremely long despite having a very low removal cost. The remaining 202 observations form the basis of our analysis.

Based on available data, we find some differences between the removed dams in the complete AR database and our final dataset (Table 1). When we compared the differences in means in height and length using t-tests, we found that on average dams in the final dataset tend to be smaller than dams in the complete database.[1] We also find some difference in the geographical distribution of removed dams in the entire AR database versus the final data subset (Table 2). Dams removed in the northeast region are overrepresented and dams removed in the west region are underrepresented. Overall, because of the missing data, our estimates are expected to be biased towards smaller dams and better representing removed dams in the northeastern United States.

Regressions

We estimated the following model:

[1] This test only includes dams for which height and length data are available. P-values for one-tailed t-tests comparing means are 0.0002 for height and 0.0195 for length.

$$COST_i = \beta_1 HEIGHT_i + \beta_2 LENGTH_i + \alpha_y + \delta_s + \gamma_{ys} + \varepsilon_i$$

$COST_i$ is the cost of removing dam i in constant 2016 USD. $HEIGHT_i$ and $LENGTH_i$ are the height and length of dam i in feet, and ε_i is an error term. Removal cost could be influenced by unobserved factors which may vary across states and years. For example, demand for expertise could raise costs (or experience could lower costs), and indeed the frequency of removals has increased consistently over the last two decades (Figure 2). To control for possible bias from these unobserved factors, we include year (α_y), state (δ_s), and year-by-state (γ_{ys}) fixed effects. We allowed for the possibility of different functional forms by including higher order terms for height and length as well as an interaction term but found that model fit did not improve. We report robust standard errors that correct for state-level clustering and heteroscedasticity, which was indicated by a Breusch-Pagan test.

RESULTS

We compare the results from three models: no fixed effects (Model 1), year and state fixed effects (Model 2), and year, state, and year-by-state fixed effects (Model 3, Table 3). There is no statistically significant difference between the coefficient estimates for height and length in Models 1 and 2, while the estimates are quite different in Model 3. When year-by-state fixed effects are added, the coefficient estimate for height is about one-third smaller while the estimate for width doubles.

The results indicate, on average, \$30,620 per additional vertical foot and \$1,360 per additional horizontal foot (Model 2). In contrast, Model 3 suggests an additional vertical foot contributes \$22,331 and an additional horizontal foot adds \$2,777 to the cost of removal. The statistical significance varies across the models, while goodness-of-fit, indicated by adjusted R^2, improves markedly as more fixed effects are added.

To understand the implications of the differences between Models 2 and 3, we apply the estimated coefficients to an average dam in our sample. For a dam of median height (8 ft) and length (100 ft), the predicted variable cost is \$380,960 based on Model 2 and \$456,348 based on Model 3, which is about 20% higher. Since length tends to dominate height, our conjecture is that Model 2 will produce more conservative estimates than Model 3 for the majority of dams, with the exception of those that are very high and located on narrow rivers. Applying both models to our data, we find the cost estimates generated using Model 2 exceed those using Model 3 for just 18% of dams. These dams tended to be above average in height and below average in length.

COMPARISION WITH OTHER STUDIES

A limited number of studies have reported dam removal costs. Magilligan et al. (2016) reported that dam removal costs around \$40,000 per vertical meter, which converts to \$24,390 per vertical foot. This statistic was computed based on a subset of their removed New England dams data that included cost information. Although we cannot compare our results directly since sample size or methodology was not provided in the publication, it is within the $22,331 – $30,620 range suggested by our models.

Other studies only report the total cost, and hence we can only compare the descriptive statistics. Bernhardt et al. (2007) gathered cost data from interviews conducted with a national sample of removal project managers. For 317 projects, the study reports a median total cost of $150,000, which is higher than the data used in this report (median cost $116,683). They find the following median costs for subsets of their data: $403,050 for 23 projects with "High Ecological Success"; $250,000 for 31 projects that followed an "Idealized Restoration Process"; and $580,000 for 8 projects falling under both categories. These raw results suggest that cost is highly sensitive to the method and process of removal, although they do not control for other factors like dam size.

Finally, in a small case study of Wisconsin removals, Born et al. (1998) reported an average removal cost of $109,500. It comes from a small sample of 14 dams removed in years ranging from 1965 to 1992, yet the dollar figures were not adjusted for inflation.

LIMITATIONS AND IMPLICATIONS FOR OUT-OF-SAMPLE PREDICTIONS

While the models reported here can provide a rough estimate of dam removal cost, results should be used with caution. In particular, it seems likely that the model will under-predict actual costs. For most dams, the AR database does not report whether the listed cost is the total cost of removal or some portion of the cost (e.g. planning/permitting or deconstruction or both). Some of the lower reported costs could have represented partial rather than total removal cost, which would explain the substantially lower median cost in our dataset compared to Bernhardt et al. (2007).[2] Despite the likely downward bias, we made the decision to keep all data points to avoid researcher subjectivity.

There are additional qualifications due to limited data. Because our final data contains smaller dams on average, out-of-sample predictions for large dams may be significantly off. Due to lack of data, we also were not able to control for the effect of potentially important factors influencing removal costs, such as building material, removal method, and the presence of possibly contaminated sediment.

Given these limitations and the lack of robustness of the model estimates, out-of-sample predictions would be most appropriate for dams that are similar to the average in our data. The constant terms can be interpreted as a fixed cost (e.g. permitting), which appears highly sensitive to timing and geography. We recommend using just the height and length coefficients to estimate the variable cost of dam removal. That is, the models should be used in relative terms to compare variable costs between dams (e.g., in a single jurisdiction) rather than to predict the absolute level of the costs (e.g., in a cost-benefit analysis).

Finally, our preferred model is Model 2. Model 2 is preferred to Model 1 because the fixed effects control for unobserved factors that are invariant across years for each state, or across

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[2] This provides additional motivation to use the coefficient estimates to predict the variable portion of removal cost only.

states for each year. Model 3 is more robust than Model 2 since it controls additionally for unobserved factors for each state in each year, but the sample size used in the regression is reduced from 196 to 139 because it drops all observations when the dam is the only one removed in its state in a given year. Depending on the application, it may be useful to generate a range of out-of-sample predictions using both models.

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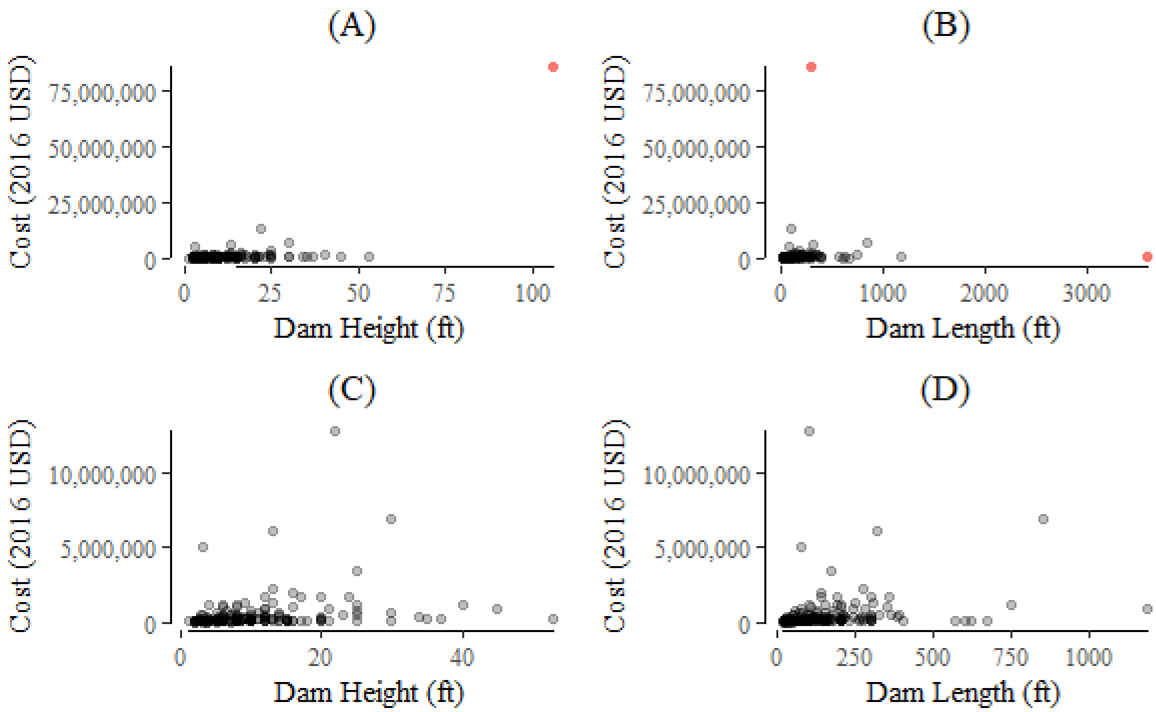
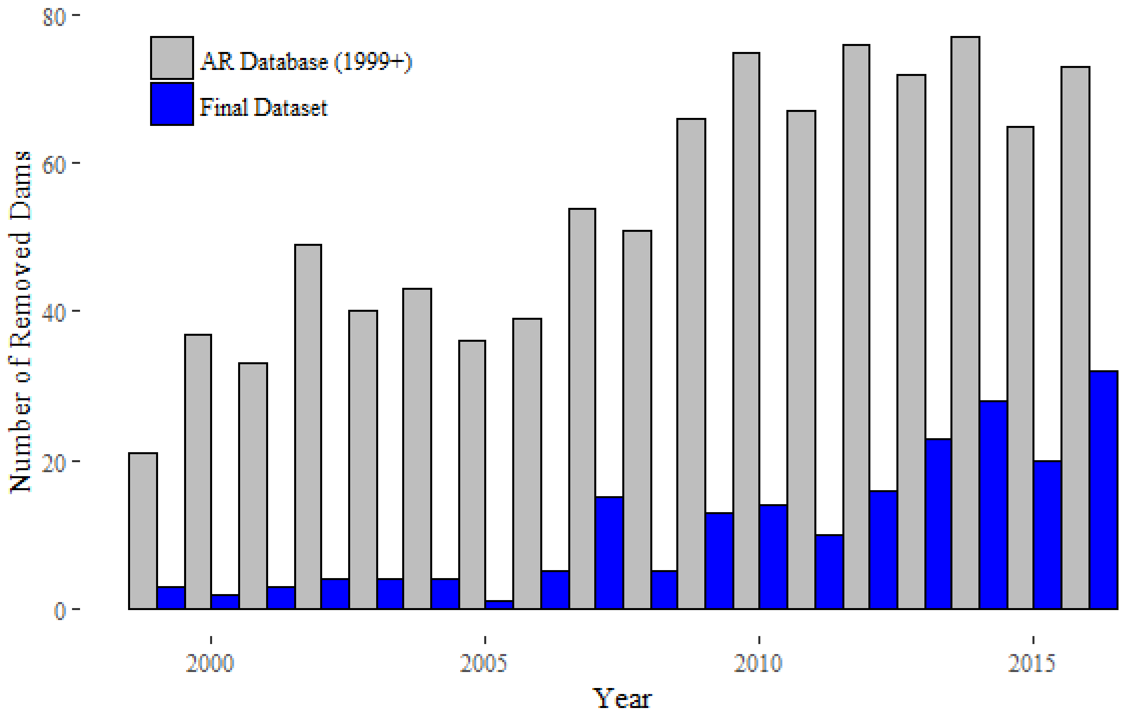
TABLES AND FIGURES

Figure 1. Scatterplots of removal cost against height and length with and without outliers



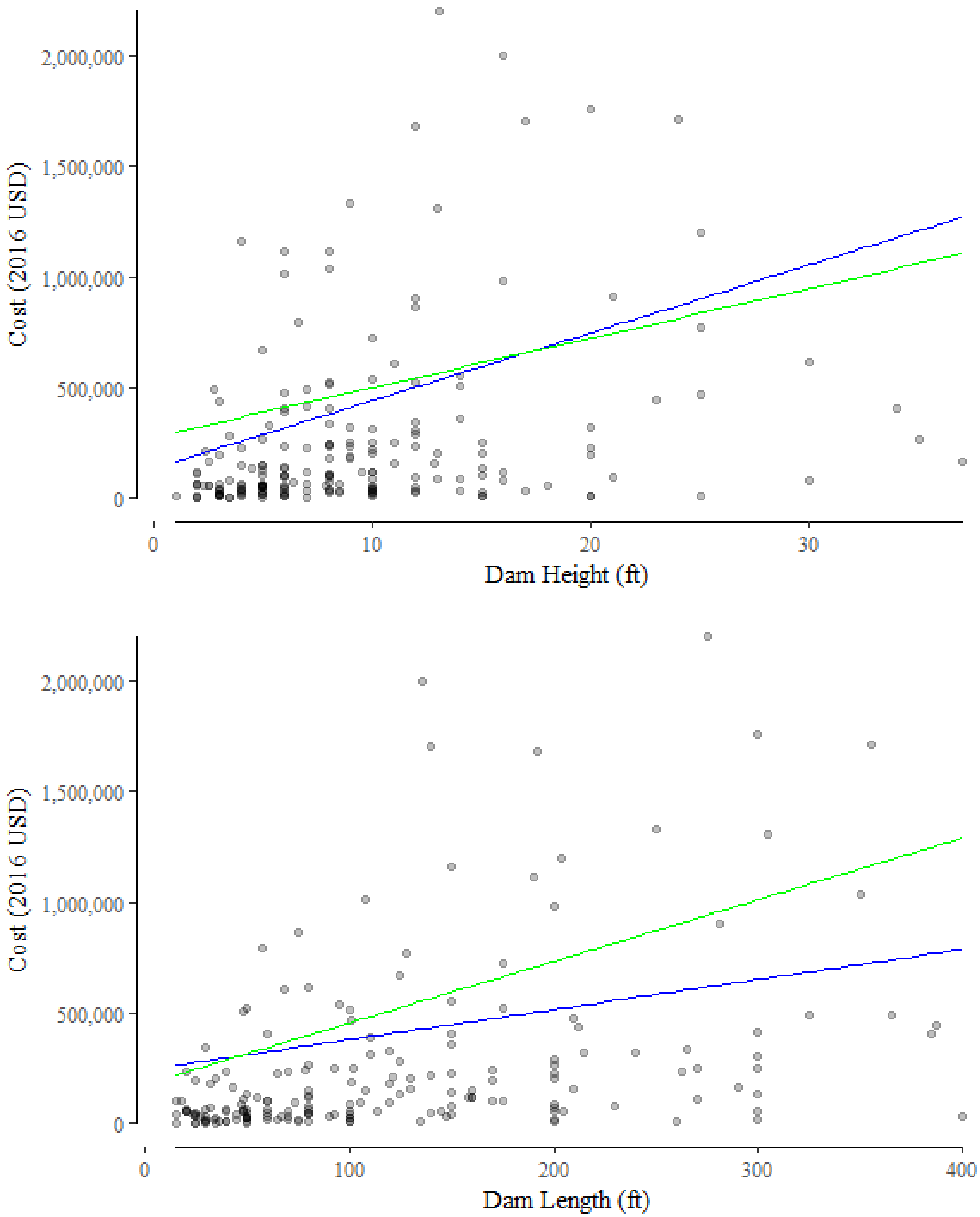
NOTES: (A) and (B) include all dams from the AR database for which Cost, Height, and Length data is available (N=205). Red points indicate outliers that were dropped to create the final dataset (N=202) shown in (C) and (D).

Figure 2. Dam removal frequency by year



NOTES: AR Database (1999+) includes all dams listed in the American Rivers *Dams Removed in the United States* database as removed since 1999 (N = 974). Final Dataset is the subset used for regression analysis in this report (N = 202).

Figure 3. Comparison of Model 2 (BLUE) and Model 3 (GREEN)



NOTES: Median values are used for length and height in the top and bottom plots, respectively. The full range of data is not pictured to facilitate visualization of the models.

Table 1. Summary statistics

	AR database	Final data
Removal Cost (2016 USD)		
Median	116,367	116,683
Mean	891,998	440,448
SD	6,069,968	1,211,279
Min	2,500	2,500
Max	85,600,000	12,800,000
Height (ft)		
Median	10	8
Mean	14.7	10.2
SD	15.6	8.2
Min	1	1
Max	210	53
Length (ft)		
Median	118	100
Mean	222.7	145.6
SD	383	150.4
Min	7	15
Max	6000	1185
Number of dams	1370	202

NOTES: AR database contains every dam in American Rivers' *Dams Removed in the United States 1912-2016* (N=1370), but data is limited to N=205 for Cost, N=998 for Height, and N=650 for Length. Final data represents observations for which data exists across all three attributes minus three dams that were identified as outliers (N=202).

Table 2. Removed dam frequency by region

	AR database	Final data
Northeast	524	98
	(39%)	(49%)
South	153	19
	(11%)	(9%)
Midwest	374	60
	(27%)	(30%)
West	276	25
	(20%)	(12%)
No data	43	
	(3%)	
Total	1370	202

NOTES: Final data is the subset of the AR database used for regression analysis in this report. Percentage of total is given in parentheses. Regions are defined by US Census Bureau.

Table 3. Regression results

Dependent variable: Removal cost (constant 2016 USD)

	(1)	(2)	(3)
Height	30556.5*	30619.9*	22330.8
	(17161.6)	(17474.5)	(16018.8)
Length	1375.0	1360.1*	2777.1
	(952.5)	(770.5)	(1799.6)
Year FE	N	Y	Y
State FE	N	Y	Y
Year x State FE	N	N	Y
N	202	196	139
Adjusted R^2	0.084	0.238	0.337

NOTES: Height and length are in ft. Standard errors clustered at the state level are reported in parentheses. *,**,*** indicates significance at the 90%, 95%, and 99% level, respectively.