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The Role of Cost, Scale, and Property Attributes in Landowner Choice of Stormwater Management Option.

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Abstract:

Cities throughout the world are experimenting with Low Impact Development (LID) strategies to replace ecosystem services degraded by urbanization. Stormwater management may need both centralized/publicly-managed infrastructure and decentralized provision by landowners. For landowners to participate in these programs they will need some latitude in the choice of techniques and siting. However, these landowner choices will affect the bundle of ecosystem services provided (such as infiltration, aesthetics, pollution filtering, and others) as well as their spatial distribution. We studied the Santa Monica (CA) stormwater regulations that require stormwater management on a large portion of development and redevelopment but allow a significant degree of landowner choice over the method of rainwater management. We use a novel dataset to investigate both the cost of rainwater best management practices (BMPs) and landowner choice of rainwater BMP. We find strong evidence of economies of scale in capital costs for the smaller size ranges of the BMPs in our data, and that property factors such as land use and overall redevelopment project cost affect rainwater BMP costs. In addition, our results are consistent with the hypothesis that property factors such as building density and land value are important factors in the landowner's choice of rainwater management option.

Keywords: low impact development; stormwater; economies of scale; ecosystem services.

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1. Introduction

Impervious hard surfaces in urban areas generate more runoff and pollution problems than the natural surfaces that they replace (NRC 2009). The National Research Council (2009) states “urban stormwater is listed as the primary source of all impairments for 13 percent of all rivers, 18 percent of lakes, and 32 percent of all estuaries.” Stormwater management is also one of the most pervasive regulations that affect landscapes. There are approximately a half-million regulated entities in the EPA stormwater regulation program (MS4), including almost all separate sewer systems in urban areas. The problem is not limited to the United States. The urban population worldwide is expected to grow to 7 billion people by 2050 (United Nations 2018). Local policymakers worldwide need insights into the ways that stormwater management can provide ecosystem services while cost-effectively reducing the water quality and quantity problems that result from urbanization.

Stormwater management mitigates the damage done to water bodies through urban development (National Research Council, 2009; Zhang and Schilling, 2006). Extreme precipitation due to climate change is likely to exacerbate this damage (LARC, 2016). In addition, stormwater management is a key climate adaptation strategy for many urban areas where climate forecasts predict increased flooding and/or drought (Cutter 2018). Dhakal and Chevalier (2016) show that to deal with these new challenges urban stormwater governance will need to control runoff from private parcels and involve landowners in decision-making. Roy et al. (2008) discuss the need for better cost data on decentralized stormwater management tools. This paper analyzes the costs of small-scale decentralized stormwater management. Then, it uses the estimates of cost curves from this analysis to examine landowners' decisions on: (1) whether to include a stormwater management device on their property or pay an in-lieu fee; and (2) if they include a stormwater management device, what type to include. We use a unique database of stormwater management devices and costs to determine role costs and economies of scale have on stormwater management provision at the property-level. To our knowledge, ours (e.g. from Santa Monica) is the only large dataset on smaller, decentralized BMPs.

One key aspect of socially-optimal stormwater management is finding the right location on the continuum from centralization to decentralization. If stormwater management has significant economies of scale, that factor will push toward provision by a few large-scale systems. Decentralized provision often offers advantages in flexibility and adaptability. If there are few economies of scale, those factors may outweigh the cost advantages of large centralized systems. This is the only paper we know of that analyzes economies of scales for the major types of property-level rainwater management technologies.

A second key question for stormwater management is the optimal mix of ecosystem services (such as infiltration, flood reduction, pollution filtering, and others.) Decentralized provision by landowners means some loss of control over the mix of ecosystem services provision. The best mix of these services likely changes from place to place as well as over time and there is no guarantee that decentralized landowner provision will arrive at the socially optimal mix of provision. The type of stormwater ecosystem service could matter a great deal to environmental outcomes, total benefits of stormwater regulation, and municipal policy (see Kandalu 2014).

This paper analyzes the mix of provision resulting from a system in which a governmental regulatory body sets the goal (such as a specific rainwater volume reduction) but largely leaves the choice of rainwater management technique (rainwater is the technical term for precipitation that falls on a property, once it leaves the property it becomes stormwater) to individual landowners. The simplest hypothesis is that landowners choose the least expensive rainwater BMP for their mitigation requirement. In order to test this idea, we first model the cost capacity curve to assess economies of scale for each of three categories of BMP using a variety of regression techniques and specifications. The costs of large-scale regional BMPs have been investigated in a few papers (Weiss 2007, Nobles 2012). However, many cities, like Santa Monica, are now requiring or incentivizing small-scale BMPs to treat stormwater flow from a single property.

We then build a multinomial logit model of rainwater BMP choice to examine the factors that influence landowners' choices over whether to install a BMP or pay an in-lieu fee and, if they install a BMP, what type to install. Our model provides insight for policymakers on what BMP choices might be in their particular area. It also sheds light on how landowner choice of BMP is likely to affect the bundle of ecosystem services provided by rainwater treatment requirements. Cadavid and Ando (2013) and Ando et al. (2020) show that the different ecosystem services generated by rainwater BMPs have widely varying social value (as measured by aggregate willingness to pay). Therefore, a key part of the design of stormwater regulations that have significant landowner choice is to understand which BMPs landowners are likely to pick. The contrast between the capital cost of the BMPs and BMP choice allows us to examine whether opportunity costs such as land or site design are important components of the landowner's decision.

We begin by laying out the choices cities face when deciding on stormwater management from among ecosystem services/treatment options known as best management practices (BMPs). Then, we discuss the particular technologies that are commonly used to manage stormwater runoff in our study city, Santa Monica, California. Next, we discuss how we assembled the data used in the analysis. Then we discuss the theoretical factors behind BMP cost and analyze the cost and economies of scale for the common stormwater BMP categories. We examine the determinants of BMP category choice, including the choice to use an in-lieu fee (one-time payment to City for a larger BMP system in place of the landowner, in public land, see Below). Finally, we discuss the implications for stormwater management and decentralized provision of ecosystem services generally.

2. Key Design Choices for Municipal Stormwater Managers

Policymakers have a menu of options (BMPs) to manage stormwater or wet weather runoff before it reaches natural water bodies. The traditional avenue for managing stormwater has been large centralized systems that prevent floods by rapidly conveying runoff to water bodies (Brabec 2009.) However, these systems can aggravate both pollution and streambed degradation for receiving water bodies. Other centralized systems use approaches such as detention ponds, infiltration, or filtration to treat stormwater on a neighborhood or regional scale. In these systems, policymakers directly choose the type of BMPs and therefore the basket of ecological services provided by those BMPs.

Decentralized strategies operating at the individual property level often go under the umbrella of low impact development (LID) strategies and green infrastructure (GI) systems. Examples are infiltration pits, permeable pavement, rain tanks or bioswales (U.S. Environmental Protection Agency, 2000). Typically, LID approaches are instituted for newly developed or redeveloped properties. Cities usually give landowners a performance standard for BMPs but leave the choice of BMPs up to the developer. However, different cities may offer different criteria for BMPs, such as managing a given volume of rainwater of a criterion rain event, a water quality criterion, a volume criterion, or some combination. Cities may also directly set the allowable LID BMPs through regulations governing which types of BMPs can be installed to meet the regulatory criteria.

Often, cities that pursue LID approaches also allow an opt out in the form of an in-lieu fee (Cutter and Hodge 2012). These one-time fees allow landowners to pay their way out of some or all of the LID requirement; the revenue from these fees can be used by the city to pay for more centralized approaches where the LID approaches do not meet the policy objectives.

The in-lieu fee serves as a critical, government-controlled balance mechanism between the decentralized LID approach and more centralized approaches. If the fee is set high then landowners will mostly install their own BMPs, and there will not be a great deal of revenue for centralized BMPs. If it is set lower, there will be fewer private LIDs installed, but more revenue for centralized approaches.

Centralized approaches have the advantage that policymakers can directly control what types of BMPs are installed and where they are placed. This gives policymakers more direct control over environmental outcomes. In addition, there are likely to be economies of scale in BMP costs, as found in Weiss (2011). However, a key disadvantage is that all the funding must come from the public purse. Also, centralized BMPs usually imply a real or opportunity cost of dedicating some land to the BMP. In areas with high land value, this cost can be significant.

3. BMP Options in Santa Monica

Santa Monica (CA) is a dense (about 11,000 people/square mile) city with expensive real estate. Therefore, it is difficult to devote valuable land exclusively to stormwater management; partly because of this constraint, the city has implemented policies to require LID strategies and GI systems on private land for new and redeveloped properties. It is an early adopter of LID policy and aims to be self- sufficient on water resources in this new decade (City of Santa Monica communication, 2020). Over the past 20 years, the city has been effective in approving LID projects on over 2,000 properties.

Stormwater management in Santa Monica allows three broad types of ecosystem service provision at the onsite parcel or property level, e.g. micro-watershed level, in rainwater management:

- harvest and return the water for direct *use*, for example by cisterns or rain barrels;
- *infiltrate* the water to groundwater (passive use);
- *filter* out pollutants and return the water to the storm drain system.

Each of these BMPs has different water management and environmental consequences:

- *Use* BMPs reduce stormwater pollution to receiving water bodies while augmenting immediate local water supply (water quality and quantity management).
- *Infiltration* augments groundwater and thus longer-term water storage, as well as removing pollutants (water quality and quantity management).
- *Filtration* removes some pollutants but releases water to the storm drain system (water quality only management).

In Santa Monica, rainwater BMPs are required for most newly developed and redeveloped properties (City of Santa Monica Urban Watershed Program 2017). Santa Monica also has an in-lieu fee option where, under some circumstances, landowners can contribute to funding for large-scale, city-run stormwater management in lieu of constructing their own BMPs.

Our cost analysis measures are derived from Santa Monica's requirements: 3/4 inches of mitigation volume for each square foot of impervious area (1.905 cm per 0.093 m^2). Santa Monica uses standardized conversion factors to estimate void volume from gross volume for the different BMP types. Void volume must equal or exceed the required mitigation volume in order to meet the BMP requirements. (City of Santa Monica Urban Watershed Program 2017).

By far the most popular BMP option in Santa Monica is ***infiltration***. The simplest technology is a gravel bed that collect rainwater runoff and then holds it as it gradually infiltrates into the soil. Quite a few varieties of this technology all operate on this principle of storing water for gradual infiltration. These technologies work best with permeable soil that infiltrates water quickly, and where the groundwater level is deep enough not to promote flooding. Cutter et al. (2018) find that municipal climate adaptation plans in Mediterranean climate zone regions (like Santa Monica) often emphasize infiltration because it has the potential to add to water supplies as well as mitigate stormwater pollution and flooding.

The next most important BMP category is ***use*** devices such as cisterns and rain barrels that hold water until it is used in the home or for irrigation. Their benefit is in direct provision of non-potable water, rather than indirect water supply through pumping out groundwater, with associated costs.

Filtration systems pass rainwater through a variety of media that remove pollutants in the rainwater or stormwater, or convert them through chemical and/or mechanical processes into harmless byproducts. These can range from low-tech options that filter this water through sand and other soil media to higher-tech engineered devices. Bioswales are a popular filtration option: water is routed through vegetation that filters out pollutants and also often provides interesting aesthetics. Other filtering systems only work to remove solids, such as trash, from runoff. There is a good deal of overlap in choice and implementation of these two technologies; we combine them in our cost analysis.

The different technologies tend to be used in different capacity ranges. Landowners choose use BMPs for fairly small systems (median 4.5 cm). They choose non-biofilter filters for larger systems (18 cm median). They use infiltration systems along most of the size range, except the largest systems (above the 75th percentile), which are mostly non-biofilter filters. Table 1 details show the percent of a given BMP type that fall into the overall capacity quartile (i.e. 69% of non-biofilter filters are found in the top overall quartile.)

	Quartile			
BMP Type	1st	2nd	3rd	4th
Filter: Biofilter	40.38	40.38	9.62	9.62
Filter: Non-Biofilter	7.41	11.11	12.96	68.52
Infiltration: Other	17.88	22.92	30.63	28.57
Infiltration: Permeable Pavement	40.00	40.00	0.00	20.00
Use	54.09	34.16	6.05	5.69

Table 1

BMP Types by Quartile of Overall BMP Capacity
(% of type total)

We focus on infiltration systems, since we have enough data on Santa Monica's installations to closely examine their cost-capacity curve; we hope our analysis might inform decision-making in the context of worldwide interest.

4. Data

The data compiled for this study primarily relies on inflation-adjusted BMP construction cost and BMP description information from Santa Monica for privately built rainwater BMPs. The data ranges over a 13-year period (2006-2018) and contains information regarding the BMP choices for every new or re-development project larger than 500 square feet since 2006. For more complete analysis, we added information from the Los Angeles County local property-roll data, including: size of property (when missing from original data), assessed land value, and built square footage. (see Appendix B for an additional data note.)

The Santa Monica data includes latitude and longitude. Fig. 1 shows a map of the Santa Monica watershed with the spatial distribution of the properties with installed BMPs overlaid. Table 2 shows the summary statistics for the data we use in this paper.

Fig. 1. BMP Locations in Santa Monica.

Variable	Obs	Mean	Std. Dev.	Min	Max
BMP Total Cost ($)	1,831	14,627.17	8,7081.13	4.00	3.47e+06
Capacity (m^3)	1,828	13.02	53.91	0.03	1,234.53
Cost per m^3	1,828	1,365.68	2,043.62	0.47	40,139.11
Cost ($10^5)	1,800	14.60	54.09	0.00	1,404.22
Fiscal Year	1,831	2,010.29	5.17	1,996.00	2,018.00
ParcelArea (ft^2)	1,831	10,770.97	20,338.18	580.00	319,002.34
Assessed Land Value per m^2	1,688	14.64	14.42	0.40	220.28
Floor Area Ratio	1,666	0.38	0.57	0.00	14.41
Mitigation Requirement (m^3)	1,815	11.19	56.65	0.00	2,146.42
Project Cost per m^2	1,800	11.10	20.36	0.00	386.40
Property Area (m^2)	1,831	1000.66	1,889.48	53.88	29,636.29
Project Cost per m^2	1,800	0.01	0.02	0.00	0.45

Table 2
Descriptive Statistics

5. Results Rainwater BMP Costs

We begin by examining the costs and size for the major BMP categories discussed above (filtration, infiltration, use). The different capacity ranges of BMPs could indicate that they may have different cost-capacity curves, so we decided to first model a relatively homogeneous category. Infiltration is the most common BMP, and has the sample size to examine functional form and specification; so we analyzed at length the cost-capacity curve for infiltration BMPs before examining whether cost-capacity curves are similar for the other BMP types. We used lowess regression as a nonparametric method to capture the cost curves for infiltration BMPs and then proceeded to examine parametric specifications using general linear regression modeling. In these regressions, total construction cost of the BMP is the dependent variable. Next, we modeled the results’ robustness to additional controls. Then, we examined whether the results would be similar if we used cost/gallon of capacity as the dependent variable.

5.1 Broad Comparison

	Mean $\$/m^3$	Mean BMP Cost	Mean BMP Capacity	Median BMP Capacity	N
Filter: Biofilter	973.013	4,959.832	7.009	5.097	52
Filter: Non-Biofilter	2,014.956	9,9872.31	54.625	18.122	54
Infiltration: Other	1,351.447	11,858.39	11.985	7.079	1,309
Infiltration: Permeable Paving	2,803.47	21,815.85	7.15	5.238	10
Use	817.03	5,911.162	9.004	4.53	281

Table 3

BMP Cost and Capacity by Category

Table 3 shows a wide range in both cost and size of the BMPs across the three major categories as well as some subcategories. Biofilters, use and permeable paving (an infiltration subcategory) BMPs cluster around the smaller BMP capacities. Infiltration BMPs other than permeable pavement and in-lieu fees are in the middle of average capacity and also have a wide range. Landowners choose filter BMPs to meet relatively large capacity requirements—the 25th percentile for filter BMPs is larger than the median for all other categories (Table 1). These different size ranges for the different BMP technologies indicate that either economies of scale or other property-size-dependent characteristics influence BMP choice.

Table 3 shows that mean per-capacity costs vary by a factor of three and median costs by more than 12 across these subcategories. These cost differences imply that the opportunity costs of BMPs, such as limitations their construction imposes on the development of the property, might be as important as the capital costs to the choice of BMP. For instance, Table 3 shows the average per-capacity cost of permeable paving is about 50% higher than the next most costly BMP. One possible explanation for these choices is that some BMPs with higher unit use less land. Another explanation is that different types of BMPs have different economies of scale, and therefore projects with smaller required mitigation have a different cost-minimizing choice than larger projects. A final possibility is that the particular aesthetic requirements of different sites are most compatible with different BMP types.

5.2 Factors influencing BMP cost.

The size of the BMP is likely to be the single largest factor in the BMP cost. In addition, the BMP type (within the categories) may influence costs even after controlling for the capacity of the BMP. The overall cost of the project is likely to be positively correlated with BMP costs. A bigger, more expensive project is likely to have aesthetic demands and lot-use demands that require a more complex and expensive approach to stormwater management. Different land uses may have different priorities for BMPs that result in different costs. In particular, commercial properties may face different demands and non-stormwater regulations than residential properties and these demands may influence the opportunity cost of land. Therefore, we controlled for land use type in the analysis. In Appendix A, we also examine other property characteristics—such as lot area, building density, and assessed value per square foot—that might plausibly be associated with BMP costs.

5.3 Infiltration BMP Results

The lowess regression with cost per gallon as the dependent variable shows an initial steep decline in cost per capacity (Fig. 2). At the 25th percentile of capacity for infiltration BMPs the predicted cost per gallon is down to $1,438 per cubic meter. The predicted cost per gallon falls slightly more to about $1,222 per cubic meter at the 50th percentile and then stays near that cost per cubic meter for the rest of the sample. These results suggest that economies of scale mainly exist at the low end of the capacity range. Equally, the figure shows that there is a wide range of costs around the average for which we needed to account in order to obtain good estimates.

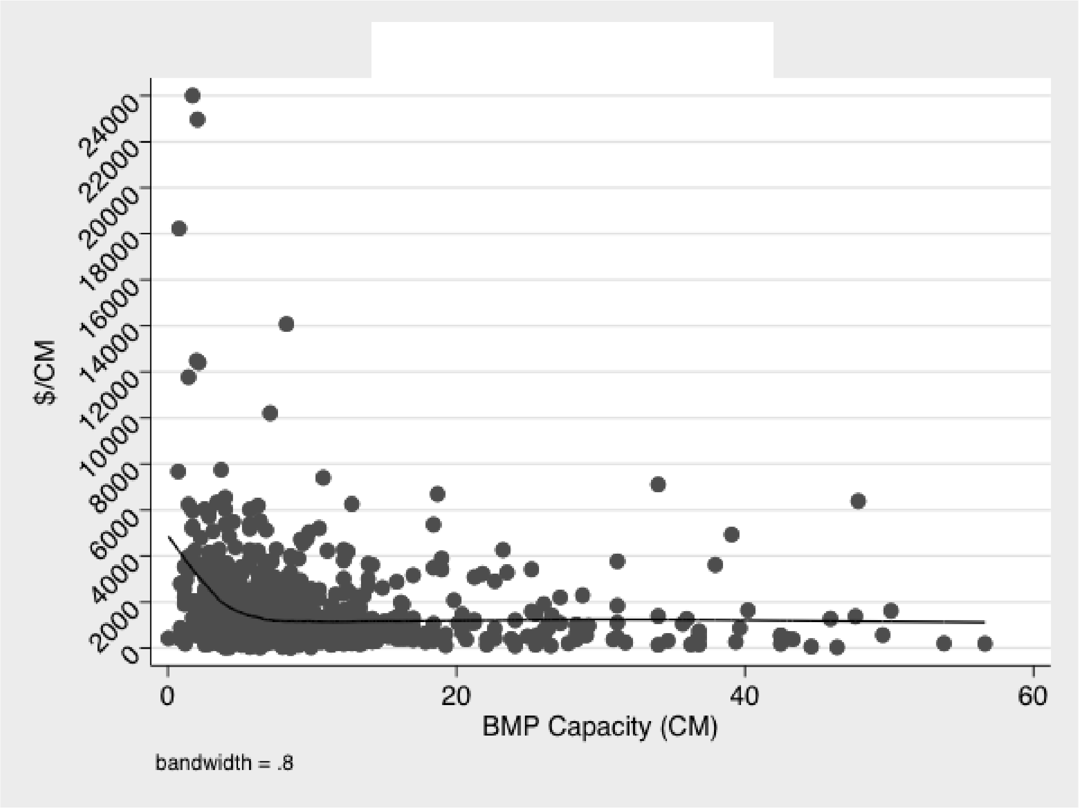

Fig. 2. Lowess Smoothed Average Cost Per CM (Infiltration BMPs).

Costs and Economies of Scale

The lowess regression (Figure 2) indicates that a linear specification is unlikely to capture the cost curve well. The relationship between capacity and cost appears nonlinear. This suggests that either a log-linear or log-log (in m^3 capacity, the main independent variable) could capture this non-linearity. (In addition, unreported Box-Cox flexible-form models indicate that log-log is the best fit.)

Table 4 shows five specifications for infiltration BMP costs. Across all specifications the coefficient on the capacity measure is highly significant at any conventional significance level. For the base specification with only capacity, a unit (cubic meter) increase is associated with 6.6% increase in total cost. When we include additional controls, this falls to about a 5% increase in total cost for a unit increase. The log-log specification (Column 5) indicates a 10% increase in capacity leads to a 3.5% increase in cost. These are similar results, a 10% increase in capacity at the mean capacity implies an approximately 0.7 m^3 increase, which would lead to about a 3.4 % increase in specification three.

	(1)	(2)	(3)	(4)	(5)
	Independent Variable= Log(BMP Cost)				
Capacity (m^3)	0.066*** (0.004)	0.058*** (0.005)	0.049*** (0.005)	0.042*** (0.005)	
Log Capacity (m^3)					0.349*** (0.050)
Log Project Cost			0.195*** (0.025)	0.192*** (0.028)	0.214*** (0.026)
Observations	1,298	1,298	1,298	1,298	1,298
R^2(LOOCV)	0.139	0.170	0.221	0.264	0.267
AIC	26,424.183	26,363.971	26,370.096	26,296.767	26,338.776
BIC	26,434.520	26,389.814	26,385.601	26,358.790	26,369.787
Year Trend	no	yes	no	yes	yes
Land Use Dummies	no	yes	no	yes	yes
BMP Dummies	no	no	no	yes	no

Standard errors are in parentheses
**** p<.01, ** p<.05, * p<.1*

Table 4
Cost Curves for Infiltration BMPs

The coefficient on the log cost of the overall project is also significant at any conventional significance levels. The estimated elasticity of project cost is about 0.19 across specifications. The BMP cost averages <2% of the project cost, so it is unlikely the BMP construction has a large effect on project cost (reverse causality). Instead, it appears the overall costliness of the project, or a variable correlated with it, is strongly associated with the cost of the BMP, even after controlling for capacity.

Additionally, the land use of the property is strongly associated with the BMP cost. The coefficients on the two residential classes are negative and significant at any conventional significance level. Their value is about -0.5, implying that residential properties are associated with almost a 40% reduction in BMP cost relative to commercial/industrial properties. One possibility is that residential properties choose less-expensive types of BMPs, but the coefficients on property type are negative and significant even when the BMP type is included as a fixed effect; also the BIC and LOOCV scores only change slightly when including BMP-type fixed effects. These results indicate that the specific type of BMP within our infiltration category is not important for predicting costs. The coefficients on the BMP fixed effects are generally insignificant if land-use controls are included (including unreported regressions with different combinations of controls). Appendix A contains several robustness tests of the results including examining cost per m^3 as the dependent variable and specifications where we included some property value and density information that is only available for a portion of the sample. These specifications do not change the key findings of this section.

One goal of this research is to provide a methodology to help guide cities that have or are considering rainwater BMP requirements. We used the Bayesian information criterion (BIC) and Akaike information criterion (AIC) as standard measures to project out-of-sample fit, and also considered leave-one-out cross-validation (LOOCV). By the BIC and LOOCV criteria specification four is superior. There is little difference in the LOOCV criterion between the capacity and logged capacity specifications (Table 4, columns 4 and 5) with the controls in specification four. More importantly, specifications two through five inclusive have similar implications for economies of scale, and specification one implies only somewhat higher elasticity. One interesting result is that the pseudo-R^2 from LOOCV are quite high for specifications four and five. This is an R^2 for out-of-sample prediction, and it explains about 25% of the variation of BMP costs. The log-log specification (column 5) captures the shape of the non-parametric lowess analysis somewhat better. The unit costs drop very quickly at first, and then are fairly constant. This matches the shape of the lowess regression and unit costs by size tabulations. Given the similar performance on information criteria and out-of-sample fit, we view the log-log model as preferable and use it in our cost comparisons later in the paper.

To summarize our findings on cost and economies of scale for infiltration BMPs:

1. The economies of scale are largely at the low end. This implies that an LID approach has a high cost per capacity for smaller properties.
2. There are significant differences in cost across land uses.
3. The log-log model performs slightly better than log-linear and matches the non-parametric results better. The linear regression model performs quite poorly relative to the log-linear or log-log models.

5.4 Costs for Filter BMPs

We used the same set of specifications to evaluate cost curves for costs for the other two BMP categories. For filter BMPS, Table 5 shows specifications that include cost of the project, fixed effects for the BMP type, an indicator for a secondary BMP, as well as capacity measure. The models that control for project cost (columns 2 and 3) perform far better on AIC, BIC, and LOOCV criteria than those that do not. The pseudo R^2 from LOOCV for column 2 is 0.31 so the out-of-sample predictions are good. The specifications show a range of elasticities from about 0.35–0.50 when we control for project costs. Columns 2 and 3 have similar AIC/BIC but model 2 has better LOOCV performance, so specification 2 appears to be a better predictor overall and is the one we use for our comparison analysis.

	(1)	(2)	(3)
	Independent Variable= Log(BMP Cost)		
Log Capacity (m^3)	0.942*** (0.076)	0.343*** (0.119)	0.496*** (0.133)
Log Project Cost		0.312*** (0.108)	0.221** (0.111)
Observations	106	101	101
R^2(LOOCV)	0.180	0.308	0.240
AIC	2263.561	2097.455	2092.140
BIC	2268.888	2123.606	2120.906
BMP dummies	no	yes	yes
2nd BMP dummies	no	no	yes

Standard errors are in parentheses
**** p<.01, ** p<.05, * p<.1*

Table 5
Cost Curves for Filter BMPs

5.5 Costs for Use BMPs

The use category is about 95% rain barrels and the rest cisterns. We dropped cisterns from the specifications because of the lack of data. Rain barrels do not require extensive construction or fixed costs like the other uses, so they are less likely to show economies of scale. Also, in this data, landowners usually choose rain barrels when there is no larger redevelopment project, so the BMP cost is the same as the project cost and we could not use project cost in the regressions. The models (Table 6, columns 3 and 4) with controls for secondary BMPs performed better on AIC/BIC and LOOCV criteria and the log-log model is slightly worse on AIC/BIC and better on LOOCV (0.13 compared to 0.10 out of sample R^2). On these grounds we chose the log-log model as the preferred specification for our comparison analysis.

	(1)	(2)	(3)	(4)
	Independent Variable= Log(BMP Cost)			
Capacity (m^3)		0.334*** (0.033)	0.288*** (0.034)	
Log Capacity (m^3)	1.217*** (0.088)			1.033*** (0.093)
Observations	269	269	269	269
R^2(LOOCV)	0.092	0.043	0.104	0.127
AIC	4810.124	4809.581	4756.583	4762.914
BIC	4817.313	4816.771	4770.962	4777.293
2nd BMP dummies	no	no	yes	yes

Standard errors are in parentheses
**** p<.01, ** p<.05, * p<.1*

Table 6
Cost Curves for Use BMPs

5.6 Cost Comparison for Best Models

Which type of BMP would landowners choose if capital cost were their main concern? We examined this question by looking at the average cost prediction for our chosen specification for each category of BMP. Figure 3 shows that use BMPs are predicted to be less expensive than the other two until about the 70th percentile of BMP capacity at 8.5 m^3. However, they only have a large cost advantage for smaller size BMPs. Infiltration BMPs are always predicted to be less expensive than filters in the range of the data, but the cost advantage narrows substantially in the higher size ranges (above 50 m^3, or in the 97th percentile). If landowners choose mainly on the basis of capital cost we would expect to see use BMPs dominate through all but the largest 30% of BMP sizes, then infiltration for the larger capacities. Of course, confidence intervals would largely overlap, so for a particular installation any of the categories could be the least expensive.

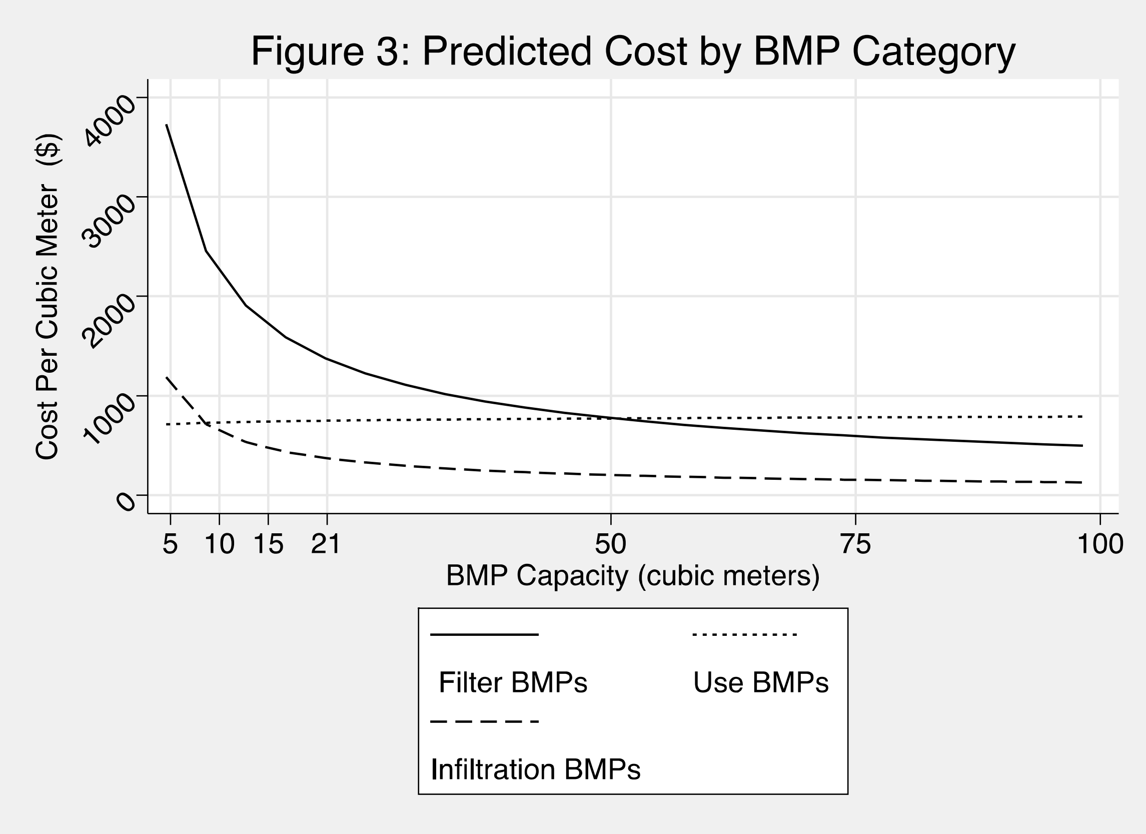
Figure 3: Predicted Cost by BMP Category

6. BMP Choice

The capital cost of BMPs is likely a significant factor in landowner choice, but opportunity costs of land and additional site design compromises forced by BMPs could also be significant choice factors. Landowners can also choose to pay an in-lieu fee if they meet certain conditions. These include a number of environmental conditions that would make on-site BMPs difficult or dangerous but also, in some circumstances, development considerations that would make installing an on-site BMP difficult. We do not have data by parcel on the relevant environmental conditions, so our analysis is confined to property and development characteristics.

The in-lieu fee was set at \$2010/m^3 of capacity for the period in question (\$7.61/gallon). This is at about the 75th percentile of reported per-gallon costs for those that constructed BMPs. Since BMP capital costs are likely to be a good bit smaller than overall costs (including maintenance, land and site design) the large number of BMPs with average costs higher than the in-lieu fee are evidence that Santa Monica's requirements for in-lieu fee qualification are strictly enforced. However, actual savings to landowners with costs above the in-lieu fee are on average small. The mean savings from all landowners who would benefit if there were no qualifications for the in-lieu fee is only \$175 and even the 99th percentile of savings is only about \$2100. These are small fractions of overall (re)development costs. This finding suggests that the in-lieu fee choice is likely more driven by land and overall development costs, and lack of annual inspection and maintenance costs than the capital costs of BMPs themselves.

These savings are low because there are few properties with on-site BMPs that have both large capacity requirements and high per-unit-capacity costs. Our cost estimation above shows that there are large economies of scale, so that the capital costs of capacity for large installations should usually be well below the in-lieu fee. The small owner-savings from universal takeup of the in-lieu fee as well as our cost estimates imply that the engineering costs of BMPs is likely a minor reason to use the in-lieu fee option.

Rather than capital and engineering costs, the opportunity cost of land, and overall design and annual maintenance costs, are likely to be more important drivers of the in-lieu option. Assessed land value per square foot is likely to be an underestimate of land value in Santa Monica. It averages $114/ft^2 in our sample and the 90th percentile is at $235. A BMP design that saves even the equivalent area of a single parking stall (about 160 square feet) would result in greater savings than the capital cost savings we calculated. In addition, BMPs might require more expensive and/or less valuable building decisions for the property (recall most BMPs are built during development/redevelopment). This is not a cost we can calculate but we see a hint of these costs in the BMP cost modeling. BMP costs are higher, even controlling for capacity and type, for projects that are more expensive overall. A possible reason for this is that landowners spend more on the BMP in order to improve the site design and profits for their redevelopment.

The above observations on in-lieu fees as well as economic theory predict that land value and building density will affect in-lieu and BMP choice. We used the Floor Area Ratio (FAR) to measure the development intensity and assessed land value per square foot of land to measure land value. Next, the intensity of the development or redevelopment may affect the choice of BMP because more intensely developed sites will have a harder time fitting BMPs into the site design. We measured this intensity of development through the cost of the redevelopment project per square foot of property area. There has been technical progress in BMPs over the time period, so we used a year trend to capture technology and other trends (initially we used year fixed effects, but a year trend had better AIC/BIC scores.) Finally, residential and commercial properties have different design and aesthetic preferences, so we included land use indicators.

BMP Category Choice Results

We used a multinomial logistic regression (Table 7) for the key choices (filtering, infiltration, use, in-lieu fee). Infiltration is the base category. The mitigation requirement coefficient is negative, statistically significant at the 1% level and economically large for the use BMP category. This coefficient is small and statistically insignificant for the other two BMP categories. This means that increased mitigation is associated with movement away from the use category to the other categories, but not with movement between the other categories. The coefficient for the single-family land use class is negative and significant for both filtering and in-lieu fees. The coefficient for multifamily land use is also negative for both filtering and in-lieu fees but significant only for filtering. This implies that residential landowners are less likely to choose filtering or in-lieu fees, ceteris paribus. The coefficient on assessed value per square foot of land is negative and significant for the use category but insignificant for the other categories. The coefficient on the FAR is positive and significant for the in-lieu fee category, but insignificant for the other categories. The coefficient on the project cost per area is negative and significant for the filtering and use categories. This implies that the greater the intensity of the overall redevelopment project the more likely the landowner will choose either infiltration or in-lieu fees.

	Filtering	Use	In-Lieu-Fee
Multi-Family	-1.849***	-0.0484	-0.865
	(-3.29)	(-0.05)	(-1.79)
Single Family	-2.101***	-0.364	-1.928***
	(-6.17)	(-0.43)	(-4.71)
Mitigation Requirement (m^3)	0.00652	-0.347***	0.00604
	(1.60)	(-8.71)	(1.11)
Assessed Land Value per m^2	-0.00774	-0.0435***	-0.00712
	(-0.64)	(-3.52)	(-0.76)
Fiscal Year	0.0676*	0.234***	0.372***
	(2.43)	(9.31)	(9.55)
Floor Area Ratio	0.0965	0.604	0.831**
	(0.27)	(1.59)	(2.81)
Project Cost per m^2	-0.0916***	-0.125***	0.000122
	(-3.91)	(-4.63)	(0.02)
Constant	-136.0*	-470.4***	-749.9***
	(-2.44)	(-9.29)	(-9.56)
Observations	1526		
AIC	1796.6		
BIC	1924.6		

Table 7

BMP Category Multinomial Logit Choice Model

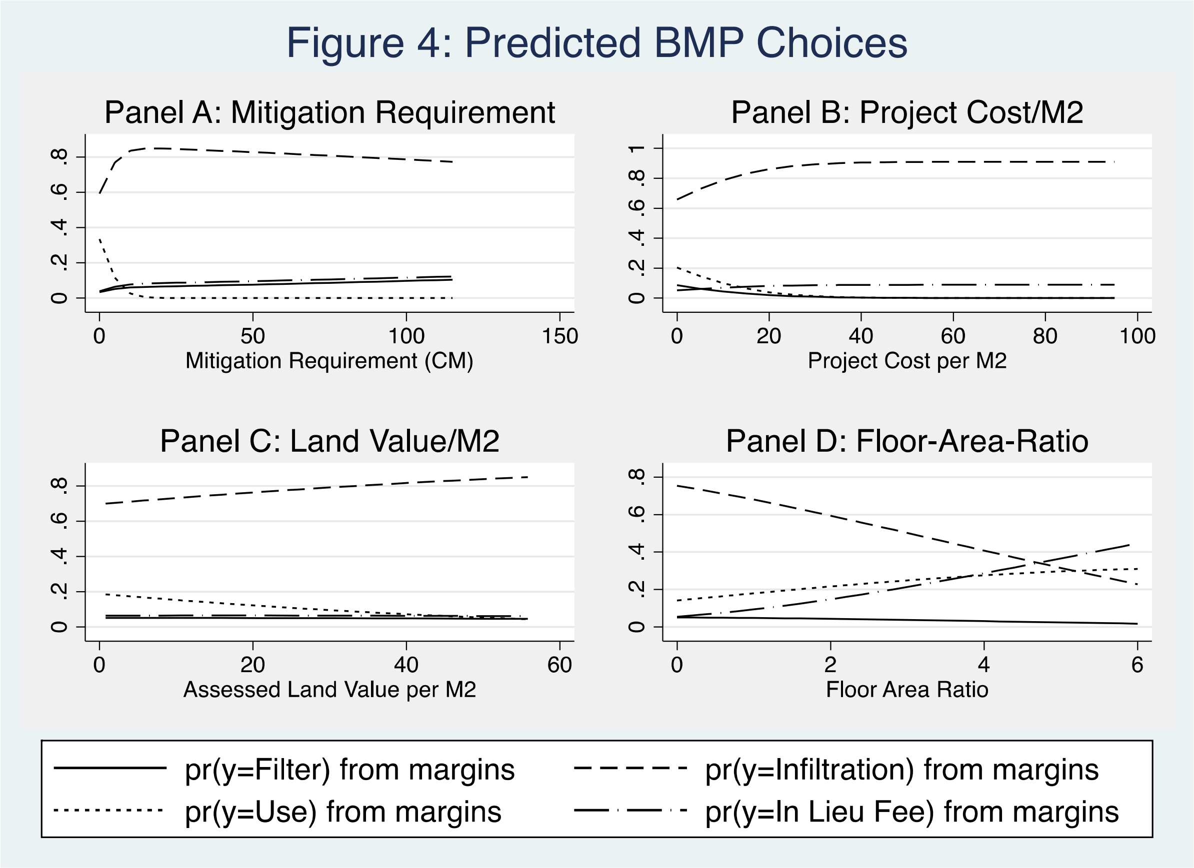

Figure 4: Predicted BMP Choices

Fig. 4A shows the predicted substitution between types as the mitigation requirement grows. The key feature is that infiltration BMPs increase sharply at the expense of use BMPs for the lower range of mitigation requirements (this is same qualitative shift shown in Table 1). The project cost per area figure shows a similar movement: as project cost increases, there is a shift from use to infiltration and in-lieu fees in the lower range of project cost per square foot, but little movement at the upper range. The figure for assessed land value per square foot is similar. Figure 4D shows that as building density (FAR) increases it is predicted that in-lieu and filter BMPs have increased probability, mainly at the expense of infiltration.

7. Discussion

The choice model findings are largely consistent with the findings about capital costs. We found large economies of scale in infiltration BMPs at the low size range. This is reflected in the fast shift away from use to infiltration in the low mitigation range in figure 4A. However, our capital cost modeling indicates that use BMPs are cheaper than infiltration until capacities are quite large. The choice model findings indicate that infiltration must have some other advantages in the size range where the cost difference is not too large. Also, we found that filter costs converge towards infiltration costs in the largest size ranges. The choice model predicts substitution toward filters and fees in the large ranges. The figure shows a large percentage increase for filters, though infiltration remains the dominant choice. During the period covered by our data, landowners were aware that infiltration technologies were familiar to and favored by city staff. When costs are close, which is what our modeling shows, it’s not surprising that infiltration dominates landowner choice.

If costs and other factors in Santa Monica are proportional to those in other areas, other cities can expect infiltration BMPs to dominate over much of the size range. Infiltration provides a wide array of ecosystem services, so it may be a fortuitous coincidence that it also has apparently low capital and opportunity costs over a wide range. If, however, a city chooses to prioritize use BMPs, it would need to have a different program structure that incentivizes or mandates them.

It seems that Santa Monica had good information on BMP unit costs and set the fee level so that most properties would implement BMPs. There are few properties with average capital costs above $7.61/gallon. Santa Monica is dense and expensive, so placing stormwater management capacity on private land makes a good deal of sense—and it appears that is what the city aims to do. The only variables in our choice analysis that significantly affects fee choice is the FAR. Higher FARs are predicted by our model to substantially increase fee and use choice. This is consistent with our idea that more heavily developed properties would have higher opportunity costs and be more likely to pay their way out of BMPs. The reason for the increase in use BMPs is not as clear. However, use BMPs can be placed aboveground instead of taking up land area and therefore might have lower opportunity costs as well. Santa Monica also only allowed the fee opt-out under certain environmental conditions (such as high groundwater), which we don’t have the information to model directly. It is likely that fee use would be higher without these limits.

The implication of this finding on FAR for stormwater and ecosystem services is clear (assuming, of course, a causal relationship). Our analysis identifies the key factor in fee take up as density of development. The other factors we could model did not have a huge marginal effect on predicted fee choice. Areas with higher density development than Santa Monica can expect higher demand for in-lieu fees, and lower-density areas less demand. Across a larger city than Santa Monica this will have a large effect on where stormwater management ecosystem service provision occurs. City managers will need to account for this pattern if they see a need for stormwater management in more built-up areas of the city.

Another factor the modeling predicts will affect the spatial pattern of BMP and in-lieu fee choice is land use. We examine the predictions for BMP choice by land use at the median requirement capacity in Table 8. Commercial and industrial properties are predicted to choose infiltration much less and filtering and in lieu fees more than single-family properties. Multifamily properties are in between these two use classes. This is not solely because of the different development intensity—the same qualitative results hold if we fix the FAR to a constant value across land uses. This result indicates that there are differences in the propensity of property types to choose BMPs even after controlling for a number of property attributes as well as the mitigation requirement.

	Filtering	Infiltration	Use	In-Lieu Fee
Commercial/Industrial Land	0.18	0.51	0.17	0.15
Multi-family Land Use	0.04	0.64	0.23	0.09
Single family Land Use	0.03	0.72	0.21	0.04
Commercial/Industrial Land, FAR=.5	0.13	0.36	0.24	0.27
Multi-family Land Use, FAR=.5	0.03	0.47	0.32	0.18
Single family Land Use, FAR=.5	0.03	0.56	0.32	0.09

Table 8

Predicted Choice Probabilities for BMP Categories

A possible reason for these differences is that the commercial and industrial and multifamily properties are likely to have less green space on the property than a single-family property with a yard. This is more difficult in the other property types. Multifamily and commercial property types, for instance, face more stringent parking requirements that means a large percentage of the property is hardscape. Thus, they may choose the in-lieu fee instead of handling the difficulty and expense of placing a BMP into a hard surface. The implications for stormwater management are clear. If Santa Monica is similar to other areas, then areas with more multifamily and commercial properties are likely to see more demand for in-lieu fees and filter BMPs than areas that are composed of primarily single-family residences. Cities will need to take this into account in deciding if they are likely to receive the mix of stormwater management ecosystem services that they desire.

8. Conclusions

We investigated the decentralized provision of an ecosystem service bundle in stormwater provision. We used the results of a Santa Monica, California, program that requires stormwater BMPs on new and re-development, with landowners given a wide choice of BMP types—or a narrowly qualified in-lieu fee option—to satisfy program requirements. Compliance and other public data allowed us to examine the costs and ecosystem service choices of landowners. The choice of BMPs determines the mix of ecosystem services (infiltration, water supply, pollution remediation) provided by the policy. We began from the simplest hypothesis—that landowners choose the BMP with the lowest engineering costs—and modeled the cost-capacity curve for each of the major BMP categories (use, filters, and infiltration). Our models indicate that: (1) both filters and infiltration have initially high but quickly declining unit costs; and (2) use BMPs (rain barrels) have flat unit costs that are less expensive on average than use or infiltration through most of the range of capacities in the data.

We then used a multinomial logit to model landowner’s choice of BMPs or in-lieu fees. We found that the mitigation requirement, land use, building density, project intensity and land value all are correlated with the landowners’ choices. Our modeling indicates that use BMPs are significantly less expensive than other BMPs throughout a large range of capacity, but landowners prefer infiltration BMPs except in the smaller capacities. Similarly, filters are always more expensive, but as the cost difference narrows they are chosen in the higher size ranges.

This indicates that the non-capital costs of infiltration and filters are less than that of use BMPs. Similarly, the choice of in-lieu fees even when it appears that another option would be less expensive indicate that landowners face significant non-capital costs for these options.

Our results indicate that different land uses and building densities are associated with substantially different preferences for rainwater BMPs. In particular, the results are consistent with the hypothesis that non-capital costs such as opportunity costs of land and design are significant factors in landowner choice of BMP or in-lieu fee. Consequently, program design choices such as in-lieu fees can have a substantial impact on the mix of ecosystem services provided in a decentralized system.

In this paper we offer a first cost modeling from a large dataset of property-level BMPs. Further research should examine in more detail the opportunity costs of rainwater BMPs and other similar technology in order to see the full cost of ecosystem service provision and how that full cost affects the mix of ecosystem services provided.

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