ECONOMIES OF SCALE IN LANDFILL COSTS

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Do landfills exhibit economies of scale, making it cheaper per ton (or per cubic yard) to dispose of waste in larger sites? That is, was Arlo Guthrie right, in *Alice's Restaurant*, to say that "one big pile of garbage is better than two little piles of garbage"?

In this paper we first present a geometric theory which predicts a particular pattern of economies of scale (Section 1), then describe a sample of California landfills which we have studied (Section 2), summarize relevant data problems surrounding that sample (Section 3), and finally test the theory on the data sample (Section 4).

1. LANDFILL GEOMETRY AND AREA-BASED COSTS

One basis for economies of scale in landfills derives from geometry. Many cost elements are related to landfill acreage, including bottom liners, final cap and cover, leachate and gas collection equipment, many postclosure costs, and others. Typically, the bigger the landfill, the deeper the garbage is piled—that is, bigger sites can accept more garbage per acre. If many costs are proportional to acreage, and there is more garbage per acre in bigger sites, then the bigger sites have lower per-ton or per-cubic yard costs.[1]

A more formal statement of this geometric argument leads to a specific prediction about landfill cost patterns. There are two key simplifying assumptions (both of which are unrealistic in detail, but may serve as interesting approximations to reality).

First, assume that all landfills, when completely filled, are geometrically similar objects: that is, the ratios of width to length to above-ground height to excavation depth, and the slope angles, are the same for all landfills. If a side of the landfill has length s, then the final fill volume and tonnage are proportional to s^3.

For instance, consider some simple but obviously absurd shapes. First, suppose that all landfills were perfectly rectangular solids with the ratios of length:width:height equal to 4:2:1. Then, if we let the length (longest side) be s, the final volume of any landfill would be $s^3/8$. On the other hand, if all landfills were perfect pyramids with square bases and slope angles of 45°, and a side of the base is s, then the volume of any landfill would be $s^3/6$. The constant of proportionality—1/8 in the first example, 1/6 in the second—reflects the specific geometry assumed for landfills, and is irrelevant for our argument.

Second, assume that all costs are directly proportional to acreage (we discuss an alternative to this assumption below). This implies that both acreage and costs are proportional to s^2. Note, also, that the final tonnage per acre is proportional to s.

It is clear by definition that

(1) cost per ton = cost per acre/tons per acre

Under our assumptions, cost per acre is constant, while tons per acre is proportional to s; so (1) may be rewritten as

(2) cost per ton = k_1/s

for some constant k_1.

Let the cost per ton be C, and the final tonnage in the entire landfill be T. By our first assumption, T is proportional to s^3, or equivalently, s is proportional to $T^{1/3}$, so (2) becomes

(3) $C = k_2/T^{1/3}$

[1]*For simplicity, we will restrict our discussion to per-ton costs. However, the entire argument is equally applicable to per-cubic yard costs; density is assumed constant* throughout.

Taking logarithms of both sides of (3) we obtain

(4) $\log C = k_3 - (1/3) * \log T$

That is, our geometric theory of landfill costs, under the assumption of constant costs per acre, predicts a linear relationship between the logarithms of cost per ton and tonnage. Moreover, it predicts a specific value, -1/3, for the slope of that relationship.

Of course, there are some landfill costs which are not proportional to acreage. As an alternative, consider costs which are more closely related to tonnage, such as equipment costs or daily cover. If all costs were directly proportional to tonnage, then in place of (3) we would have C being constant, and in place of (4) we would find that the slope of the relationship between log C and log T is 0.

Thus we suggest (without proof) that if some costs are based on area and others on tonnage, there will be a relationship between log C and log T, with a slope between 0 and -1/3. Intuitively, it seems that a slope closer to 0 implies more tonnage-based costs, while a slope closer to -1/3 implies more acreage-based costs.

In interpreting an empirical test of our theory, such as we present in Section 4 below, it must naturally be recognized that our assumption of geometric similarity of all landfills is an oversimplification. Nor are all cost elements strictly proportional to either acreage or tonnage. However, these simplifying assumptions may still be useful if the deviations from them are relatively small and uncorrelated to landfill size. The calculated correlation coefficients indicate, for any data set, how much of the variance in costs could be explained by our theory alone.

2. THE CALIFORNIA LANDFILL STUDY

We recently participated in a Tellus Institute study entitled, "A Cost Analysis of Municipal Waste Landfilling in California." It was performed for the California Waste Management Board, and directed by Dr. Allen White; other co-authors included John Schall and Todd Schatzki, all of the Tellus Institute.

Since California has approximately 300 active and permitted landfill sites, we selected a sample of 27 landfills for detailed analysis. Selection criteria established for the study included coverage of a wide range of landfill sizes; public and privately owned landfills; a range of locations throughout the state; and inclusion of all 3 landfills sited under the new, strict regulations adopted in 1984. Further information on the sample selection and the individual sites is available in the Tellus Institute study.

The sample selection and data development were not influenced by the theory presented in Section 1. Indeed, we did not develop this theory until late in the process of analyzing the California data set. Other approaches to understanding the relationship between costs per ton and landfill size, which we tried first, proved far less successful.

For each landfill, the Tellus study developed three types of cost data, each expressed as a cost per ton: "conventional" costs, closure/postclosure costs, and environmental remediation costs.

By "conventional" costs we mean operating and maintenance (O&M) and capital costs. The distinction between O&M and capital costs was not made consistently by the sampled landfills, so we analyzed total conventional costs. Of the 27 sites, 20 reported conventional costs. For the 7 remaining sites, we used gate fees (tipping fees) as surrogates for conventional costs.

In the second cost category, 17 sites reported estimates for closure and postclosure costs, although they varied widely in completeness and level of disaggregation. For the remaining 10 sites we used the average per-acre closure cost, and the average annual per-acre postclosure cost, calculated from the 17 sites with data.

For each site we calculated the net present value of closure and postclosure costs, then amortized those costs over the remaining lifetime of the landfill. In effect, we assumed that no funds have yet been set aside for closure or postclosure costs at any landfill, but that starting now, each landfill will charge enough to recover the present value of closure and postclosure costs during its remaining lifetime.

Third, we studied in some detail the appropriate choices of remediation technology, if the sample landfills were to require ground water or surface water remediation. This led to development of estimated environmental remediation costs for each landfill, which were then multiplied by a "risk score" (ranging from 0 to 1) reflecting the relative likelihood of water pollution. As in the case of closure costs, we amortized the remediation costs over the remaining lifetimes of the landfills.

3. DATA PROBLEMS IN THE CALIFORNIA SAMPLE

A number of data problems arose in preparing the California sample for use in testing our theory. First, an estimate of tonnage handled at each landfill is required. The theory in Section 1 is based on final tonnage received by the time the landfill is closed. However, landfill operators do not typically report this figure. We could use daily tonnage received; if all landfills had the same lifetime, and operated at a constant rate throughout that lifetime, then daily tonnage received would be proportional to total lifetime tonnage. However, even daily tonnage received is not uniformly reported.

We settled on permitted tons per day (PTPD) as a reasonable proxy for daily tonnage received. PTPD is known for all permitted landfills. However, even this did not avoid all data problems. One landfill, occupying 49 acres, was permitted to receive only 1 ton per day; it had

20 years of remaining lifetime. Other landfills of the same acreage or smaller had 20 - 65 PTPD (and several had similarly long remaining lifetimes). For the purposes of the regression analysis presented below, we conclude that in the 1 PTPD case, PTPD is not a reasonable proxy for lifetime tonnage. Hence we have dropped that site from our analysis.

For the surviving 26 sites, PTPD is the measure of tonnage, both for calculating costs per ton (landfills are assumed to receive waste at the PTPD rate, year-round), and as the independent variable in testing the theory developed in Section 1.

For conventional cost data, we used all 26 of these sites. We tested the alternative of excluding the 7 sites where gate fees were used as proxies for conventional costs; the 19-site results were very similar to the 26-site results reported here. For environmental costs, we also used all 26 sites. For closure/postclosure costs, we used the 16 (of the 26) sites which reported closure and postclosure costs. Visual inspection suggests that 4 of the 16 are outliers, about which more below; we also present results for the 12 "well-behaved" sites.

4. TESTING THE THEORY

To test our theory, we performed ordinary least squares regressions of our three cost-per-ton variables against permitted tons per day (PTPD). Our regression results are presented in Tables 1 and 2, containing logarithmic and nonlogarithmic variables, respectively. Line-by-line comparison of the tables shows that the logarithmic regressions, in Table 1, are uniformly superior to the nonlogarithmic regressions, in Table 2. In fact, every t statistic in Table 1 is above 2 in absolute value, while every t statistic in Table 2 is below 2.

We take these comparative results as confirmation that the preferable functional form of the relationship between cost per ton and tonnage is a logarithmic one, as presented in equation (4) above.

In each table, the first results are for conventional costs, i.e. current capital and operating costs. The coefficient shown in Table 1 is -.14; it is significantly different both from 0 and from -.333 at the 5% level. As discussed in Section 1 above, this might be taken to suggest a mixture of acreage-based costs and tonnage-based costs. The relationship between conventional cost per ton and PTPD explains about one-sixth of the variation in cost per ton (as measured by adjusted r^2).

In the case of closure/postclosure costs, the regression coefficient in Table 1 is not significantly different from -.333, and the regression explains 27% of the variation in the data. This seems easy to understand, since closure and postclosure costs are among the most obviously acreage-related. Other sources of variation include years to closure, and differences in closure or postclosure technology.

Environmental remediation costs are also intrinsically per-acre costs; indeed, we assigned these costs on a per-acre basis. (We did use different technologies depending on site characteristics.) Here years to closure, and risk scores, as well as site-to-site variation in remediation technology, will introduce variation in cost per ton. Again, the coefficient in Table 1 is not significantly different from -.333. Other sources of variation are important, though: PTPD explains only one-eighth of the variation in environmental remediation cost per ton.

Only a few other relevant variables were available in our data set. In each of our three cost categories, we tested the influence of three variables: years remaining to closure, private (vs. public) ownership, and post-1984 licensing (when new regulations applied). Specifically, we added each of these variables, one at a time, to the three regressions shown in Table 1. Years remaining to closure was significant in all three cases; the other variables were not significant in any case. The significant results, involving years to closure, are shown in Table 3.

The added variable, years remaining to closure, has a positive sign for conventional costs, but negative for the other two cost categories. This is not surprising. In conventional costs, newer landfills, which tend to have more years remaining to closure, were typically built with more extensive pollution controls—hence higher conventional

TABLE 1
Log Cost Per Ton Vs. Log PTPD

Cost category	N	Coefficient (std err)	t	adjusted r^2
Conventional	26	-.138 (.058)	-2.40	.160
Closure/postclosure	16	-.468 (.182)	-2.57	.273
Environmental	26	-.324 (.154)	-2.10	.120

TABLE 2
Cost Per Ton Vs. PTPD

Cost category	N	Coefficient (std err)	t	adjusted r^2
Conventional	26	-.00118 (.00064)	-1.86	.090
Closure/postclosure	16	-.000475 (.000599)	-0.79	.000
Environmental	26	-.00197 (.00248)	-0.79	.000

TABLE 3
Log Cost Per Ton vs. Log PTPD and Years to Closure

		Coefficients (standard errors)		
Independent variable	N	Log(PTPD)	Years remaining to closure	Adjusted r^2
Log of conventional costs	26	-.119 (.055)	.0122 (.0058)	.263
Log of closure/ postclosure costs	16	-.424 (.157)	-.0434 (.0178)	.462
Log of environmental costs	26	-.380 (.144)	-.0358 (.0153)	.259

costs per ton. In closure/postclosure costs and environmental costs, however, landfills with more years remaining to closure have more tonnage remaining, over which the costs can be spread—hence lower costs per ton. For the case of closure/postclosure costs, more years remaining to closure also means that the present value of the future costs is lower.

In all three cases, the inclusion of years remaining to closure substantially increases the explanatory power of the regression, as measured by r^2. The coefficient of log(PTPD) is not significantly different from -.333 in the closure-/postclosure and environmental cost regressions; for conventional costs, the coefficient remains between 0 and -.333, suggesting a mixture of tonnage-based and acreage-based costs.

Visual inspection of the closure/postclosure data suggests that 4 of the 16 points are outliers. Two have very low lifetime tonnage remaining; hence amortization of closure costs over these tonnages leads to very high costs per ton. Our assumption that future costs are amortized over remaining lifetime tonnage may not be viable for such landfills. Another two sites reported extreme values of closure or postclosure costs per acre—one much lower, and another much higher, than is typical of the remaining sites.

Excluding these 4 sites, the results for closure/postclosure costs for the remaining 12 sites are shown in Table 4. The coefficient of log(PTPD) is not significantly different from -.333 in either case; when years remaining is included, the regression explains virtually all (92%) of the variation in the data.

Finally, what do these results mean for the costs of large vs. small landfills? First, suppose that costs are entirely area-based, so that the true coefficient, as suggested by our theory, is -.333. Then doubling the acreage of a landfill implies a 21% reduction in cost per ton. On the other hand, if the true coefficient is -.12, as estimated for

TABLE 4
Closure/postclosure Cost Results with Outliers Removed

		Coefficients (standard errors)		
Independent variable	N	Log(PTPD)	Years remaining to closure	Adjusted r^2
Log of closure/ postclosure costs	12	-.409 (.142)		.400
Log of closure/ postclosure costs	12	-.411 (.050)	-.0461 (.0055)	.925

conventional costs in Table 3, then doubling the acreage implies only a 8% reduction in cost per ton.

In the end, Arlo Guthrie is vindicated by our California data set: one big pile of garbage is slightly better than two little piles, particularly in closure and postclosure costs. Landfill economies of scale, based on geometry, are a subtle but statistically significant effect.