To the Graduate Council:

I am submitting herewith a thesis written by Neal Charles Davis entitled "An Economic Model for Siting Sanitary Landfills." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Economics.

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AN ECONOMIC MODEL FOR SITING SANITARY LANDFILLS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Neal Charles Davis

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This is dedicated to the memory of my brother,

C. Keith Davis, who died on December 9, 1983.

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ABSTRACT

Landfilling is one of three alternatives presently available for disposing of solid waste, along with recycling and incineration. Landfilling appears to be the most cost efficient alternative for the foreseeable future. Landfills do have a limited life, so the problem of siting periodically recurs. It has been estimated that 72% of the county landfills in operation in Tennessee in 1979 will require location within 10 years of that time. A well-managed sanitary landfill is considered by some to be a nuisance free method of waste disposal; however, acceptance of a site is often difficult due to adverse public reaction. Real or at least perceived external effects have been shown to depress nearby property values. These external effects can be estimated and explicitly included in the siting decision-making process. Conflicts over siting decisions may be more readily resolved through identification of the social cost-minimizing site and the use of a tax-compensation scheme to adjust location incentives facing operators and reduce protest and approval costs.

The objectives of this study were to estimate the costs associated with landfilling which vary with the distance a site is located from a population center and derive implications from these estimates for siting and tax-compensation strategies. Transportation costs were expected to increase with distance, while external costs, protest costs (the legal fees, time expenditures, and other costs incurred by nearby

residents in opposing a potential site), and approval costs (the legal fees, time delays, and other costs incurred by the operator due to protest activities) were all expected to decrease with distance. It was thus hypothesized that there would be some distance from the population center where the sum of these costs would be minimized.

Two scenarios were then examined to determine what the cost-minimizing distance would be in each. The first was the case of no internalization of the external costs by the operator or compensation to affected residents. Under this scenario cost-minimizing distances for the landfill from the operator's perspective and from society's perspective would diverge. Under the other scenario internalization of the external costs was accomplished through placing a tax on the operator. The revenue raised from the tax would then provide the financing for compensation payments to affected residents. This would serve two purposes: 1) the operator's costs would more fully reflect the true social costs of the landfill, correcting his location incentives and 2) the affected residents would be less inclined to protest the landfill being placed nearby, which would reduce their own protest costs and, subsequently, the approval costs of the operator. Under this scenario the optimal distances for the operator and society would be the same, and total social costs of landfilling would be lower because of the shift away from the population center and the reduction in protest and approval costs.

Empirical illustration of this approach was done using a case study area. Variable transportation costs were estimated, based on

data covering a full year for the twenty-two mile round trip from a transfer station to an existing landfill. External cost estimates were developed based on a coefficient for distance from a landfill in Baker's hedonic price model. Percentage reductions in property values which varied with distance from a landfill site were applied to census information on numbers and value of residential property for sites along a ray from a transfer station through an existing landfill in order to develop the external cost function. The distance at which the sum of transportation and external costs were minimized was identified. Due to the limitations inherent in the data and methodology, analysis was undertaken to determine how sensitive the conclusion as to social cost-minimizing distance was to variations in transportation and external costs.

The level of external costs at the social cost-minimizing distance suggested an appropriate level for the tax and compensation payments. Average annual compensation per household for several ranges of distance from the site was indicated. Several alternative methods for compensation were outlined. The cost of compensation in terms of increased costs per household in the case study area for solid waste disposal services was estimated.

The basic conclusion of the study was that the conceptual framework developed provides a useful way to address systematically the problem of landfill siting and tax-compensation schemes, as the empirical illustration demonstrates. Limitations inherent in the data and methodology and suggested areas for further research were outlined.

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CHAPTER 1

INTRODUCTION

Solid waste disposal is presently a significant problem in the United States. According to Badger the daily per capita generation rate of solid waste material was estimated to be five and one-half pounds in 1971, but was predicted to reach eight pounds by 1980. As recently as 1920 this generation rate was estimated to be two and three-quarters pounds. The continuing trend toward convenience in the preparation and consumption of foods and other products has caused additional processing steps to be taken. At each processing stage additional solid waste is generated. Final products are never actually consumed and ultimately end up, along with packaging, as a component of solid waste. A growing population also increases the amount of solid waste generated. These two trends will serve to exacerbate the problem which presently exists regarding the disposal of solid wastes.

Three alternatives exist as solutions to the problem of solid waste disposal: recycling, incineration and landfilling. Recycling is a very desirable method of at least partially solving the problem of solid waste disposal. Recycling removes those elements of solid waste which are in some way salvageable and converts them into useable material, thus reducing the rate of natural resource depletion. Recycling is feasible only when the cost of recycling is offset by the value of the useable material. That is, the market value of the

salvaged materials must be at least as great as the cost of the salvaging process, otherwise salvaging will not be undertaken by private individuals or firms. Recycling processes generally involve significant economies of size and thus are usually attempted only when a large volume of solid waste is available. Metropolitan areas are more likely to find recycling economically feasible than smaller cities or rural areas. However, all political entities must provide some method of solid waste disposal, and recycling is often prohibitively costly. Once as much recycling has been accomplished as is feasible, some waste remains, possibly a large percentage of the original amount. This residual typically must be disposed of in a landfill.

Incineration is another possible solution to the problem of disposal of solid waste. Incineration supplements the supply of energy sources and lessens the rate at which fossil fuels are depleted. Incineration plants can perform a twofold function; they reduce solid waste to ashes and contribute the energy they produce to the existing energy network. Again, there is the question of whether the political entity actually has enough solid waste material that can be burned to justify the cost of conversion of an existing plant and the construction of processing facilities to prepare the solid waste material for incineration. The often changing complexion of emission regulations may also create such uncertainty as to limit the incentives for using this method. Even in those cases where incineration is economically feasible, residual ash still requires disposal.

The third solution to the solid waste disposal problem can be used as the first and only step in a system of solid waste disposal or,

as suggested by the discussion of recycling and incineration above, as the final step. Landfilling is the most commonly used method for reasons noted above regarding the costs and other drawbacks of alternative methods.

The major problem associated with landfilling is the problem of siting. The first task in site selection is to satisfy the geological requirements, such as isolating areas where particular soil types provide suitable cover for the compacted waste materials and proper drainage without contaminating ground or surface water [Allen & Hoshall Consulting Engineers, pp. 72, 157]. These geological requirements are occasionally so constraining that only one site among various proposed alternatives is possible. This is not always the case. Usually the geological requirements and constraints imposed by current land use serve only to reduce the number of alternatives rather than actually dictating the site chosen. Once this criterion has been satisfied the actual choice from the remaining alternative must be made. It is this particular task that this study addresses, a difficult one in view of the fact that no one wants a landfill or "dump" in his back yard.

The citizenry of the City of Knoxville and of Anderson and Knox Counties are particularly aware of the difficulties of siting landfills. The Knox County landfill, which was also used by the City of Knoxville, reached its capacity recently and was retired. The waste management firm which contracted with Knoxville to dispose of the city's solid waste purchased land for a new landfill in Anderson County. After a lengthy and costly legal battle between several

parties, the landfill site in Anderson County received legal approval and is now operating.

Landfills are not characterized by a limitless life, thus the problem of landfill siting will periodically recur unless some other method of solid waste disposal is developed. A study by Garland and Frank of the County Technical Assistance Service of The University of Tennessee indicated that a total of fifty-seven landfills were being operated in Tennessee in 1979. By 1984 twenty-eight of these will have been retired. Another thirteen will be retired within the following five years. This means that nearly 72% of the county landfills in operation in 1979 will need to be relocated within ten years, This illustrates the significance of the siting problem for Tennessee counties.

Economic theory can provide principles applicable to the siting decision and introduce a measure of objectivity into what is often a highly subjective and emotional process. Part of the costs associated with landfilling are internal costs. These include costs associated with the acquisition and development of the site, operation of the landfill, and transportation for the solid waste. These costs are incurred by the public or private entities which transport the waste and operate the landfill and must be covered by revenue from charges for provision of this service to individuals and firms. These costs are relatively easy to measure and can be expected to be fully taken into consideration when deciding where to site a landfill. The acquisition costs of the landfill would probably decrease slightly as a landfill site was shifted away from a population center, however the post-landfill use value of the land will be lower as well. Thus,

acquisition costs may not be a particularly significant factor relative to distance. Costs for development and operation will vary little with location. Costs of transporting the solid waste, though, would increase significantly as a landfill site was moved away from the center of the generation area.

On the other hand, there are also external costs associated with a landfill. Briefly, external costs occur when not all of the costs of an activity are borne by the party which receives the benefits [Baumol and Oates, p. 18]. The external costs of a landfill arise due to at least the perception that odors, blowing trash, vermin, and potential water contamination are associated with landfills. These external costs are at least partially reflected in decreased property values. One way of estimating the external costs is to estimate statistically the effect of a landfill upon the property values of nearby residents. This was done by Havlicek, Richardson and Davies in 1971 and Baker in 1982. In both studies a significant effect was found to exist. Other means exist to measure the effect, including personal interviews of landowners near potential landfill sites to determine the amount of compensation they would require not to oppose the site or the amount of payment they would be willing to make to avoid the landfill being placed nearby.

External costs are expected to be positively related to the population density and residential property values surrounding the landfill. Population density generally declines as one moves away from a population center. As long as property values also decline as one moves away from a population center, or the effect of increasing

property values on external costs is outweighed by the effect of declining population density, external costs will fall as a landfill site is moved further from a population center.

Assuming that other costs are invariant with location, this potential trade-off between transportation costs and external costs suggests that at some particular distance from a population center, total social costs of a landfill may be minimized. However, if external costs to nearby residents of a landfill site are ignored in whole or in part by decision-makers or the operator, a socially inefficient site may be selected, where total social costs are not minimized. That is, the landfill may be located too close to the population center if internal costs (in particular, transportation costs) weigh more heavily in the minds of decision-makers than external costs. On the other hand, the operator may be forced to deal with external costs at least indirectly. The expectation of external costs will lead nearby residents to invest in protest efforts, which may increase approval costs for the operator well above the costs of standard administrative procedure, e.g., in the form of legal fees and time delays. Thus, the operator may have some incentive to locate the landfill too far from the population center in attempting to reduce external costs, protest efforts, and thus approval costs.

In view of these possibilities, then, compensation from the operator to nearby residents may potentially play a dual role in reducing total social costs of solid waste disposal through landfilling. Requiring payment of compensation by the operator would lead to selection of a site with lower total social costs. The receipt of

compensation by nearby residents would be expected to reduce protest and approval costs. Compensation may also be considered appropriate from an equity standpoint, depending on the property rights perspective taken, since external costs at the social cost-minimizing location may yet be substantial.

Objectives

The objectives of this study are to accomplish the following within a case study framework:

(1) To develop estimates of the transportation and external costs of landfilling as they vary with distance from a population center, so as to indicate at what distance from the population center the sum of these costs is minimized.

(2) To outline the magnitude and types of compensation schemes which might be employed to promote social efficiency in the landfill siting process.

The remainder of this report is structured in the following manner. Theoretical considerations are discussed in more depth in Chapter 2. Empirical estimates of transportation and external costs for the existing landfill site and as they vary with distance from the City of Knoxville are presented in Chapter 3. Chapter 4 includes discussion of the estimated cost-minimizing distance and possible compensation schemes. The final chapter includes a summary of the study's findings and discussion of conclusions and policy implications to be

drawn from the study, limitations of the study, and future research needs suggested by the study.

CHAPTER 2

THEORETICAL CONSIDERATIONS

The theoretical foundations of this study are twofold: Location theory provides a framework for developing a cost-minimization model for siting sanitary landfills. Welfare theory is used as a perspective to address the question of external costs of nearby residents of the landsill site and the role of compensation in improving the social efficiency of the siting process.

Location Theory

Location theory based upon the least-cost location concept was initially developed by Johann von Thunen. He investigated the effect transportation cost had upon the allocation of land among alternative activities. von Thunen assumed that land was homogeneous and that the marginal productivity of labor was uniform across all agricultural activities. Land use occurred in concentric circles around a single consuming center. The difference in land prices between zones was due to the difference in transportation costs. Land uses which incurred the highest transportation costs would locate nearest to the consumption center and produce output which received the highest prices. Conversely, land uses which incurred the lowest transportation costs would locate furthest from the concumption center and receive the lowest price for their output. The profit margins for all activities

would then be equalized by land rent, which was negatively related to the distance from the consumption center.

Alfred Weber suggested a theory similar to von Thunen's but with the assumptions of homogeneity of land and a single consumption center relaxed. Weber also added labor costs and agglomerating forces into the location decision framework. If transportation cost is the only variable cost factor, then the location decision minimizes this cost. If labor cost is significant, then the decision becomes more complicated. A net savings in total cost may be gained by choosing a different location when the reduction of labor cost is greater than the increase in transportation cost. Agglomerating forces include various economies associated with size of operation, improved marketing channels, and proximity to tertiary industries. Disagglomerating forces are the diseconomies associated with the same factors.

Edward M. Hoover also made a major contribution to the least-cost theory by including demand determinants as well as cost factors. His costs were composed of transportation costs and production costs. Hoover included institutional factors and explicitly recognized the substitution of transportation costs and production costs with the objective of minimizing total cost [Clayton and Huie, pp. 13-14].

This study uses Hoover's contribution as a theoretical framework. The typical "production" costs of a landfill include those of acquisition, development and operation, as well as external costs. Since costs of acquisition, development and operation are not expected to vary much with distance from a population center or location, the

cost-minimizing location can be expected to depend primarily on the relationship between external and transportation costs.[1]

Transportation cost incurred will be a direct function of the distance the landfill site is located from the population center as represented in Figure 1.[2]

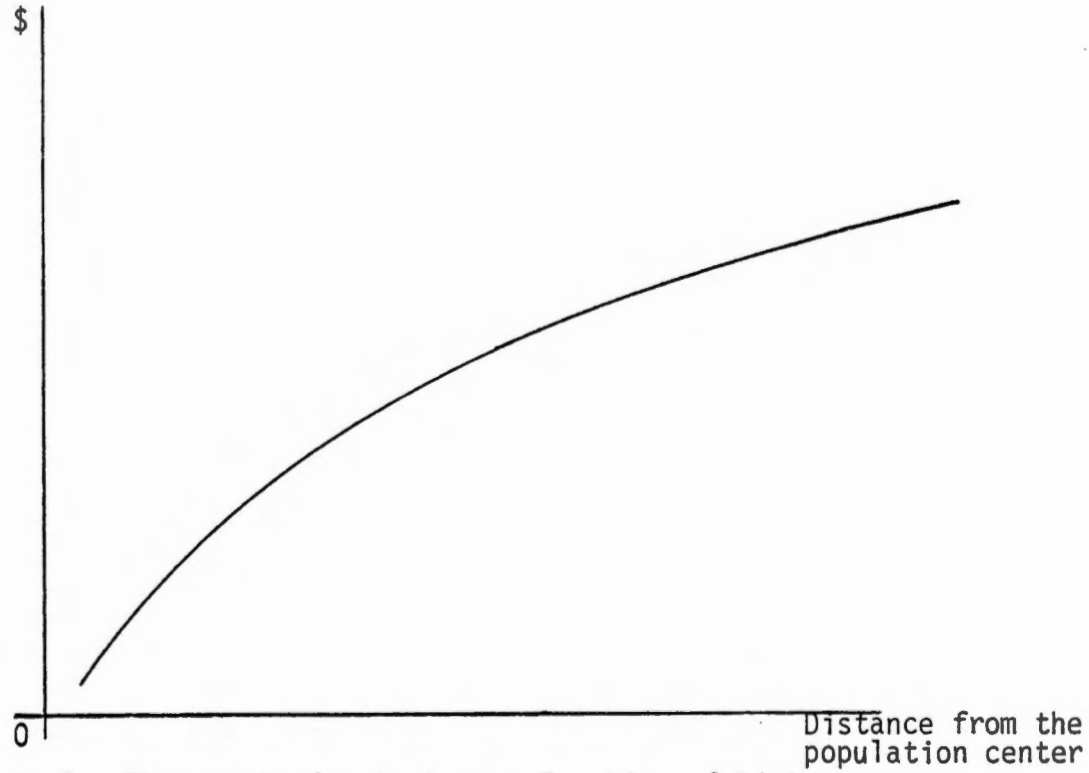


Figure 1. Transportation Cost as a Function of Distance.

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[1]Acquisition, development and operation costs per volume unit of solid waste disposed can be expected to vary with the size of the landfill site. Economies of size exist for operation and probably for development. Acquisition cost may demonstrate economies or diseconomies of size according to Clayton and Huie (pp. 70-71). Massey found that the larger the landfill site, the longer its life, the more opposition to its establishment.

[2]The cost curve may or may not be smooth depending upon the lumpiness of the inputs. It appears that the inputs would be very lumpy in some uses (e.g., trucks) and almost continuous in others (e.g., varying the number of hours employees work).

The external cost of the landfill site would be expected to vary negatively with the distance the landfill is located from the population center, as represented in Figure 2. This expectation rests primarily upon the assumption that as one moves away from the population center, population density diminishes. While the pattern of population density may not approximate concentric circles as von Thunen assumed, this assumption appears reasonable. If so, external costs must fall as the landfill site is shifted away from the population center into less urbanized or rural areas, as long as increasing property values do not offset the density effect.



Figure 2. External Cost as a Function of Distance.

Welfare Theory

Pareto optimality is the most fundamental concept of economic welfare theory according to Herfindahl and Kneese. Welfare theory is based upon two ideas: 1) The individual's preferences are important. A person is better-off only if he feels so. 2) A change which makes everyone better-off increases the total welfare of society [Herfindahl and Kneese, p. 41]. Randall defines a Pareto optimum as a situation where everyone is so well-off that no one can be made better-off without at least one other person being made worse-off. Herfindahl and Kneese indicate that a Pareto optimum includes: 1) the efficient allocation of resources in the production of goods, 2) the efficient distribution of goods among consumers, and 3) the allocation of resources among activities according to consumers' preferences. These conditions will be achieved under the restrictive assumption of perfect competition. The Pareto optimum is optimal only relative to the particular distribution of income present at that time. If the distribution of income is altered, another optimum may be reached. However, if the marginal utility for money is presumed to be equal and constant for all individuals, then a single Pareto optimum solution exists.

A number of factors prevent a Pareto optimum solution from being achieved. One of the most obvious ones is market power. The assumption of perfect competition is often violated in reality.

Another constraint on achieving a Pareto optimum is the existence of external effects, or externalities. These are called spillovers by McConnell. He defines spillover cost as the production or

consumption of a commodity which inflicts some cost upon a third party without compensating for the cost. Baumol and Oates state two conditions which define an externality. These conditions are: 1) that some individual A's utility or production relationships include real variables whose values are chosen by B with no particular attention paid to how it will affect A's welfare; and 2) that B does not receive/pay in compensation for this activity an amount equal in value to the resulting (marginal) benefits/costs to others. Baumol and Oates conclude that the second condition is not necessary for an externality to exist. Using only the first condition allows more flexibility in dealing with the externality since various prices and/or taxes can be applied, depending upon the situation, in order to attain Pareto optimality. To include the second condition presumes only particular pricing and/or taxes yield efficiency and Pareto optimality.

Externalities may be pecuniary or technological in nature. Pecuniary externalities result when the prices of inputs or outputs change. They affect only monetary variables and do not affect real variables in utility or production functions [Baumol and Oates, p. 29]. Since the market system is built to deal with changing prices, pecuniary externalities are not expected to cause resources to be misallocated [Davis and Kamien, p. 65]. Technological externalities, on the other hand, do cause resources to be misallocated since they do affect the production function of goods. The result is that people would not be indifferent between the state of nature regarding outputs and utilities prior to imposition of the externality and that present after imposition of the externality. If inputs were used exactly the same

after as before a pecuniary externality is imposed, members of the economy would be indifferent between the two states. The full impact of actions are not borne by the entity creating the technological externality, resulting in overproduction if it is a negative effect [Hirshleifer, pp. 532, 533]. Underproduction results if it is a positive effect [Hirshleifer, p. 540].

There are several ways to correct for a direct externality; i.e., to adjust the incentives of the generator to align with overall social welfare. These include tax/subsidy adjustments, unitization, property rights specification [Hirshleifer, pp. 534, 535], and regulation.

Tax/subsidy adjustments are aimed at forcing the generator to take account of the external effect. For a negative externality, a tax would increase the cost of the activity which creates the externality by the amount of the external cost. The private cost plus the amount of the tax will equal the social cost of the external effect. The case of the positive effect would involve a subsidy rather than a tax. The private benefit plus the subsidy would equal the social benefit.

Unitization is another method of internalizing the external effect. The generator and all the recipients of the externality are collected within a single group. The group then determines the amount of the external effect which is socially acceptable by balancing the gains from the action creating the external effect with the costs.[3] A socially appropriate level would thus be determined.

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[3]For a more complete discussion of unitization see Hirshleifer (p. 535).

Property rights specification is another method of internalizing an external effect. One of the problems of external effects is that property rights are not clearly defined in all cases. Determination of these is a difficult problem. Do parties have the right to undertake activities regardless of the external effects produced? Or do parties have the right to an absence of external effects? Once property rights are defined the producer and recipient of the external effects have a basis for negotiation. Socially acceptable levels of external effects may be determined this way. This is known as the Coase Theorem and works best when the number of parties involved is small (i.e., transaction costs are low). Negotiation costs escalate rapidly as the number involved increases and may be greater than the benefits of the negotiation, resulting in no reduction of the external costs (if the right to produce the cost exists) or in elimination of the external costs (if the right to be free of all external costs exists) [Randall, p. 169].

Regulation is another method to abate externalities if the regulating body is given sufficient power to enforce its rules [Fletcher, pp. 275, 276]. However, regulation in practice has often been a less than satisfactory option in terms of its social efficiency characteristics [Randall, p. 174].

Given that negative external costs are imposed by landfills, society can potentially be made better-off by the internalization of the external costs. That is, a Pareto-preferred[4] solution can be

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[4]This is a situation where some could be made better off without any being made worse off, attaining a more efficient situation

achieved through the use of one of the above methods. A tax paid by the entity operating the landfill (whether a municipality or private firm) is one appropriate vehicle for internalizing the external costs of the landfill siting decision. If taxation is used to internalize the externality, use of the tax revenue to compensate affected residents is not necessary to insure that the operator's incentives for location are appropriately corrected. However, use of the revenue for compensation may increase social efficiency indirectly through its effect on protest costs and, thus, approval costs for the operator.

A property rights assignment which requires that nearby residents be bribed to allow the landfill to be placed near them is another possible method of internalization. This method would function in practice similarly to that of placing a tax upon the operator and using the revenue to compensate the affected residents. A potential difference is that under the property rights assignment, external costs as reflected by willingness to accept compensation may be higher than external costs under the tax method, as reflected by property value impacts or a willingness to pay measure. Given their similarity in practice and what seems to be the current property rights perspective regarding this issue, the following more rigorous graphical treatment will focus exclusively on the tax plus compensation method.

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but falling short of Pareto optimality [Hirshleifer, p. 523].

The Impact on Location and Social Costs of a Tax Compensation Scheme

The situation of no internalization is graphically represented in Figure 3. The operator's decision-making process minimizes the transportation (T) and approval[6] (A) costs it has. Their summation is the total cost curve for the operator. Its minimum point (D_o) represents the optimal distance for the landfill site relative to the population center from the standpoint of the operator. The external (E) and protest[7] (P) cost curves indirectly enter the firm's decision-making inasmuch as they affect the approval costs of the firm.[8] Society must consider the external and protest costs in addition to the costs the operator directly considers in choosing the socially optimal location for the landfill. The summation of society's costs is the total social cost curve. Its minimum point (D_s) indicates the optimal distance for the landfill relative to the population center from the

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[6]Approval costs are legal fees, time delay costs, and other costs the operator entails above standard procedural costs involved in gaining approval of the landfill site. These costs should be zero when protest costs are zero. However, no particular relationship is otherwise implied or presumed.

[7]Protest costs are legal fees, time costs, and other costs the nearby residents of the landfill incur in opposing the landfill.

[8]No particular relationship between external, approval and protest costs are to be implied by those curves drawn above. Relationships could be hypothesized but empirical estimation would be difficult. Empirical estimation of approval and protest costs with no compensation could conceivably be accomplished with data from a number of sites with varying levels of external costs. All are downward sloping with respect to distance but no other assumptions should be inferred from Figure 3.

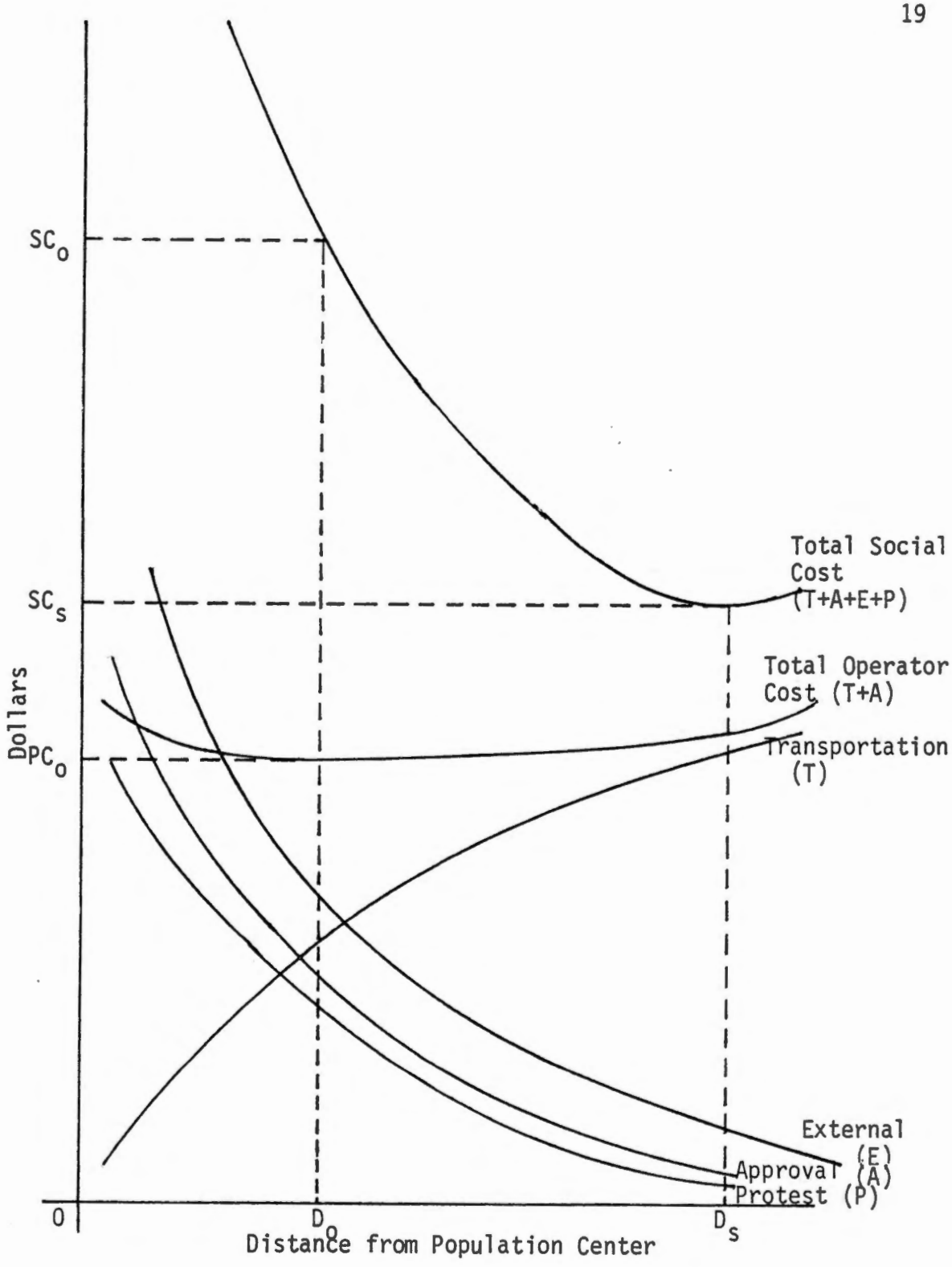


Figure 3. Costs of Siting a Landfill Without a Tax-Compensation Scheme.

standpoint of society. The divergence of the operator's optimal distance from that of society indicates inefficiency due to the external effects and protest costs not borne by the operator (SC_o) versus (PC_o). Total social costs are higher for the operator's site than for society's (SC_o versus SC_s) as higher external, approval, and protest costs outweigh the lower transportation costs.

Placing a tax upon the operator forces full internalization of the external costs. Consequently, the costs which were considered external costs (E) in Figure 3 are now actual costs faced by the operator. If the tax revenue is not used to provide compensation to nearby residents, the implications can be seen in Figure 3. Total operator cost will now include external costs (E) in addition to approval (A) and transportation costs (T). This will raise the operator's costs closer to the total social costs and shift its minimum point from D_o toward D_s, reducing the divergence between the operator's optimal site and society's optimal site. If full compensation is paid to affected residents, from the tax revenue, it is assumed that both protest costs of the affected residents and, subsequently, approval costs of the operator would be eliminated. If protest and approval costs were eliminated this would result in only having to consider the external costs (which have now been internalized by the operator) and transportation costs for the operator in making the siting decision (see Figure 4). This would result in a convergence of the operator's and society's optimal landfill sites. Total social cost would be reduced by the amount of protest and approval costs, due to the payment of compensation. This would represent a gain in social efficiency since compensation would

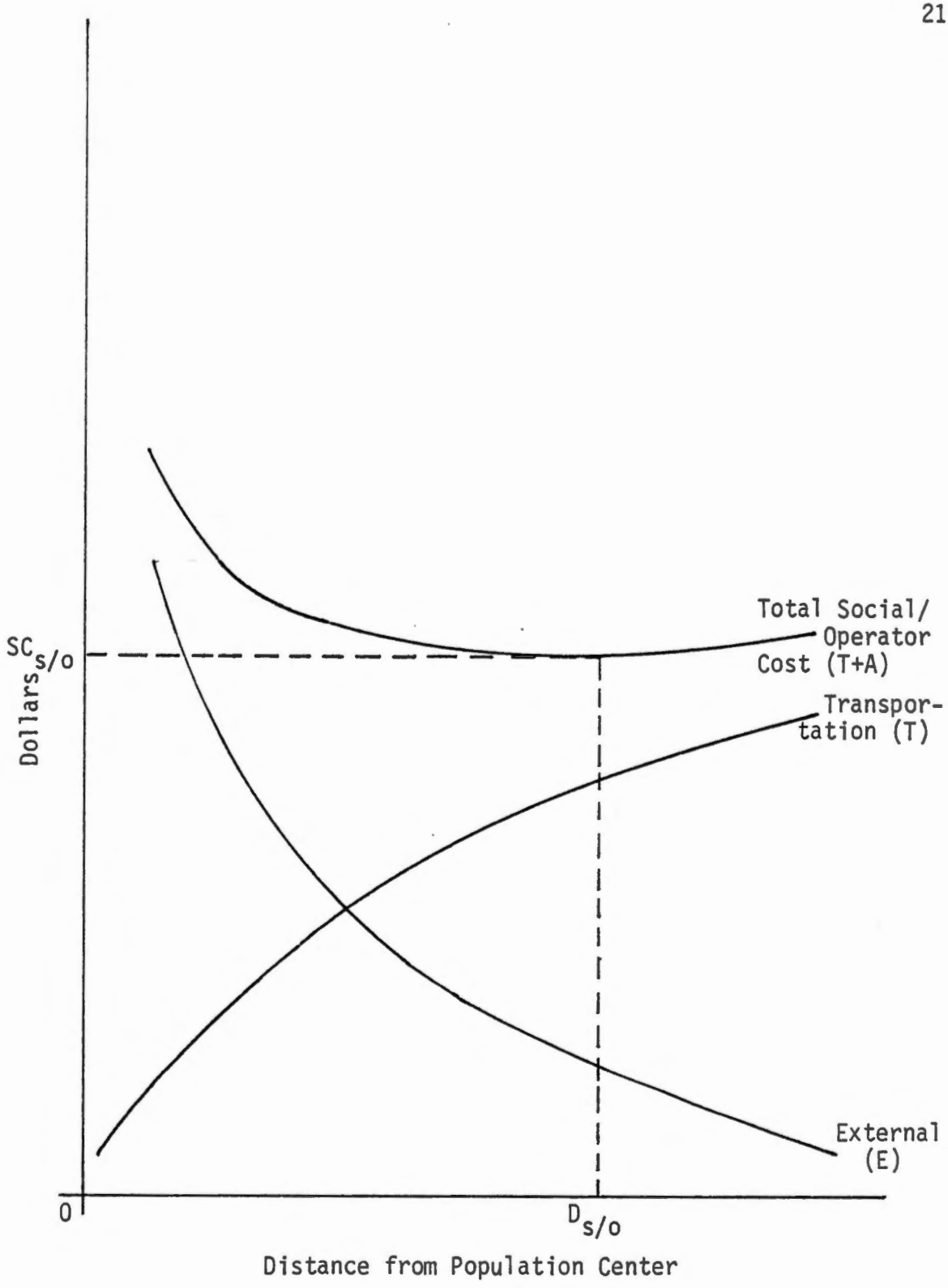


Figure 4. Costs of Siting a Landfill with a Tax-Compensation Scheme.

simply be an income transfer.[9] This tax compensation scheme, then, provides the conceptual framework to be empirically illustrated in the following chapters.

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[9]Basing compensation on anything other than each individual's voluntary willingness to accept payment suggests some protest activity may remain, given differing utility functions among individuals or simply as a matter of "principle." The point is that protest and approval costs, which are real social costs, could be reduced as a result of compensation payments, which are simply income transfers.

CHAPTER 3

EMPIRICAL ANALYSIS OF TRANSPORTATION COSTS AND EXTERNAL COSTS

The empirical estimates of both transportation and external costs as a function of distance from the population center were made in the following way. A ray was drawn from the Baxter Avenue transfer station (near the Knoxville population center) through the Fleenor Mill Road landfill site. Then points at two mile intervals were used as observations to fit the cost functions in relation to distance. Not all of the points along the ray were potential landfill sites, given geological and current land use constraints. Moreover, using a ray in a different direction from the transfer station or using potential sites that were actually considered at varying distances and directions would result in different cost functions. The latter approach of these two alternatives was seriously considered but rejected due to difficulty in locating enough sites with the type of information needed to estimate the transportation and external costs. Thus, combination of the two cost functions in the next chapter serves primarily to illustrate empirical application of the model rather than to provide any definitive conclusion regarding the socially optimal landfill site for Knoxville. The cost figures were estimated using different data sources which were from the same general time period but have been adjusted to apply to the fiscal year from July 1982 through June 1983.

Transportation Costs

The estimates of transportation costs were based upon data secured from the Department of Public Service of the City of Knoxville. The data were from the fiscal year July 1982 through June 1983 and based upon the twenty-two mile round trip from the Baxter Avenue transfer station to the landfill site on Fleenor Mill Road just inside Anderson County. Employees of the Department of Public Services collect waste materials from businesses and residences with the City. Collection trucks deposit their loads at the Baxter Avenue collection station. There it undergoes processing to ready it for loading into the trucks that will haul it to the landfill. The landfill is privately owned and operated by the company which has contracted with the City to dispose the City's solid waste. After the trucks are unloaded at the landfill they return to the transfer station for additional loads. Delays typically occur only when there are mechanical difficulties or when there is less than a truckload of solid waste at the transfer station.

The trucks hauled 3918 loads of solid waste totaling 84,824.4 tons from the Baxter Avenue transfer station to the Fleenor Mill Road landfill during the 1982-83 fiscal year. The City of Knoxville was charged a total of $241,267, or $2.84 per ton, for the disposal of solid waste at the landfill. It is assumed in this study that the amount of solid waste handled would remain constant regardless of landfill location and over the life of the landfill. It is recognized that the amount may actually increase over the life of the landfill

due to an increase in economic activity, making the transportation cost function somewhat higher relative to the estimate used.

The area serviced by the Knoxville waste disposal trucks is sufficiently large that the landfill location would seem to have no bearing upon the collection costs. For a small area, landfill location may affect the collection costs by influencing the transfer station location. However, for the City of Knoxville it appears reasonable to assume that collection costs will be completely independent of the landfill siting decision.

Transportation costs then are the costs of transporting solid waste from the transfer station to the landfill site and can be broken down into two components, vehicle expense and driver expense. Vehicle expense is the amount Fleet Management charges the Department of Public Service for leasing, maintenance (including fuel), and repairing the vehicles the Department of Public Service uses. Fleet Management is the part of the City of Knoxville which owns, maintains, and repairs the city's vehicles. The 1982-83 fiscal year vehicle expense for the trucks used to haul solid waste from the transfer station to the landfill was $159,743.26. The total mileage the trucks were driven was 84,970. Vehicle cost was thus approximately $1.88 per mile driven, and was assumed to remain constant regardless of landfill location. A reasonable hypothesis would be that true vehicle cost per mile would decrease as miles per trip or per day increased, due to the presence of fixed costs related to fuel use for warm-up or depreciation as a function of time alone. However, the Department of Public Service is charged by Fleet Management almost exclusively on a mileage basis.

The department spent $102,734.50 during the same fiscal year for drivers' salaries. Five drivers were employed from July 1982 through January 1983 and four thereafter. Thus, on average 4.58 drivers were employed over the entire year. The drivers worked 45 hours a week and were paid one and one-half their normal wage for their hours of overtime. The drivers each worked 52 weeks (with the exception of the driver who worked only seven months) and totaled 2080 hours of straight time and 260 hours of time and one-half (the fractional worker was accorded a proportional amount of straight time and time and one-half which worked out to 1206.4 and 150.8, respectively). This implies an hourly wage of $9.07 per hour including all fringe benefits.

Department of Public Service personnel indicated that the round trip from transfer station to the landfill takes approximately 58 minutes. In addition, 15 minutes were necessary to load each truck at the transfer station while 15 minutes were required to unload each truck at the landfill. The 3918 trips were made over the course of 261 working days, implying an average of 3.26 trips per driver per day. With each trip involving 58 minutes of driving and 30 minutes of loading/unloading, then, each driver spent, on average, three hours and five minutes (3.15 hours) driving and one hour and 38 minutes (1.63 hours) being loaded/unloaded each day. This leaves on average four hours and 17 minutes (4.22 hours) per day of slack time in waiting for a full load, taking breaks, etc. Clearly, actual driving cost varies with the distance the landfill is placed from the transfer station, while the loading/unloading cost is fixed. The slack time component

of driver expense was treated as a fixed cost as well, though it could be argued that slack time might vary with trip distance. Since the trip was 22 miles in length and required approximately 58 minutes to complete, about 2.64 minutes (.045 hours) were required to drive each mile. At $9.07 per hour the variable cost component of driver expense is thus $0.40 per mile.

This figure was added to the $1.88 per mile vehicle cost to yield a variable transportation cost of $2.28 per mile, which is presented graphically in Figure 5. Given 3,918 trips, this means that annual transportation costs would be increased (decreased) by $35,732 (3,918 x 4 x $2.28) for each two-mile increment further from (nearer to) the transfer station that the landfill was located. The cost curve has an intercept, implying a fixed cost of $65,950 due to the loading/unloading and slack time components of driver expense. Given the difficulty in isolating the variable cost component of both types of transportation expenses, sensitivity analysis is undertaken in Chapter 4 to reflect the possibility that the true variable transportation cost per mile is higher or lower than $2.28.

External Costs

Estimation of external costs in the form of property value impacts was based upon population and housing data secured from the State Data Center within the Center for Business and Economic Research at The University of Tennessee in Knoxville. Specifically, a Knoxville-Knox County Metropolitan Commission publication entitled 1980 Census of Population and Housing provided information on the median housing

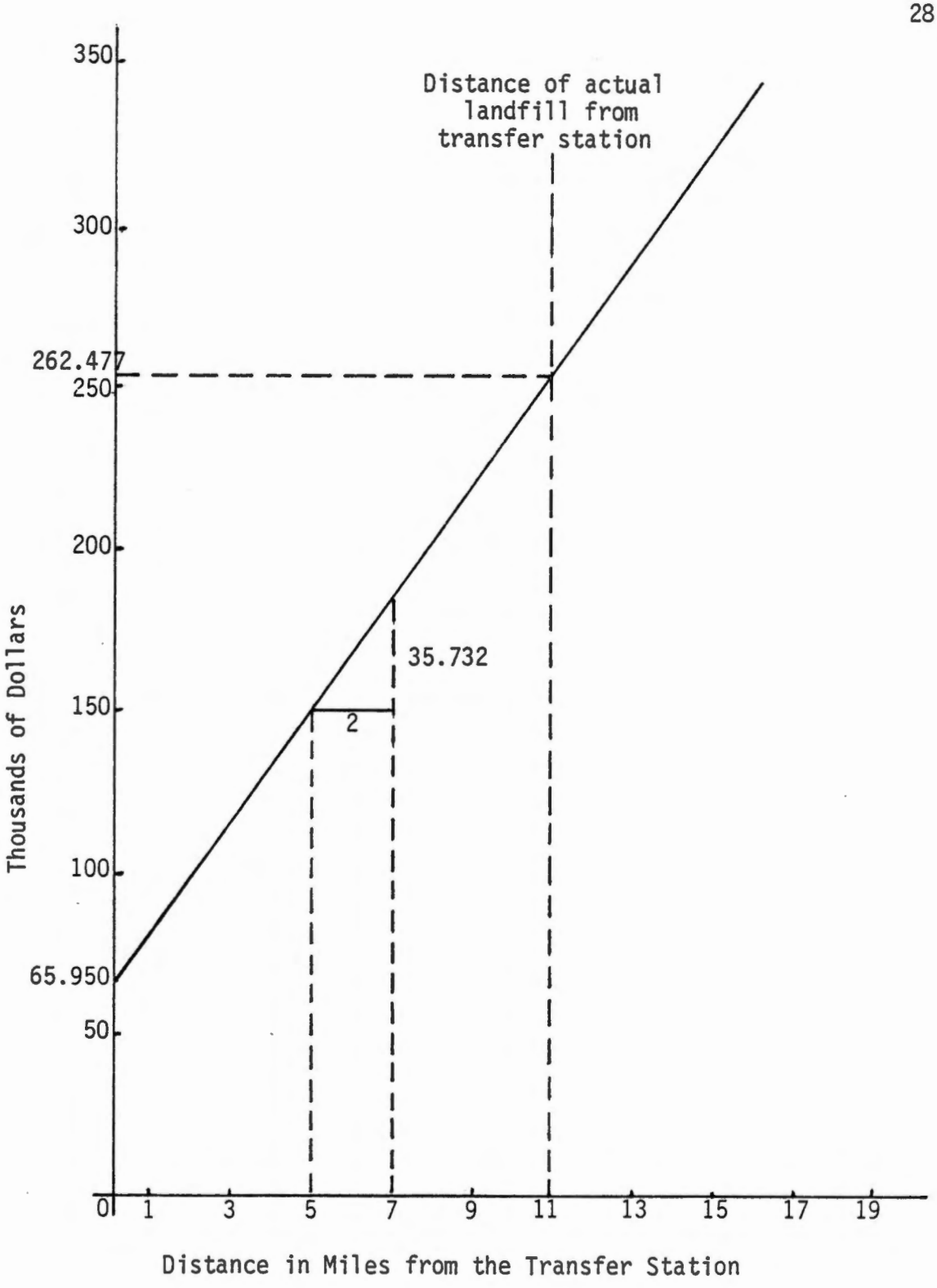


Figure 5. Transportation Cost as a Function of Distance from the Transfer Station.

value for owner occupied dwellings, median rent and area of the census tract for all Knox County census tracts. The information concerning Anderson County census tracts was taken directly from the State Data Center. This information indicated how densely scattered and valuable housing units were around the points on the ray discussed above. The general pattern found was one of declining density of housing units more than offsetting the rising housing values as one moved from the Baxter Avenue transfer station to the Fleenor Mill Road landfill and beyond.

The coefficient relating external costs, in terms of decreased property values, to proximity to a landfill was taken from Baker's Dryden landfill natural logarithm model. The study converted the distance (measured in terms of hundreds of feet) between a house and the Dryden landfill to its natural logarithm. Baker found that as the natural logarithm of distance increased, the sale price of the houses increased; for each unit increase in the natural logarithm of distance, the value gains $3,651.43.[10] The limitations of transferring Baker's distance coefficient, which was based on a study done in New York, to Tennessee are recognized. Since the housing values in Baker's study were somewhat below those in the vicinity of the Fleenor Mill Road landfill, Baker's distance coefficient was converted in the following manner from absolute dollar terms into percentage terms for use in this study.[11]

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[10]See Appendix A for Baker's model results in full.

[11]Baker's sample of nominal values was skewed to the right with the mean equal to $29,043.24, the standard deviation equal to $12,665.56

The percentage effect was assumed to be zero beyond a distance of two miles, corresponding to the maximum distance in Baker's data set, 11,000 feet. The natural logarithm for 110 is 4.7. (Baker's distances were measured in terms of hundreds of feet, thus, 11,000 feet is 110 units in Baker's model.) This was set as the zero point on the scale and for each unit change in the natural logarithm from this value, the value of the housing unit was expected to change $3,651. For example, the natural logarithm of 13.2 (1320 feet) is 2.58. The difference between 4.7 and 2.58 is 2.12 which was then multiplied times $3,651, resulting in the discounted dollar effect per house reported in Table 1 for 1320 feet, $7,741. This number was then used as the numerator in a fraction to determine the percentage effect which is also reported in Table 1. The denominator was the per house discounted dollar effect added to Baker's median nominal house price for the Dryden model. To continue with the 1320 feet example, the per house discounted dollar effect was found to be $7,741 and the median nominal house value of Baker's Dryden model was $29,043. Consequently, the fraction for 1320 feet would be $7,741/($7,741 + $29,043) which is $7,741 ÷ $36,784, or .2104, a 21.04 percent reduction in the value of a housing unit 1320 feet from the Dryden landfill. The remaining

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and a range of $62,500 to $11,000. The median would lie to the left of the mean since the distribution is skewed to the right. The medians of the 3 census tracts of Anderson and Knox counties within two miles of the Fleenor Mill Road landfill were $34,300, $36,487 and $36,800. It appears that the populations are different, but no appropriate statistical test was found to examine whether the two medians are statistically different without information on the standard deviation for each. This information is not included in the U.S. Census Bureau's publicly released information.

Table 1. Property Value Effect of Location Relative to a Landfill Site[a]

Distance in Feet (Miles)	Natural Logarithm of Distance in Hundreds of Feet	Present Value Dollar Effect Per House	Present Value Percentage Effect Per House
1320 (.25)	2.580	7741	21.04
2640 (.500)	3.273	5211	15.21
3960 (.750)	3.679	3728	11.38
5280 (1.0)	3.967	2676	8.44
6600 (1.25)	4.190	1862	6.03
7920 (1.50)	4.372	1198	3.96
9240 (1.75)	4.526	635	2.14
10560 (2.00)	4.660	146	0.55

[a]Based on Baker's Dryden landfill natural logarithm model.

values in Table 1 were similarly computed. Table 1 indicates the relationship between distance and percentage reduction in property value.

These percentage reductions were then applied to both annual rental values and owner occupied housing values (which were amortized into annual rent equivalents)[12] in order to put external costs in annual terms for comparison with transportation costs. Estimates of the external costs were made for four regions relative to potential landfill sites along the ray by drawing concentric circles at half mile intervals out to two miles and assuming the percentage reduction for the entire area was that associated with the midpoint of each concentric ring. For example, the external effect for all houses within one-half mile of a landfill site was assumed to be the percentage reduction associated with a distance of one-quarter mile.[13] The resulting external cost curve is represented in Figure 6. Together with the estimates of transportation costs, these external cost estimates are used in the following chapter to illustrate empirically the cost-minimizing distance and compensation issues discussed previously.

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[12]Owner occupied house values were amortized using 1% of the house value as an approximation of its monthly rental value if it were not occupied by its owner. The 1% was found to be a widely accepted rule of thumb up to about the time of the 1980 Census and corresponds to an expected life of 30 years and a discount rate of 11½%, for example.

[13]Based on analyses of one point on the ray, it was found that breaking the two-mile radius area down more finely resulted in estimates that differed by only 1 or 2%. This process of estimation of external costs is similar to that used by Hwang in his estimation of the external costs of sanitary landfill sites in the Chicago metropolitan area using Havlicek's estimated coefficients.

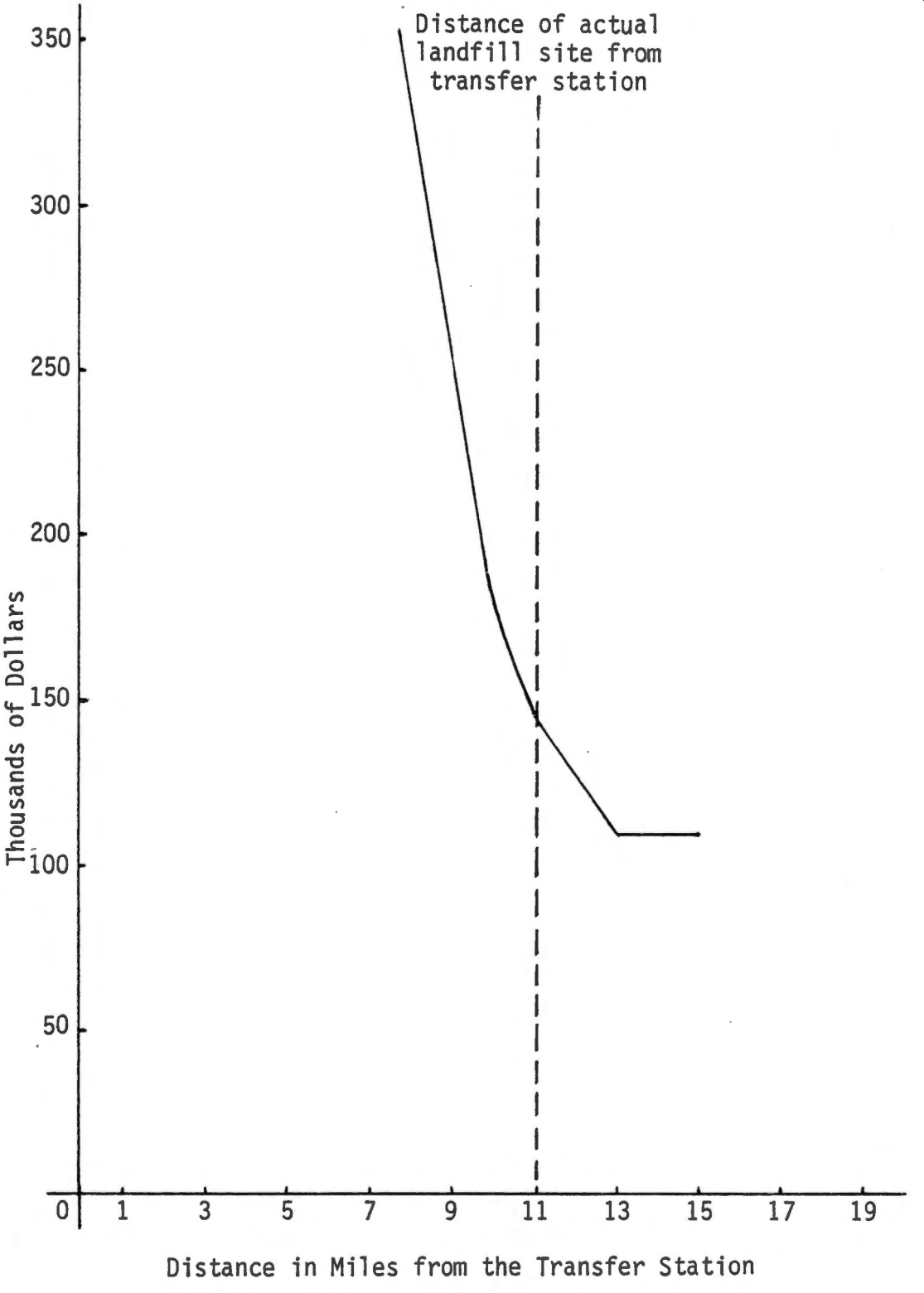


Figure 6. External Cost as a Function of Distance from the Transfer Station.

CHAPTER 4

COST-MINIMIZING LOCATION AND COMPENSATION SCHEMES

In this chapter the transportation and external cost curves which were estimated in Chapter 3 are combined to identify the distance at which the sum of these two costs is at its minimum. This cost-minimizing distance has important implications for determining the socially optimal landfill site. The solution is then tested for sensitivity with respect to the estimates of transportation and external costs. Finally, the nature and magnitude of possible compensation schemes which could lead to acceptance of the socially optimal site are discussed.

Identification of the Social Cost-Minimizing Distance

The estimated values for transportation costs, external costs and their sum, total social cost,[1] are presented in Table 2 for various distances from the Baxter Avenue transfer station along a ray through the Fleenor Mill Road landfill site. Again, it should be noted that discussion of the socially optimal distance for the Knoxville case study is primarily illustrative, for reasons discussed previously.

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[1]This is the "total" only of social costs which can be expected to vary with distance under the situation of full compensation.

Table 2. Annual Transportation, External, and Total Social Costs for Selected Sites Along the Ray Connecting the Baxter Avenue Transfer Station with the Fleenor Mill Road Landfill.

Distance from Transfer Station	Transportation Costs (1)	External Costs (2)	Total Social Costs (1 + 2)
	- - - - - - - - - - - - dollars - - - - - - - - - - - -		
3 Miles	119,549	1,956,130	2,075,680
5 Miles	155,281	930,940	1,086,221
7 Miles	191,013	542,211	733,224
9 Miles	226,745	273,492	500,237
10 Miles	244,611	181,478	426,089
11 Miles	262,477	142,352	404,829
13 Miles	298,209	110,711	408,921
15 Miles	333,942	110,711	444,653

The transportation and external cost curves are portrayed graphically in Figure 7; their summation, the total social cost curve, is shown in Figure 8. Total social cost is thus minimized at approximately eleven miles. To attempt to determine more closely the cost-minimizing distance, costs were estimated for the ten-mile point after the initial set of estimates at two-mile intervals were made.

It is quite interesting that this is the distance the actual Fleenor Mill Road landfill is located from the transfer station. If the Fleenor Mill Road site had been found to be the site at which transportation plus external costs were minimized out of all truly potential sites in the area (based on a more comprehensive study), the following conclusions could have been drawn. Given that no tax was charged or compensation made, decision-makers, in locating the landfill, must have believed they faced an approval cost function similar to the external cost function, at least in a distance range around 11 miles. However, without compensation, the presence of significant protest and approval costs suggest that the social cost-minimizing distance would have been greater than 11 miles.

Sensitivity Analysis

While the estimates of transportation and external costs have been made conscientiously, it is recognized that innacuracies may exist in the data and procedures. To give some indication of the sensitivity of the findings reported above, cost-minimizing distance is estimated under varying assumptions regarding both transportation and external costs to give some idea of the confidence which may be placed in conclusions drawn from the estimates in Table 2.

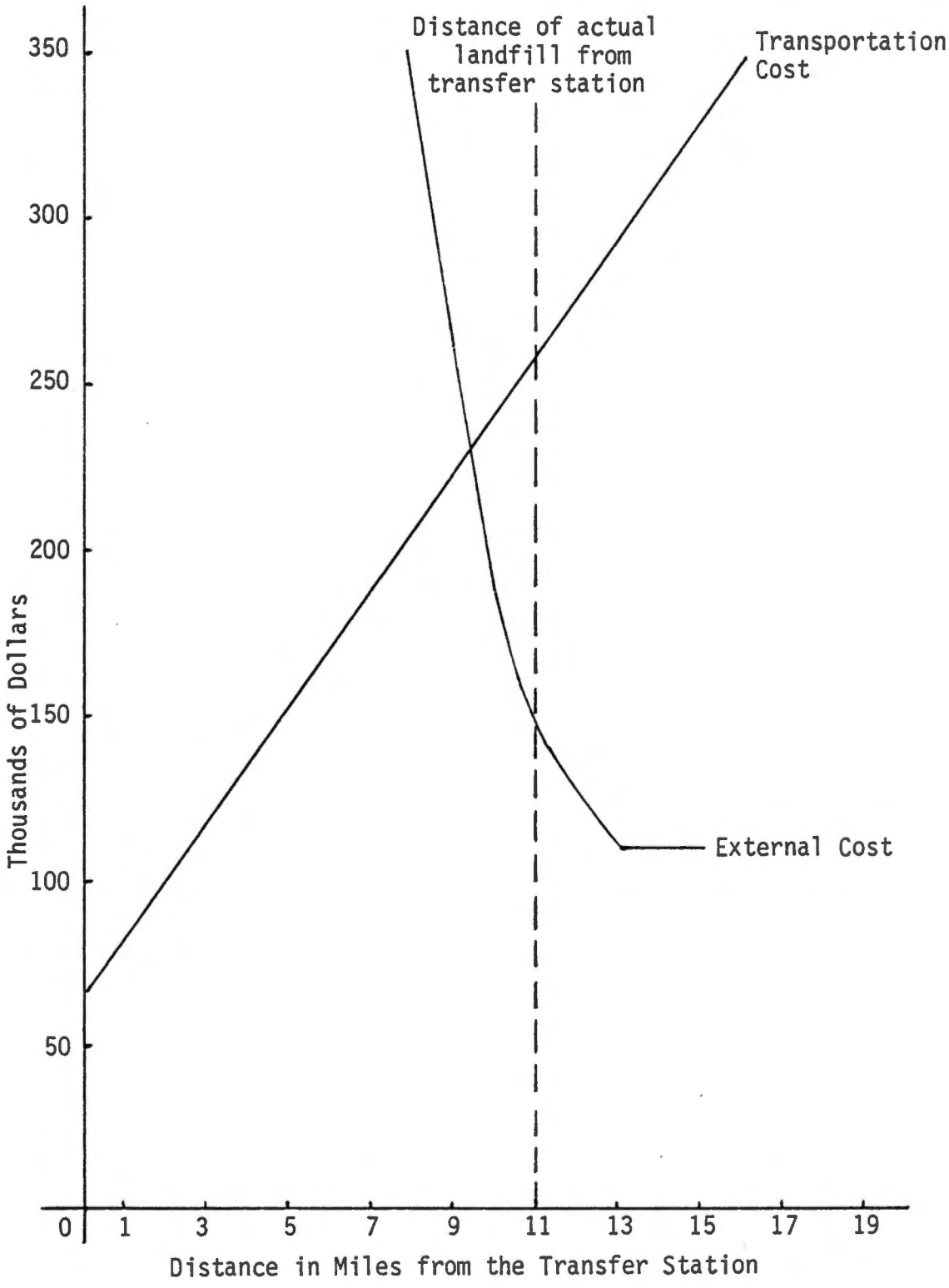


Figure 7. Transportation and External Costs at Selected Distances from the Transfer Station.

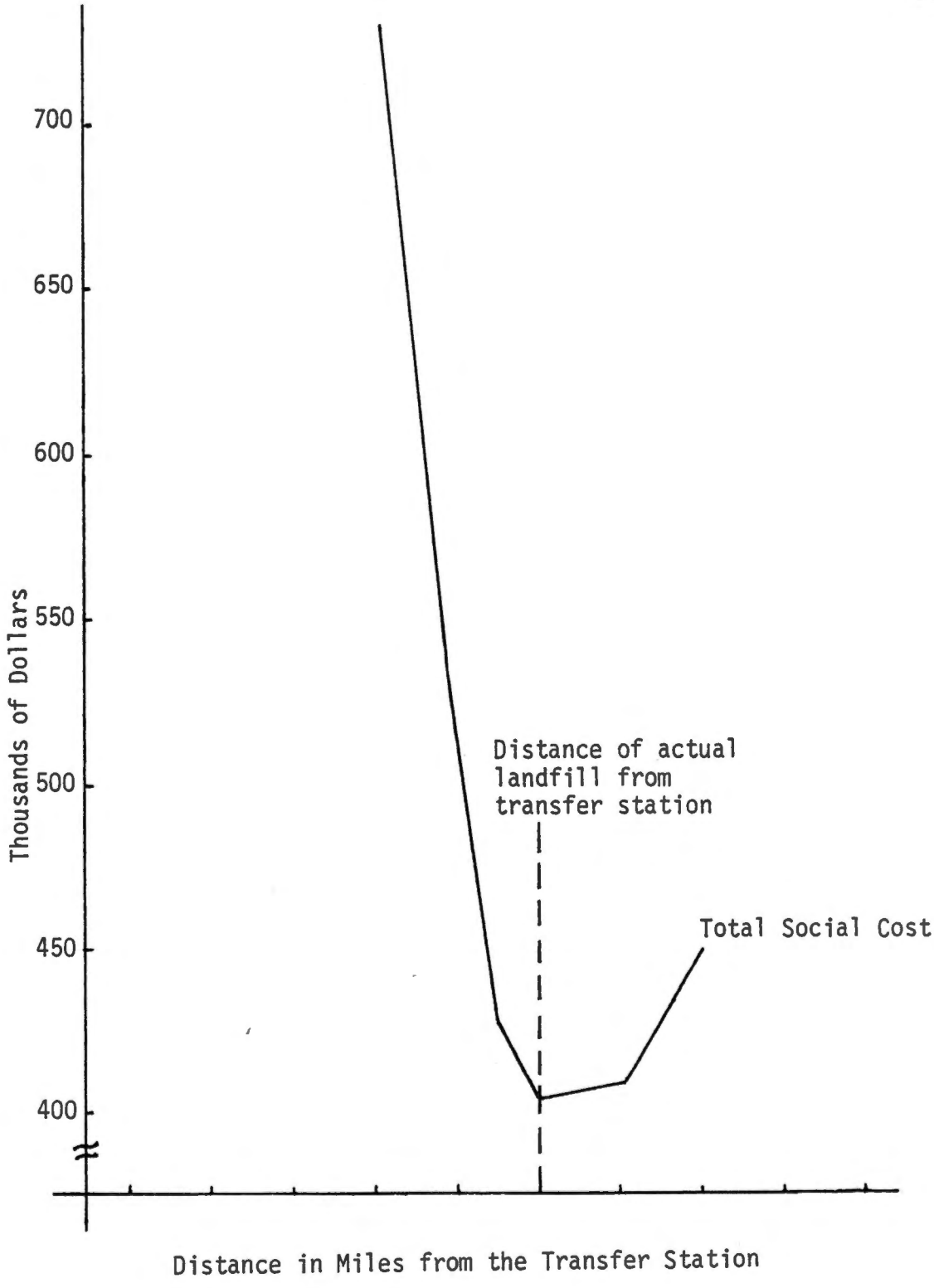


Figure 8. Total Social Cost as a Function of Distance from the Transfer Station.

The amount by which transportation costs were expected to change per mile by which the landfill site varied from its actual site was estimated to be $2.28 per mile. However, given the uncertainty regarding how to handle the slack time in labor costs and the variable cost component of the vehicle costs, the $2.28 estimate must be considered to have a sizable standard error. If the slack time component of driver expense had been assumed to be variable, that is, to increase proportionally with driving time, this would have increased cost per mile by $0.57 or 25% over the estimate of $2.28 per mile. This 25% variation was used on the lower side as well, somewhat arbitrarily, to reflect the possibility that vehicle expense was actually $0.57 less than $1.88 per mile. Total transportation costs and total social costs based on all three variable transportation cost figures ($1.71, $2.28, and $2.85) are presented in Table 3. Thus, if transportation costs were actually $1.71 per mile the social cost-minimizing distance would be shifted to 13 miles. If the true transportation cost was $2.85 per mile, there would be no change.

In testing for sensitivity to external cost estimates the same 25% variance was used, again, somewhat arbitrarily. In terms of Baker's distance coefficient, $3651 (per natural logarithm of distance in hundreds of feet), this meant a variance of $913, approximately one-half the $2030 standard error associated with Baker's estimate. The effect of using these alternative figures ($2,738 and $4,564) for the distance coefficient upon the dollar and percentage reductions presented in Table 1 (page 31) is indicated in Table 4. These alternative percentage reductions were then applied to the census tract information

Table 3. Effect of Alternative Transportation Cost Figures on Social Cost-Minimizing Distance.

Distance in Miles	Transportation Cost @ $2.28 (1)	Transportation Cost @ $1.71 (3)	Transportation Cost @ $2.85 (2)	External Cost (4)	Total Social Cost with Transportation Cost @ $2.28 (1 + 4)	Total Social Cost with Transportation Cost @ $1.71 (3 + 4)	Total Social Cost with Transportation Cost @ $2.85 (2 + 4)
	dollars						
3 Miles	119,549	155,281	83,816	1,956,130	2,075,680	2,111,412	2,039,947
5 Miles	155,281	182,080	128,482	930,940	1,086,221	1,113,020	1,059,422
7 Miles	191,013	208,879	173,147	542,211	733,224	751,090	715,358
9 Miles	226,745	235,678	217,812	273,492	500,237	509,170	490,637
10 Miles	244,611	249,078	240,145	181,478	426,089	430,556	421,623
11 Miles	262,477	262,477	262,477	142,352	404,829	404,829	404,829
13 Miles	298,209	289,276	307,142	110,711	408,921	399,988	417,854
15 Miles	333,942	316,076	351,808	110,711	444,653	426,787	462,519

Table 4. Effect of Alternative Distance Coefficients on Property Value Impacts of Location Relative to a Landfill.

Distance Coefficient			----- @ $3651 -----		----- @ $2738 -----		----- @ $4564 -----	
Distance in feet	Distance in miles	Natural Logarithm Distance in hundreds of feet	Present Value Dollar Effect Per House	Present Value Percentage Effect Per House	Present Value Dollar Effect Per House	Present Value Percentage Effect Per House	Present Value Dollar Effect Per House	Present Value Percentage Effect Per House
1320	(.25)	2.58	7741	21.04	5805	16.66	9676	24.99
2640	(.5)	3.273	5211	15.21	3907	11.86	6513	18.32
3960	(.75)	3.679	3728	11.38	2796	8.78	4660	13.83
5280	(1.0)	3.967	2676	8.44	2007	6.46	3345	10.33
6600	(1.25)	4.19	1862	6.03	1396	4.59	2327	7.42
7920	(1.5)	4.372	1198	3.96	898	3.00	1497	4.90
9240	(1.75)	4.526	635	2.14	476	1.61	794	2.66
10560	(2.0)	4.66	146	0.55	109	0.38	182	0.62

to develop new estimates of the total external costs associated with the various sites. The results of this sensitivity analysis are presented in Table 5. If external costs were actually 25% higher, the social cost-minimizing distance would be shifted to 13 miles, but no change would result if external costs were actually 25% lower.

The effects of both costs differing by 25% in opposite directions are presented in Table 6.[3] This indicates that with external costs 25% higher and transportation costs 25% lower, the social cost-minimizing distance is again shifted to 13 miles. As a whole then, the social cost-minimizing distance is not very sensitive to variations in costs of the magnitude considered. This is primarily due to the shape of the external cost curve which is a function of the particular pattern of population density and property values along the ray between the transfer station and landfill. The implications of using the "ray" approach for estimating costs are discussed in the final chapter.

Compensation Schemes

Compensation payments have been part of the landfill siting process for at least the past 15 years. In the final report of a study conducted by Sheaffer, Tolley et al., for the Center for Urban Studies of the University of Chicago from March 31, 1969, through April 30, 1971, the authors indicated that "remuneration and/or other benefits have been promised" but in many cases, "they have not met with any great success so far" (p. 11). The authors found that 8 of 20 cases

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[3] If both costs varied by 25% in the same direction, no change would occur.

Table 5. Effect of Alternative External Cost Figures on Social Cost-Minimizing Distance.

Distance	Transportation Cost @ $2.28 (1)	External Cost @ $3,651 (2)	External Cost @ $2,738 (3)	External Cost @ $4,564 (4)	Total Social Cost with External Cost @ $3,651 (1 + 2)	Total Social Cost with External Cost @ $2,738 (1 + 3)	Total Social Cost with External Cost @ $4,564 (1 + 4)
3 Miles	119,549	1,956,130	1,507,692	2,380,333	2,075,680	1,627,236	2,499,877
5 Miles	155,281	930,940	714,567	1,137,063	1,086,221	869,849	1,292,344
7 Miles	191,013	542,211	417,154	660,907	733,224	608,167	851,921
9 Miles	226,745	273,492	210,225	333,609	500,237	436,971	560,354
10 Miles	244,611	181,478	139,757	221,007	426,089	384,369	465,619
11 Miles	262,477	142,352	109,557	173,453	404,829	372,035	435,931
13 Miles	298,209	110,711	85,225	134,874	408,921	383,435	433,084
15 Miles	333,942	110,711	85,225	134,874	444,653	419,167	468,816

Table 6. Effect of Alternative Transportation and External Cost Figures on Social Cost-Minimizing Distance.

Distance	Transportation Cost Lower @ $1.71 (1)	Transportation Cost Higher @ $2.85 (2)	External Cost Lower @ $2,738 (3)	External Cost Higher @ $4,564 (4)	Total Social Cost[a] (1 + 4)	Total Social Cost[b] (2 + 3)	Total Social Cost with Original Estimates (5)
3 Miles	155,281	83,816	1,507,692	2,380,333	2,535,614	1,591,509	2,075,680
5 Miles	182,080	128,482	714,567	1,137,063	1,319,143	843,049	1,086,221
7 Miles	208,879	173,147	417,154	660,907	869,787	590,301	733,224
9 Miles	235,678	217,812	210,225	333,609	569,287	428,038	500,237
10 Miles	249,078	240,145	139,757	221,007	470,085	379,902	426,089
11 Miles	262,477	262,477	109,557	173,453	435,931	372,035	404,829
13 Miles	289,276	307,142	85,225	134,874	424,151	392,368	408,921
15 Miles	316,076	351,808	85,225	134,874	450,950	437,033	444,653

[a]With Transportation Cost Lower and External Cost Higher.

[b]With Transportation Cost Higher and External Cost Lower.

studied involved offers of remuneration which were "impressively arbitrary" (p. 14). They suggested that the success of compensation as a strategy to reduce the amount of protest associated with potential landfill sites involved three points. The first is the environmental goals of the community in which the landfill is to be sited before the siting process begins. The second is the amount of risk the landfill site presents to these goals. The third is whether the remuneration and/or other benefits can balance the risks to the initial environmental goals. If money is paid to the community or other benefits are offered which will be used in such a way that the entire community benefits equally, the residents nearer the landfill are shortchanged because they bear more of the risk from the landfill.[4]

This study illustrates a method for estimating the amount of compensation appropriate to any particular landfill site, eliminating some of the arbitrariness noted by Sheaffer et al. Full compensation for the external cost associated with the Fleenor Mill Road landfill at the cost-minimizing distance of 11 miles from the Baxter Avenue transfer station, would have been $142,352.

Considering the results of the sensitivity analysis, this represents an upper bound. In all cases, whether the social cost-minimizing distance was shifted to 13 miles or not, external costs were less than or equal to $142,352. The lower bound on full compensation would have

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[4]This may have been the case for the Fleenor Mill Road landfill site to some extent. Anderson County was offered a reduced rate for disposal of solid waste at the landfill in return for an end to the protests. The offer was rejected, however, perhaps because the residents living near the proposed site felt their costs would still have outweighed their benefits.

been $110,711 where transportation costs were 25% lower, as indicated in Table 3 (p. 40). Annual payments per household and numbers of households involved if full compensation had been made for the Fleenor Mill Road landfill are reported in Table 7.

Table 7. Estimated Annual Full Compensation Payments for the Fleenor Mill Road Landfill Site.

Range of Distance in Feet (Miles)	Number of Households	Average Annual Payment Per Household in Dollars
0-2640 (0.5)	33	878
2641-5280 (.5-1)	85	574
5281-7920 (1-1.5)	144	299
7921-10560 (1.5-2)	203	106

Methods of payment of the compensation to the affected residents could conceivably include:

a) Direct payment to affected residents

b) Reduced rates for solid waste services for affected residents

c) Reduced property taxes for affected residents

d) Development of the retired landfill site into a facility whose value to the affected residents would equal or exceed their external costs.

These alternative methods may differ, of course, in terms of legality, acceptability by the general public, impact upon protest efforts and

approval costs, administrative cost and other factors, analysis of which would involve another study in itself.

It is of interest to note the magnitude of added tax burden or added costs for solid waste disposal which would be required for city residents in order to generate the revenue needed for full compensation of affected residents. There were 175,045 people living in Knoxville based on the 1980 Census. The cost of the maximum compensation needed, $142,352, is thus $0.81 per capita per year. According to the 1980 Census figures there were 2.39 persons per household in the City of Knoxville, meaning a cost of $1.95 per household per year. City residents pay for their solid waste pickup through their property taxes. However, Knox County residents are charged $7.20 per month for solid waste pickup and disposal, a figure which can be used as representative of the actual cost to city residents. The $1.95 annual cost represents then a $.16 or 2.22 percent increase relative to this $7.20 monthly fee.

CHAPTER 5

CONCLUSIONS

Summary

Landfilling is one of three alternatives presently available for disposing of solid waste, along with recycling and incineration. Landfilling appears to be the most cost efficient alternative for the foreseeable future, except perhaps for large metropolitan areas where economies of size may make one or both of the other alternatives economically feasible. Landfills do have a limited life, so the problem of siting a landfill periodically recurs. It has been estimated that 72% of the county landfills in operation in 1979 in Tennessee will require relocation within 10 years of that time. A well-managed sanitary landfill is considered by some to be a nuisance-free method of waste disposal; however, acceptance of a site is often difficult due to adverse public reaction. Real or at least perceived external effects associated with landfills have been shown to depress nearby property values. These external effects can be estimated and explicitly included in the decision-making process. Conflicts over siting decisions may be more readily resolved through determination of the social cost-minimizing site and the use of a tax-compensation method of internalizing these external costs.

The objectives of this study were to estimate the costs associated with landfilling which vary with distance from a population

center and derive implications from these estimates for siting and compensation strategies. Acquisition, development and operation costs were assumed to be unrelated to distance. The external costs of the landfill site may reasonably be expected to be negatively related to the distance the site is from the population center, inasmuch as the density of the population and, in some cases, property values diminish as one moves from the population center. Certain costs may be associated with these external costs, in particular protest costs incurred by nearby residents opposing the landfill site (e.g., legal fees and opportunity cost of time) and approval costs incurred by the operator (e.g., legal fees and time delays). These costs would be expected to diminish, too, as distance from the population center is increased. Conversely, transportation costs of hauling solid waste from the transfer station to the landfill would certainly be positively related to the distance from the population center. Therefore, at some distance from the population center, the sum of these social costs will be minimized.

However, the operator's incentives may encourage him to locate the landfill too close to the population center, if he ignores external costs to some extent, or too far from the population center in an attempt to reduce protests and thus his approval costs. Internalization of the external costs through a tax upon the operator and use of this revenue to provide compensation to affected residents could be expected to correct the operator's location incentives and reduce protest and approval costs, thus reducing total social costs of landfilling in two ways.

Empirically, then, this study sought to illustrate identification of the minimizing distance and use of a tax-compensation scheme for a case study area. Estimates of transportation and external costs were developed using data for the Knoxville, Tennessee, metropolitan area to demonstrate how the model would operate in an actual case. Based on actual cost information for transportation to the existing landfill site, variable transportation costs was estimated to be $2.28 per mile traveled. The estimate of external cost was based on percentage reductions in property values which varied, depending upon the distance from the landfill site, from 21% at a quarter of a mile to less than 1% at two miles. These were developed from the distance coefficient of Baker's Dryden landfill natural logarithm model. These percentage reductions in property values were applied to Knox and Anderson Counties 1980 Census information on rents and house values. Sites along a ray drawn from the Baxter Avenue transfer station to the Fleenor Mill Road landfill were examined at two-mile intervals from 3 through 15 miles. The distance at which the sum of transportation and external costs was minimized was found to be approximately 11 miles, which happens to be the distance the Fleenor Mill Road landfill is located from the Baxter Avenue transfer station.

Given the level of uncertainty with regard to the estimates of external and variable transportation costs, both were varied 25% higher and lower separately and then together in opposite directions, to indicate how sensitive the cost-minimizing distance was to such cost variations. The result indicated little sensitivity to changes in the figures used, as in three cases the cost-minimizing distance remained

at 11 miles, and in three cases the cost-minimizing distance was shifted out to 13 miles. This result was encouraging in view of the limitations of the data and methods of analysis used. This lack of sensitivity was a function primarily of the shape of the external cost curve and thus the pattern of population density overcoming the pattern of property values.

The highest level of annual external costs under any of the seven cases (the basic estimates and the six estimates developed in the sensitivity analysis) examined was $142,352. The lowest level of external costs was $110,711. These figures represent a range of taxes/compensation which may be considered appropriate given the conceptual arguments developed earlier. Equity considerations also may be used to argue for compensation to existing property owners. Annual compensation of $142,352 can be put in perspective by converting it to the $1.95 that would be required annually per household in the City of Knoxville to cover the higher real costs of solid waste disposal through an increase in the property tax or some other means. Given the $7.20 per month charge for solid waste disposal services in Knox County, this $.16 per month increase would represent a 2.2% increase in the cost of solid waste disposal.

Conclusions

The primary conclusion to be drawn from this study is that the economic model developed in Chapter 2 and empirically illustrated for a case study area appears to provide a useful perspective from which to analyze the problem of sanitary landfill siting. The empirical

findings support the hypothesis that a trade-off exists between external and transportation costs with regard to the distance at which a landfill is located from a population center. This trade-off must be explicitly addressed in the interest of social efficiency in landfill siting policy, both in choosing the best site and in consideration of compensation strategies to limit protest and approval costs.

Secondarily, it is not surprising that the Fleenor Mill Road landfill site was marked by such a bitter protest on the part of nearby residents, in view of the estimate of $142,352 in annual external costs associated with the site. However, it is readily admitted that only a limited degree of confidence can be placed in this external cost estimate for basically two reasons. The first is uncertainty associated with Baker's distance coefficient of $3651, given the standard error for this coefficient of $2030. Second, even if the true distance coefficient for Dryden, New York, were $3651, there remains the problem of transferring this coefficient to the Knoxville, Tennessee area.

One further policy implication may be noted. Given the magnitude of this external cost estimate, recycling may be competitive with landfilling in terms of social cost, suggesting a potential justification for public subsidization of recycling in solid waste disposal. This would be an alternative to taxing of landfill operators in the interest of increasing social efficiency.

The limitations on the study imposed by use of the "ray" method for estimating costs requires some discussion. Not all of the points along this ray for which costs were computed were necessarily potential sites based on geological feasibility and current land use. The

external cost curve had a shape which was peculiar to that particular ray. Use of ray in some other direction from the transfer station would have resulted in an external cost curve shaped somewhat differently. Thus, in regard to the Fleenor Mill Road landfill, nothing can really be said about whether it is the site in the Knoxville area for which the sum of transportation and external costs are minimized. Given a different pattern of residential development in other directions, there may well have been a closer site with lower external costs. Consideration was given in this study to using the limited number of sites which were considered as alternatives to Fleenor Mill Road as the basis for estimation of the cost curves, a direction which certainly could be pursued in the interest of making an "ex post" evaluation of a siting choice. Similarly, this model can be applied to landfill siting in an "a priori" framework, providing estimates of external and transportation costs for a set of sites determined to be feasible given geological constraints and current land use. In doing this, care would need to be given to measuring the distance trucks would actually have to travel from the transfer station to a particular landfill site, since travel distance and time may not be in the same proportion to map distance for different directions from a transfer station.

Additional research is needed in a number of areas relating to this study. One area would be estimates of external costs of sanitary landfills. Using a linear model covering the 1962-1970 period, Havlicek et al., estimated an external cost of $.61 per foot of distance from a landfill. Some adjustment for time would be needed to compare this estimate with Baker's estimate for the latter 1970's. Baker,

using a logarithmic model, estimated an effect of $.96 per foot for the one-half mile to one-mile range and smaller effects for ranges further away. While certain obvious differences in the studies (natural logarithm v. linear models; Dryden, New York, v. Fort Wayne, Indiana) probably played roles in the estimated differing, the estimated coefficients seem different enough to suggest that additional studies to estimate external costs are needed. The uncertainty associated with transportation costs that was mentioned regarding the driver expense component and accounting for the apparent slack time suggests that additional work in the area of transportation costs might prove valuable. In fact, distinguishing between fixed and variable costs for both vehicle and driver expense portion could well be pursued. There also is a need for work to analyze the legality, social acceptability and administrative costs of alternative compensation schemes. Some may be possible only in a limited number of areas, while others may be widely available for use. Finally, there is also a need for analysis of relationships among protest, approval and external costs and the impact of compensation on protest and approval costs.

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APPENDIX

BAKER'S DRYDEN NATURAL LOGARITHM

MODEL'S RESULTS[a]

Dryden: Log Model Results

Variables	Estimated Coefficients	Standard Error	T-Statistics
Intercept	-8155.80	10308.00	-0.79
Water	497.55	1470.91	0.34
Acres	-1.79	2.29	-0.78
SFLA	9.28	4.98	1.86
Age	-102.59	37.06	-2.77
Stories	196.85	428.97	0.46
Rooms	-1104.22	1131.08	-0.98
Baths	512.90	200.75	2.55
Distance*	3651.43	2029.54	1.80

$R^2 = 0.55$ $\overline{R}^2 = 0.42$ $F(8.28) = 4.21$
Condition of the X Matrix = 36.41
* Logarithm of Distance.

[a]Page 36 of Baker's study entitled, Land Values Surrounding Waste Disposal Facilities.

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