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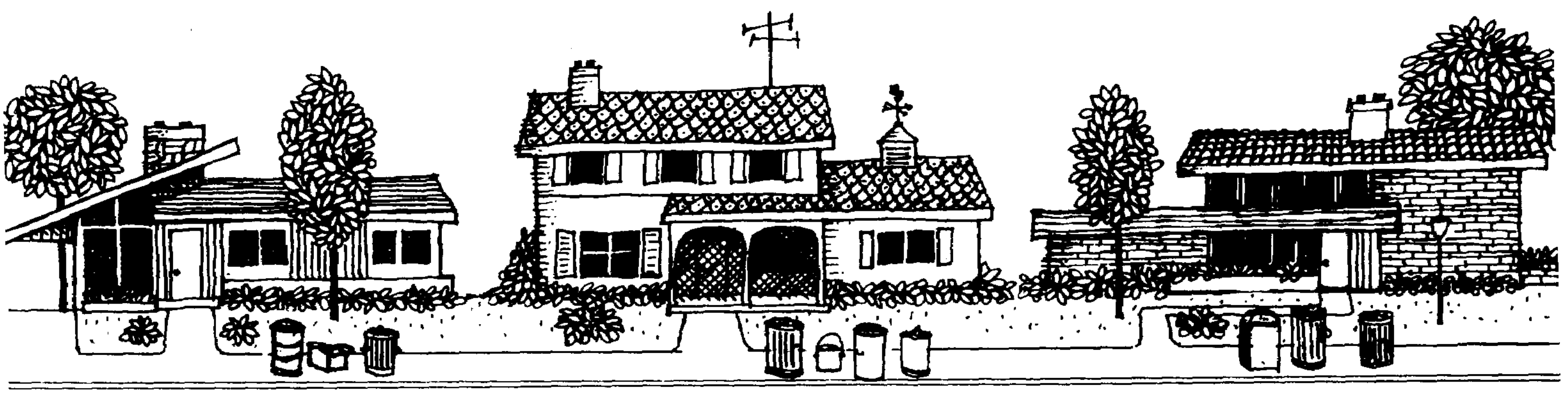
Solid and Hazardous Waste

EPA

Economics of Municipal Solid Waste Management

The Chicago Case



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ECONOMICS OF MUNICIPAL SOLID WASTE MANAGEMENT:

THE CHICAGO CASE

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report provides an extensive discussion of the theory of demand for household solid waste collection and disposal services, and concepts for measurement of the quantity and level of services demanded. An investigation of relationships between several socio-economic characteristics and quantity of household solid waste, conducted in an earlier study for the Chicago area, is repeated to determine to what extent the earlier hypotheses are supported by use of more current data. It is hoped that the results of this study will provide policymakers and solid waste managers with additional information on the structure of demand and implications for managing the increasing quantities of household solid waste.

Francis T. Mayo, Director
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ABSTRACT

This study is a result of a request by the U.S. Environmental Protection Agency (EPA) to undertake and extend certain economic studies related to municipal solid waste collection/disposal services. The EPA requested that four tasks be undertaken: 1) an extension of the theory of demand with particular attention to methods of financing, factors affecting demand shifts, and price elasticity, 2) a review and critique of prior studies of demand for residential solid waste collection/disposal service, with particular emphasis on empirical results related to price and income elasticities, 3) statistical regression analysis to update the analysis in the 1971 Sheaffer and Tolley study on solid wastes collection in Chicago, and to compare results with related studies, including but not limited to a number of studies specified, and 4) the identification of areas of needed research on the economics of solid and hazardous waste management and the recommendation of procedures and methodology. Each task comprises a separate section.

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ACKNOWLEDGMENT

Various officials of the City of Chicago cooperated in providing the necessary information for this study. Mr. Oscar W. Albrecht of the Solid & Hazardous Waste Research Division, Municipal Environmental Research Laboratory, Cincinnati, Ohio served as the EPA's project officer, and he and Dr. Haynes C. Goddard, Associate Professor of Economics, University of Cincinnati, provided valuable comments on a draft of this study. Dr. Yi Wang assisted in data collection and analysis of previous work and provided valuable comments.

SECTION I

EXTENSION OF THE THEORY OF DEMAND FOR MUNICIPAL SOLID WASTE COLLECTION/DISPOSAL SERVICES

INTRODUCTION

General

As pointed out in the 1971 Sheaffer-Tolley solid wastes study, one way of projecting future demand for waste collection and disposal services would be to simply extrapolate past trends. However, one might be caught by surprise in so doing, as new trends may become predominant that were not apparent in global figures, but would have been detected upon more careful analysis and systematic analysis of the data. The trend approach would leave unutilized the more specific information that is in fact available. In introducing the subject of applying economic analysis, the Sheaffer-Tolley study emphasized that the elements that enter into the economic analysis of the quantity of services demanded over time are becoming important topics to economic theory, even without the obvious need for projecting the future volume of household wastes. These elements include 1) costs (which, with external environmental costs included, are increasing at a rapid rate) and 2) the demand functions for waste services. They are important because they bear on effective and efficient ways of achieving private and social objectives related to collection and disposal of solid wastes.

The Sheaffer-Tolley report extended the conceptual basis of the demand for residential and municipal solid waste collection/disposal services further than it had been carried previously, and further extensions have since appeared in the literature. There have been some notable extensions since the Sheaffer-Tolley report. (These extensions, as well as empirical findings contained in the literature, will be discussed in Section II of this study, A Review and Critique of Prior Studies of Demand for Residential Solid Waste Collection Disposal Service. In addition, at various points in this first section, significant contributions by others in extending the theory will be cited and referenced.) Nevertheless, there is room for still further extension. The EPA request for further work suggests some of the areas in which extensions are needed. A major area is on the specific effects of price. The empirical part of the Sheaffer-Tolley study, because of lack of data, was void of price considerations, as is this study for the same reason. Review of the literature reveals that little has been done in this area. Another area is that of analysis at the disaggregated level for particular kinds of service such as more or less frequent service or different service for different types of solid wastes. Still another area in which the need for extension is emphasized is the effect of financing methods on the quantity of services demanded. Little has been done on this, again largely because of the lack of specific data needed to conduct the analysis.

The Role of Public and Private Economic Utilities in the Extension of the Theory of Demand

Demand for residential solid waste collection and disposal services is based on the consumer utility that a household derives from these services. The services are thus inputs to consumer production functions producing such utilities. In the Sheaffer-Tolley report, Tolley, who was the author of the economics sections of the report, begins with the consumption decision, adding to it the related waste decision in producing consumer utilities. In this framework, wastes are an output of the general utility production process. Economists have for long treated this output as having a zero price, but in fact, at least in a social sense, this output has a negative price, i.e., there is a demand for, and it costs something for, getting rid of the wastes.

Overall utility is maximized not only by taking action to get rid of the wastes, based on utility derived from that action per se, but also by undertaking consumption actions that produce the wastes, based on the utilities derived from consumption. Since the consumption decisions necessarily involve some waste production, the cost of waste disposal bears on the consumption decisions and the overall maximization of consumer utilities.

The utility derived from waste collection and disposal is based on the desire to get wastes out of the way and to provide a clean, orderly, healthy, and safe environment. The interest applies not only to wastes generated in one's own household, but to those generated at the residences of others, in the streets, public areas, and in the off-the-beaten-track areas of the community. Leaving a picnic area littered or depositing wastes in open dumps, in abandoned quarries or in a marshy area behind the woods are no longer acceptable disposal methods. Cleaner methods produce greater utilities.

It is this public interest in a pollution-free environment that justifies public intervention in the solid waste area. The individual is willing to pay not only for collection of his own household wastes, but also, through a public agency, some amount to induce or require others to have wastes collected and disposed of in a non-polluting way. Indeed, he himself may require some inducement to act in the way he desires others to act, because, if he does not so act, the main adverse effect of his action alone is on others, not himself. In other words, self interest alone may not produce optimum waste collection and disposal. Incentives, educational programs, enforcement programs with penalties, and the like may be required.

There is, of course, a fundamental interest on every individual's part in obtaining and inducing others to obtain waste collection and disposal services to maximize his utilities derived from them. Maximizing individual utilities in this way will produce the socially optimum waste services. This involves finding the least cost way of obtaining utilities and "buying", either directly (for service to one's own residence) or indirectly through a public agency, an incremental utility when and only when it costs no more than it is worth, taking into account in the solution all benefits and costs including the environmental.

The solution would be relatively simple if the interest were in fact solely in the collection and disposal of one's own wastes, or if others in the community, through no special inducement, always acted in a non-polluting non-littering way. In such a situation, while there would still be an interest in a clean community, there would be no need for concern, nor need to provide inducements to (or impose penalties on) others to achieve it.

In fact, in some communities, something very close to this situation may apply. With increasing awareness of the advantages of a clean environment, this may include an increasing number of communities. In such communities, sanitary land-fill operations are required by law. Even if incremental user charges are imposed for collection and disposal services, and these are based on the higher costs of non-polluting collection and disposal operations, households do not avoid these costs by disposing in alternative ways that litter or pollute. This may be basically because of altruistic public interest, but partially because there are real as well as psychological costs attached to the alternatives. Litter baskets are provided and are used in public places, with costs financed by taxes or through fees for use of public parks, and refuse containers are kept in cars and the contents disposed of at home. Finally, with incremental user charges for the various services provided, households generate and dispose optimum amounts of refuse based on these costs. Thus, there is no reason for concern with respect to non-optimum use of resources.

In such a situation, the essential role of government would be reduced to minimum surveillance and enforcement needed to ensure continued successful operation of the system. There would still be private reasons for continued local government involvement based on tax and subsidy considerations, but there would not be valid social reasons. These points will be discussed. The specific Federal concern, however, would be reduced to general interest in surveillance and general interest in the economic use of the nation's resources.

As pointed out earlier, the major governmental concern would be where pollution externalities are involved. However, from the standpoint of developing the framework of demand for services, it will be convenient to start with the relatively simple case of non-concern with pollution externalities. The demand and optimum resource allocation framework will then represent a building block to which the analysis of externalities can be added. In addition, starting with this will give a basis for gauging the relative importance of factors that may affect externalities.

The organization of this section will thus be to first look at extension of the theory of demand where only private economic utilities are involved or are of concern. What is needed is an economic model that can be used both to explain and predict the amounts and kinds of services that are and will be demanded, and in a way that maximizes the individual utilities from such services. It was pointed out in the 1971 study that a comprehensive economic analysis of waste demands can be organized using a three-part framework consisting of demand, supply, and price. This basic procedure will be followed here. First, what-is-demanded and supplied will be listed, disaggregating the separate kinds of services provided from a demand standpoint. Again, as earlier pointed out, analysis can proceed at the aggregate level, but a comprehensive extension requires disaggregation. Measurement of what-is-demanded will be discussed. The what-is-demanded listing and discussion will be followed by development of cost or supply concepts, and this by the development of demand concepts. Then price will be discussed as the integrating factor between supply and demand. However, this will not be the first introduction of price, since price is intimately and directly involved in the concepts of supply and demand themselves. Finally, the concepts of environmental externalities will be added.

In developing these theories, it will be convenient to assume, at a first level of analysis, that the costs of administering a price system, that is of measuring and charging for services based on quantity, are zero. The effect of the assumption of costless billing and how these costs would actually be charged and passed on to households will be discussed in the price section.

EXTENSION OF THE THEORY OF DEMAND - PRIVATE ECONOMIC UTILITIES ONLY INVOLVED

Disaggregated Municipal Solid Waste Collection/Disposal Services

Identifying and Listing the Services

Ernst (1975), in a section on "supply of solid waste management services," provides one possible categorization of the solid waste collection and disposal services that are demanded and supplied. He divides the basic solid waste management (SWM) services into two broad categories: 1) collection and transportation (C&T) and 2) processing and disposal (P&D). He then adds to this a third, which he terms ancillary services. Under this heading, he includes "management of the system, with its implications for institutional and financial arrangements, and the enforcement of ordinances and regulations against improper waste disposal methods."

For purposes of analysis in this paper, the focus will be on the services demanded, rather than supplied. This will at least serve the purpose of keeping things in order, since it is the demands for the various services that bring forth the supply of these services. Looked at this way, many of the services discussed by Ernst are not really services directly demanded by households, but, rather, are inputs to the production function for producing the services that are in fact demanded by households. (They are, rather, services demanded by the suppliers of services to households.) Transportation is a good example. This is an input, the need for which varies from place to place and possibly from time to time. Nevertheless, it is an input for providing collection and non-polluting disposal services which are demanded by households.

In addition, although households do demand non-polluting disposal of their wastes, in this section the disposal services per se, along with processing, will be treated as a production function input for providing "collection/disposal" services. This point is worth at least a paragraph of discussion here, and is also covered, along with the need for treating and analyzing disposal as a subject of demand analysis, in Section IV of this paper, Identifying Areas of Needed Research on the Economics of Solid and Hazardous Waste Management.

In this section, it will be taken as given that society accepts the air quality, water quality, and sanitary land fill standards that are associated with solid wastes processing and disposal, and that are imposed by various Federal, state, and local jurisdictions. Thus, the transportation/processing/disposal requirements to achieve these standards are treated as necessary inputs for following through with collection services. They will not be treated as services demanded that may vary with their cost independently of the amount or types of wastes collected. No consideration will be given to pricing them separately. Nor will they be treated as subject to independent variation with income or other household means or characteristics. There are basically three reasons for treating these standards as given and accepted. First, the question of what standards to set for maximizing social welfare, or alternatively how to determine the amount of pollution control that society should "buy", is in itself a large subject. If it can be feasibly isolated for independent analysis without reducing the relevance of the analysis, and this is in fact the case, it makes the analysis more manageable. Second, the analysis methodologies required are quite different, as Ernst points out, with the determination of the optimum amount of pollution control over the processing/disposal of community collected solid wastes involving the estimation of social environmental-damage functions. Third, while there has been some progress along these lines of environmental analysis, the analysis is largely undeveloped in any application to the solid wastes field. Thus, it is more appropriately treated under needs for new research than under extending the theory and reviewing the existing literature on theory of demand for solid wastes collection/disposal.

Given the focus on waste collection/disposal services from the household demand viewpoint, which is at the collection end, the list of important services demanded and provided is limited. The important services, as identified in the literature, include frequency of collection and location of pickup. Services can be measured by the frequency of collection and location of pickup, and by the amount of pickup and the kind or character of wastes picked up. This latter is included for two reasons. First, there may be a different demand function for different type wastes. One may want to get rid of the garbage quickly, but not be so concerned with newspapers. One may have a relatively low cost means of disposing of newspapers (giving them to Boy Scouts) but not lawn clippings. Second, the household may be faced with different supply functions (prices for collection) of different type wastes if differentiations are made with respect to salvage value or difficulty of handling different type wastes.

Amount and frequency of collection are in one sense merely measurements of the quantity of the basic service demanded and provided, which is collection/disposal. Location of collection (curb, back door) is merely a description of the bundle of collection/disposal services provided. And kind of service is merely a description of what is collected. Nevertheless, there is a separable demand, as well as supply, for each. Thus, in this paper, they will be treated as separate services. Recapitulating, the services are:

1. frequency of collection
2. amount of collection
3. location of collection (curb, back door)
4. kind or character of wastes collected.

There may, of course, be other demands for services associated with waste collection. For example, there may be an interest in which day of the week the service is provided--Monday may be preferred because it follows weekend lawn, yard, and home clean-up activities. Noiseless refuse trucks, as well as collectors, or trucks that come only during waking hours, may be preferred. However, it is believed that the four services listed above represent the main ones, and that they provide a sufficient coverage of disaggregated demands for realistically developing the supply, demand, and price concepts.

Measuring the Services

Before proceeding to the development of these concepts, however, it will be useful to discuss measurement of the quantities involved. Ernst again introduces this as a supply side problem. He states that the major supply side questions are 1) How can solid waste management outputs be adequately measured? and 2) What are the cost functions associated with these outputs? Of course, measurement of services is as much a demand side question as a supply side question.

With respect to frequency of service, the usual measure is the number of collections per week, a very unambiguous quantitative measure. There is both conceptual and empirical support that both costs on the supply side and utilities on the demand side are directly associated with this variable.*

As for location of collection, the usual place is either the curb (or alley), or back door, and the usual quantitative measure assigned in analysis is a zero for curb (or alley) service, this representing no special service, or a one for backdoor service. Again, there is both conceptual and empirical support that both costs on the supply side and utilities on the demand side are directly associated with these variables. There is, of course, the fact that some back doors are farther from the street than others. The distance also is a clear quantitative measure that may directly

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* The point is sometimes made that the demand is really for reducing the interval between pickups rather than for frequency, since it is the length of the interval that causes space and nuisance problems. Regardless, except for the fact that 7 days does not divide easily into equal parts, service tends to be spread into equal intervals, and frequency, that is collections or collection visits per week, is thus a measure of interval.

affect both cost (supply) and willingness to pay for the service (demand).

The major demand problem, as discussed in the literature, is with the measure of the quantity of wastes collected. The quantity has two important dimensions, volume and weight. Both dimensions may affect costs (supply functions), and both may affect demand. Taking the supply side first, space or volume required for ultimate disposal (sanitary land fill) is an important cost component. To hold down these costs, wastes are compacted and sometimes reduced (incinerated or composted). For compacting, collection trucks with compactors are now frequently employed. These trucks compact wastes as collected and thereby also hold down the collection and transportation costs that are associated with uncompacted volume (as well as ultimate disposal costs). The compacting costs are relatively low cost compared to the costs of weight-associated haul to disposal sites and ultimate disposal; thus the main supply side costs are associated with compacted volumes, for which weight of the collected refuse is believed to be a better proxy measure than uncompacted volume. Thus, if incremental user charges are to be instituted, and if to reduce complications one measure must be chosen over the other, it should be weight. Households would then pay attention to weight, but ignore as inconsequential any volume effects of their waste generation, except to the extent that volume might affect household costs other than those imposed by the user charges (the costs of storing greater volumes in the between collection intervals). In buying, households would tend to shift to lighter weight packaging, ignoring volume (to the extent such discriminations may be possible.)

However, these considerations are probably inconsequential compared to the problems and costs that would be involved in measuring individual household quantities on a weight basis. Accounting for the number of containers (cans or bags), on the other hand, is relatively low cost, and, in fact, volume by container is the measure used where user charges are imposed (Ernst, 1975, p42). Unless or until a practical way of weighing and recording weight by individual household collections is found, volume will probably have to do as a proxy for weight, that is for the main system cost-causing factor.

In addition to volume not being a perfect proxy for weight, there is an additional problem. Households can avoid charges by doing their own compacting. To overcome this, there could be one charge, that is one price per container, for uncompacted wastes, another, higher price per container, for household-compacted wastes. Possibly on a weight basis, the compacted waste price could be slightly lower since the waste is already compacted, thus saving the collection agency a slight amount on compacting. This would slightly reduce the overall collection costs. The household could decide whether the storage space savings the household would obtain from compacting, along with possible collection cost savings, would justify compacting. Another way to overcome the problem might be to outlaw household compactors. However, this would deny households the opportunity of reducing their storage costs, and in fact some households own and use compactors for this or other reasons even without user charges.

In any event, these possible solutions appear impractical, and are in fact not used, and in the presentation of concepts below, number of containers is used as the measure of quantity. This is done despite the fact that all empirical analysis to date has been in weight terms. It has all been in terms of weight collected by community, community subsection, or collection route, either on a total or average per household or per capita basis. This makes sense since it is easier to determine the net weight of a truckload than to count the number of containers emptied into it. There has, in fact, been no empirical analysis uncovered in this study based on the measurement of individual household amounts. This is also true of the one analysis uncovered of the effect of imposing or not imposing user charges (Wertz, 1976). This study, using San Francisco area data, compared average pounds collected per capita between areas where charges are on a container basis and all areas, where flat charges predominate. Indeed, for more sophisticated and detailed analysis of the effect of incremental user charges, weight rather than volume would probably be used for two main reasons. First, individual responses are not interesting; it is the average that is of concern. Second, it would be impractical to measure and record gross amounts on a volume basis. For example, "truckloads" might tend to measure what the truck contained at the end of a route, rather than a more or less definite number of containers. Thus, another measurement error may, of practical necessity, be introduced by turning the measure back to weight for analysis, even though charges are in fact made on a volume basis.

Finally, the measure by type of waste presents no particular additional problem. The identification of different, at least grossly different, types is relatively easy. Newspapers are newspapers, and the same is true of garbage, metals, and bottles. For separation of wastes, the problem of measurement for some types might be eliminated. There would be no measuring of quantities needed if, for certain wastes such as metals, the unit salvage values just offset the unit collection costs. For the usual case, however, the same problems in measurement would apply.

Having discussed these preliminary matters of the measures of the services involved, development of supply, demand, and price concepts can now proceed. Again, it is emphasized that social costs from alternative disposal, such as littering, are not included in this development of basic concepts. In this development of basic concepts, the previous work by Ernst (1975) and others is drawn upon. Goddard's (1975) work is also drawn upon, but mainly in carrying the work forward to include littering and the like.

Cost or Supply Concepts

The first step is to develop the concepts of cost or supply for the services. The costs would be those to the entity supplying the collection services. Under marginal cost pricing, these would also be the costs to the consumer. The costs of three of the four services--frequency, amount, and location-- are relatively easy to visualize, and it should not be difficult to obtain data on them. The marginal costs would be the costs added to the total costs of a particular service by more of that service.

Figure 1 is a hypothetical depiction of total costs for different levels

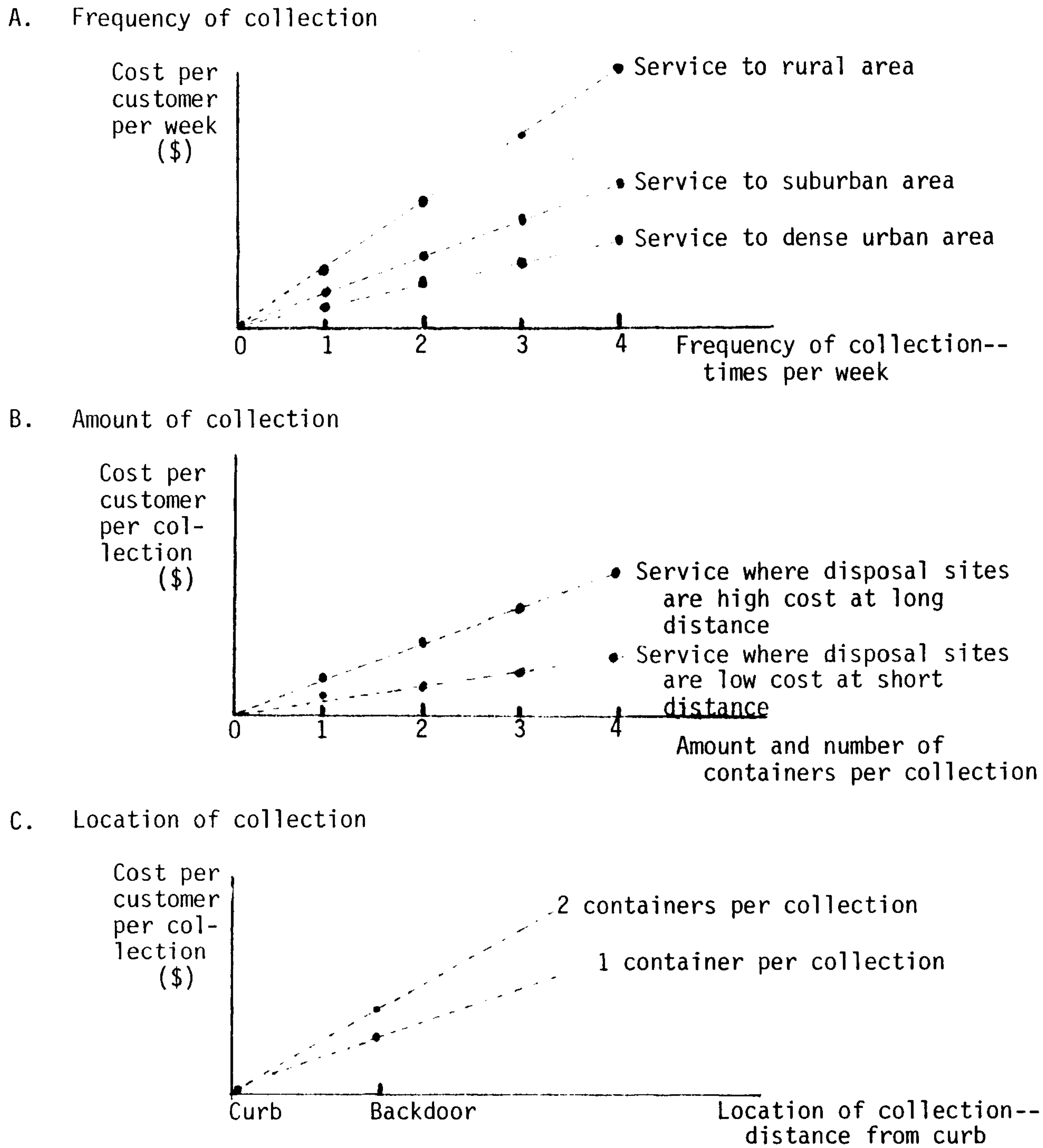


Figure 1. Cost functions for waste collection and disposal services.

of these three services. Note that in the depiction, it is the total cost of the particular service only that is depicted. For example, the cost of location-of-collection is taken as zero at the curb. This is not, of course, the total cost of collection service at the curb. Also, in the depiction, marginal costs (the slopes of the total cost functions shown) are shown as constant. However, this is for purposes of simplifying the presentation only. It should be emphasized that this might not necessarily be the case. However, this would not affect the conceptualization. Also shown is an indication of how total costs would tend to vary with other things. Sometimes this may be a strict cost factor, sometimes a level-of-service factor imposing added costs. For example, the cost of a collection should be higher the more sparsely populated the area of service because of the greater travel distances from one residence to the next. The term supply shifters is used below to refer to such changes in cost relationships due to other things.

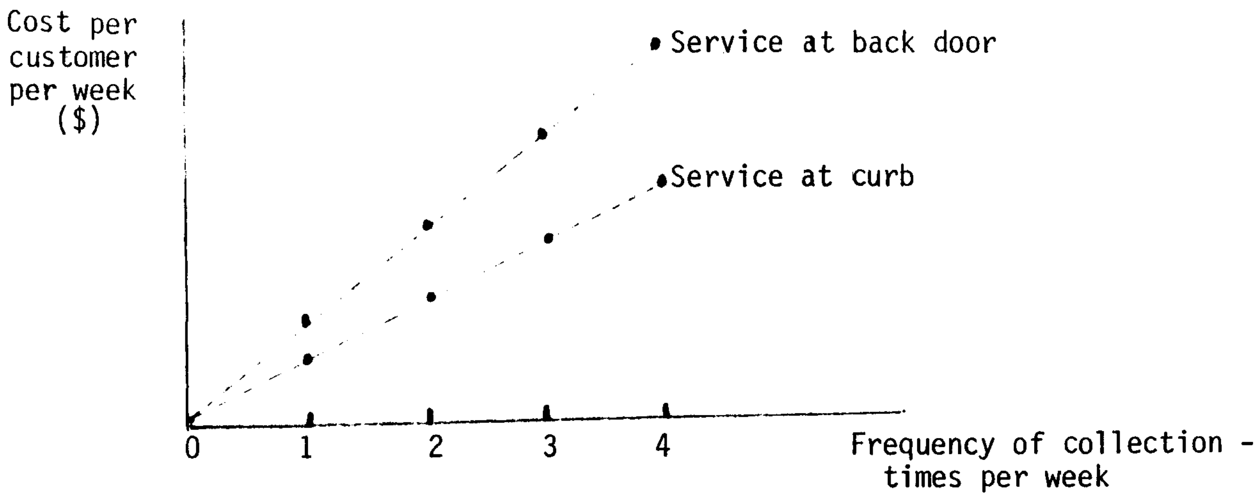
The location-of-collection costs, shown as separate functions in Figure 1, can be treated as supply shifters of the frequency-of-collection and amount-of-collection cost functions. This is shown in Figure 2. The most obvious shifter is with respect to the cost of collection. Each time an additional collection per week is added, another trip to the back door is added, regardless of the amount of collection. However, an additional amount of time and thus cost may be required for each container. There may, in fact, be something like a break point between 2 and 3 containers per collection. Three containers may require an extra trip to the back door, but carrying 2 containers or the waste from 2 containers from the back door to the curb may require no more time than carrying one. Thus, for other than developing basic concepts, a linear assumption would be unrealistic.

The cost function for waste collection and disposal services for different types or character of wastes cannot be depicted as a single function in the same way as the above three services, since there is no continuum; different costs are associated with different waste types. Nevertheless, the elements of the relationships between characteristics and costs can be described and these can be treated as supply shifters, as will be indicated. There are basically two different types of wastes, those that cost less than the average to service, which are basically those with a salvage value, and those that cost more, which are basically those that are hard to handle. Each basic type is discussed separately below.

Providing collection and disposal services for wastes with a higher scrap or salvage value will tend to cost less for two reasons. Salvage values may be obtained, and there is less waste to dispose of as a waste when materials are salvaged. Salvage or recycling values may be obtained in two ways: 1) by the collecting agency or enterprise separating and selling salvageable materials (these may include glass, metals, paper, and animal-edible garbage for their material value, or burnables for their fuel value and 2) the collecting agency or enterprise may be able to obtain labor at a lower cost if there are valuable items such as old furniture, appliances, and clothes that collectors may salvage and sell for supplementing their incomes.

The salvageable content of refuse may vary from place to place and time

A. Frequency of collection



B. Amount of collection

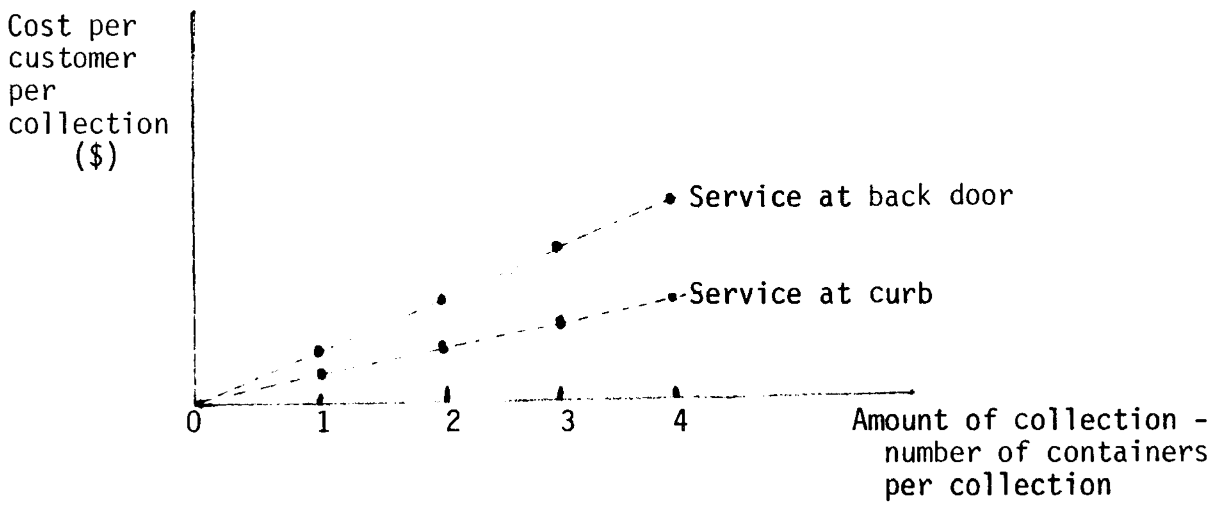


Figure 2. Location of collection point as supply shifter.

to time for various reasons, including the consumption habits of the waste generators (buying returnable or non-returnable bottles, wearing old clothes out and making a patchwork quilt with them after they do) and their own salvaging activities (finding a market for the old appliances rather than scrapping them). The actual value itself will also vary from place to place and time to time based upon costs of salvage operations and prices for salvaged items and materials.

Pre-separation by the waste generators will tend to further reduce costs; indeed, in some areas, this may make salvage and recycling viable where it would otherwise not be. (It is not necessary that the same enterprise collect the salvageable and non-salvageable materials.)

Certain characteristics of waste would tend to increase costs of waste collection/disposal. Bulky items with no salvage value would tend to cost more to handle than general wastes, the inclusion of hazardous materials in the waste requiring special handling would increase costs, as would any other materials that might be difficult to handle for various reasons. As with salvageable materials, separation of these items from the general wastes would tend to change the cost functions, in this case decreasing average costs for the total waste.

The depiction of the characteristics of wastes as supply shifters, as previously suggested, is shown in Figure 3. Costs for collecting and disposing refuse containing relatively large proportions of salvageable materials are shown as less than costs for handling normal refuse. Costs for collecting separated wastes may be positive, as is depicted for separated glass, although less than for average refuse because of salvage value, or negative--that is, a positive price paid for that separated "refuse"--as is depicted for separated metals, such as aluminum. In other words, the most economically separable item as represented here is separated metals. (Note again that all of the cost functions have a zero intercept because costs apply only to the service of quantity collected.)

These cost relationships can be generalized in mathematical form as follows. Again, it is emphasized that the linear form adopted for presentation purposes is not meant to imply that the relationships are necessarily linear. Indeed, empirical evidence is available to indicate non-linearity in a number of cases.

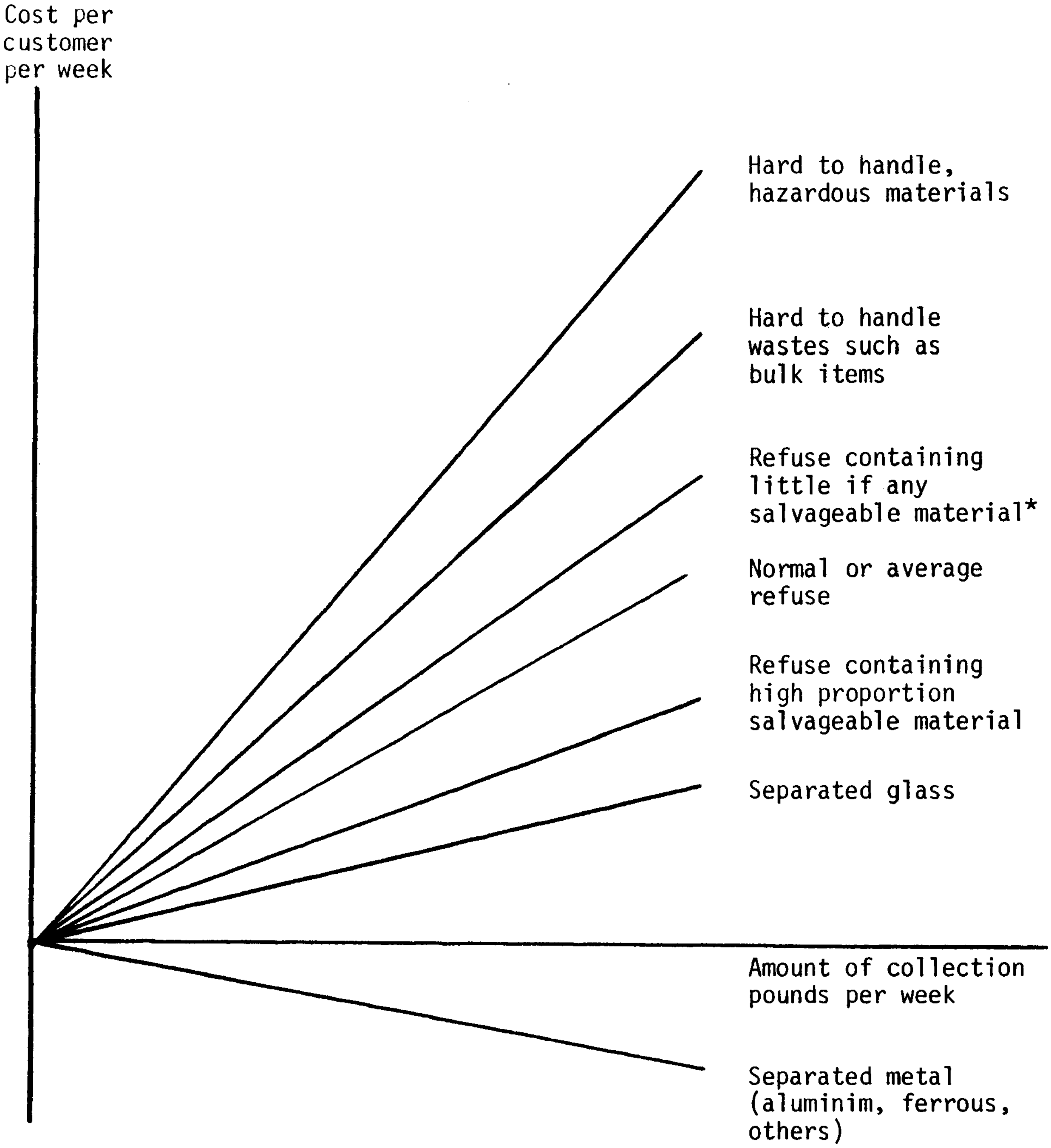
The cost per customer per week is the sum of the cost for collections (number of visits) per week and the amount of collection per week, or

$$C_w = C_f + C_q (F) \tag{1}$$

The cost for collection visits, without considering shifters, is a function of the frequency of collection, or

$$C_f = \beta_1 F \tag{2}$$

When shifters are considered, the cost function is



* May contain little salvageable material because of pre-separation or merely due to the general waste characteristics of a particular area.

Figure 3. Cost functions for waste collection and disposal services for different types of waste.

$$C_f = (\beta_1 + \alpha_1 --- + \alpha_n)\ F \qquad (3)$$

Specifically, for those shifters discussed, we have α_1, the urban density shift factor, and α_2 the location-of-collection shift factor. The marginal cost or supply price, for visits is the derivative of the function, or

$$\frac{dC_f}{dF} = P_{fs} = \beta_1 + \alpha_1 + \alpha_2 \qquad (4)$$

Stated another way, this is the added cost of each collection visit.

The cost for quantity collected, again without considering shifters, is a function of the amount collected, or

$$C_q = \beta_2\ (Q) = \beta_2 f\ (F) \qquad (5)$$

When shifters are considered,

$$C_q = (\beta_2 + \gamma_1 --- + \gamma_n)\ Q \qquad (6)$$

Again, for those shifters specifically discussed, there is γ_1, the shifter for haul distance, γ_2, the shifter for location of collection, and γ_3, the shifter for type of waste. The marginal cost, of supply price, for number of containers collected is again the derivative of the function, or

$$\frac{dC_q}{dQ} = P_{qs} = \beta_2 + \gamma_1 + \gamma_2 + \gamma_3 \qquad (7)$$

If prices are set to customers according to these marginal cost factors, that is the α's, β's, and γ's in Equation (4) and (7), there can be optimum (conceptually optimum) provision of waste collection and disposal services. The conceptually optimum billing, B, would be at least a two-part tariff:

$$\begin{aligned} B &= C_f + C_q F \\ &= P_{fs}F + P_{qs}QF \\ &= (\beta_1 + \alpha_1 + \alpha_2)F + (\beta_2 + \gamma_1 + \gamma_2 + \gamma_3)QF \end{aligned}$$

Conceptually optimum here means optimum before taking into account measurement and billing costs that may make marginal cost pricing not optimum in fact.

If back-door service were fully optional, and two separated types of wastes, Q_1 and Q_2, were involved, the back-door service and each waste should be charged for separately, based on the quantities of each involved. The billing would become quite complex. While a computer could handle the computations, explaining the billing and its interrelationships would be quite difficult. (Separate count must be kept of each back-door service and of the quantities of each type waste collected at the curb and at the back door. Also, the cost of back-door service depends both on the number of collection visits to the back door and the quantity carried from the back door.) The billing computation for a weekly period would be:

$$B = (\beta_1 + \alpha_1 + \alpha_2)m + (\beta_1 + \alpha_1)(F-m)$$

$$+ (\beta_{21} + \gamma_{11} + \gamma_{21} + \gamma_{31})n + (\beta_{21} + \gamma_{11} + \gamma_{31})(FQ_1-n)$$

$$+ (\beta_{22} + \gamma_{12} + \gamma_{22} + \gamma_{32})p + (\beta_{22} + \gamma_{12} + \gamma_{32})(FQ_2-p)$$

where m = the number of collections per week at the back door out of F total for the week

n = the number of containers with type Q_1 waste carried from back door out of Q_1 total containers for the week

and p = the number of containers with type Q_2 waste carried from back door out of Q_2 total containers for the week.

(The β's and γ's may be different for different type wastes because the handling requirements may be different. Thus, they are designated with different subscripts, 1 for type Q_1, 2 for type Q_2.)

While a charge based on frequency of service alone, that is a flat charge of a given amount per week for a given frequency of service, might come close to the conceptually optimum, it would only be the actual optimum if the added cost per container were small, and not worth the trouble and cost of setting up the charge system on the full marginal cost basis.

For the case where this latter might be true, a cost function can be derived. Given the various demand factors, for each location, frequency, and type (waste type) of service, and with no charge on a container basis, a certain number of containers per collection will be "generated" (the free-service amount). Then the cost per week is the sum of the cost for collection visits (what visits cost per se) and the cost related to the specific amount collected on visits. Then

$$\text{the cost per week,} \quad C_w = C_f + C_{qd}F, \qquad (8)$$

$$\text{and the cost per collection visit,} \quad P_{sd} = C_f/F + C_{qd} \qquad (9)$$

where the subscript d indicates that costs and prices are demand as well as supply determined.

To complete the discussion of the various ways of charging, just as a charge based on number of collections, or a flat weekly charge, would be non-optimum, so would a charge based on quantity alone. This might be termed a flat quantity charge. A cost function can be set up on such a flat quantity basis, made up of the variable cost for quantity and a charge, distributed on a quantity basis, for service, as follows:

$$C_{Qdd}\ (=P_{qsdd}) = C_q + \frac{C_f}{Q_{dd}F}$$

Note again that the Q, in this case Q_{dd}, and thus the cost per unit or "supply price," is demand determined. Also note that marginal cost pricing based on quantity alone would not cover costs.*

Table 1 presents these various cost and conceptual optimum billing functions, along with units of measurements, in a single table, and in the order presented above.

Before proceeding, it will be useful to discuss alternative means of financing, and ways in which the alternative means may affect supply functions, and thus prices or charges that households face and their resulting demand for services. If services are paid for through local taxes but not explicitly paid for, there may be a savings to households because the payments are deductible on Federal and State income taxes, and because the base for Federal revenue-sharing is enlarged. This is true whether or not the local government actually operates the collection/disposal service. The work could be contracted out. In addition, local government operations, as opposed to business-run operations, may qualify for research and demonstration grants that may help reduce costs to households, even though direct reduction in costs may not be the purpose of the grants. From a community standpoint, although not from an overall social (national) viewpoint, there is apparent reason for members of a community to consider taking advantage of these cost savings, particularly those related to taxes and revenue-sharing which are automatic and do not depend on any action such as applying for a grant or becoming involved in a grant program. In fact, results of surveys indicate that most communities do finance service from general revenue, that is from taxes (Wertz, 1976, p 264). The question might be, why don't they all? The answer is not that private firms are favored by some communities, because this is not the issue; the work can be contracted to private firms. Nor would the fact that private firms are already set up in a community be a convincing answer. If this were the case, payment of bills to

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* Ernst, in his 1975 study, reached the same conclusion, but apparently confused this with true marginal cost pricing. Ernst assumed that a choice must be made between either a flat charge or a quantity charge. He related all costs to quantity. This led him to attribute certain empirical findings to "scale" factors related to population size, whereas in fact there are other much more plausible and reasonable explanations, based on true cost relationships. Ernst's cost relationships would result in no costs for traveling a route or going to the back door to look when no wastes were collected. His conclusions concerning the efficacy of quantity and marginal cost pricing are subject to similar comments.

TABLE 1. COST FUNCTIONS FOR SOLID WASTES COLLECTION SERVICES

1. Basic Number-of-Collection Cost Functions

Total cost of a collection service

Without shifters

$$C_f = \beta_1 \times F$$

$$\frac{\text{cost of collection}}{\text{per customer per week}} = \frac{\text{cost of collection}}{\text{per customer per collection}} \times \frac{\text{collections}}{\text{per week}}$$

With shifters (Shifters specified are urban density, α_1, and back-door service, α_2. Back-door service is subject to individual choice, and α_2 is a function of distance, street to back door.)

$$\hat{C}_f = [\beta_1 + \alpha_1 + \alpha_2] \times F$$

$$\frac{\text{cost of collection}}{\text{per customer per week}} = \left[\frac{\text{"basic" cost of collection}}{\text{per customer per collection}} + \frac{\text{density cost shifter}}{\text{per collection}} + \frac{\text{back-door service cost}}{\text{per collection}}\right] \times \frac{\text{collection}}{\text{per week}}$$

where

$$\alpha_2 = \alpha_3 \times D$$

$$\frac{\text{back-door service cost}}{\text{per collection}} = \frac{\text{back-door service cost}}{\text{per unit of distance}} \times \frac{\text{distance}}{\text{per collection}}$$

Marginal cost of a collection service (added cost per visit, since the basic cost, as shifted by density, applies for the visit, not whether or not an actual collection is made.)

$$\frac{dCF}{dF} = P_{fs} = \beta_1 + \alpha_1 + [\alpha_2 \times \mu]$$

$$\frac{\text{cost of collection}}{\text{per customer per collection}} = \frac{\text{"basic" cost of collection}}{\text{per customer per collection}} + \frac{\text{density cost shifter}}{\text{per collection}} + \left[\frac{\text{back-door service cost}}{\text{per back-door collection}} \times \frac{\text{back-door collection}}{\text{visit}}\right]$$

($\mu = 0$ if back-door collection not made; $\mu = 1$ if back-door collection is made)

(continued)

TABLE 1 (continued)

2. **Basic Quantity-of-Wastes-Collected Cost Functions**

Total cost of quantity-of-wastes-collected

Without shifters

$$C_q = \beta_2 \times Q$$

$$\frac{\text{cost of the quantity collected}}{\text{per customer per collection}} = \frac{\text{cost of quantity collected}}{\text{per unit of quantity collected (containers)}} \times \frac{\text{quantity collected (containers)}}{\text{per customer per collection}}$$

$$C_q(F) = \beta_2 \times Q \times F$$

$$\frac{\text{cost of the quantity collected}}{\text{per customer per week}} = C_q \times \frac{\text{collections}}{\text{per week}}$$

With shifters (Shifters specified are haul distance, γ_1, location of collection, γ_2, and type of waste, γ_3. Again, back-door service is subject to individual choice, and γ_2 is a function of distance, street to back door.)

$$\hat{C}_q = [\beta_1 + \gamma_1 + \gamma_2 + \gamma_3] \times Q$$

$$\frac{\text{cost of the quantity collected}}{\text{per customer per collection}} = \left[\frac{\text{basic cost of quantity collected}}{\text{per container}} + \frac{\text{haul distance cost shifter}}{\text{per container}} + \frac{\text{back-door service cost}}{\text{per container}} + \frac{\text{type of waste cost shifter}}{\text{per container}}\right] \times \frac{\text{containers}}{\text{per customer per collection}}$$

$$\gamma_2 = \gamma_4 \times D$$

$$\frac{\text{back-door cost}}{\text{container}} = \frac{\text{back-door cost}}{\text{per container per unit of distance}} \times \text{distance, back door to street}$$

Marginal cost of quantity of wastes collected.

$$\frac{dCq}{dQ} = P_{qs} = \beta_2 + \gamma_1 + \gamma_2 + \gamma_3$$

(continued)

TABLE 1 (continued)

3. Optimum Cost (Billing) Functions

With back-yard service on an either/or basis, and one type waste

$$B = C_f + C_q(F)$$
$$= P_{fs}F + P_{qs}\,QF$$
$$= (\beta_1 + \alpha_1 + \alpha_2)F + (\beta_2 + \gamma_1 + \gamma_2 + \gamma_3)\,QF$$

With back door/curb service optional at each collection visit and two type wastes, Q_1 and Q_2

$$B = (\beta_1 + \alpha_1 + \alpha_2)m + (\beta_1 + \alpha_1)(F-m) + (\beta_{21} + \gamma_{11} + \gamma_{21} + \gamma_{31})n$$
$$+ (\beta_2 + \gamma_{11} + \gamma_{31})(FQ_1-n) + (\beta_{22} + \gamma_{12} + \gamma_{22} + \gamma_{32})p + (\beta_{22} + \gamma_{12} + \gamma_{32})(FQ_2-p)$$

(See text for definition of symbols)

4. Combined Number-of-Collections and Quantity-of-Wastes-Collected Cost (Billing) Functions on a Flat Weekly Basis

Basic combination, regardless of basis for charge

Without shifters

$$C_w = C_f + C_q\,(F)$$

$$\frac{\text{(cost of all services)}}{\text{per week}} = \beta_1(F) + \beta_2 Q(F)$$

With shifters

$$C_w = [\beta_1 + \alpha_1 + \alpha_2]\,(F) + [\beta_2 + \gamma_1 + \gamma_2 + \gamma_3]\,Q(F)$$

(continued)

TABLE 1 (continued)

Combined charge with rates for all services on a weekly basis (the charge on a weekly basis only with no incremental quantity charge):

The quantity, $Q = Q_d$

and the cost per unit of quantity, $C_q = C_{qd}$

where the subscript d denotes the quantity, or cost for the quantity, at a zero quantity charge.

Then, $C_w = C_f + C_{qd}F$

The cost per collection:

$$\frac{dC_w}{dF} = P_{sd} = (\beta_1 + \alpha_1 + \alpha_2) + (\beta_2 + \gamma_1 + \gamma_2 + \gamma_3)Q_d$$

Where the back-door/curb service is optional on an either/or basis and separately charged:

$$P_{sd} = \beta_1 + \alpha_1 + (\alpha_2\ \mu) + \left[\beta_2 + \gamma_1 + (\gamma_2\ \mu) + \gamma_3\right] Q_d$$

(The case where back-door/curb service is optional for each visit is much more complex to express on a weekly charge basis, and is not given.)

(continued)

TABLE 1 (continued)

5. **Combined Number-of-Collections and Quantity-of-Wastes-Collected Cost (Billing) Functions on a Flat Quantity Basis**

$$C_{Qd} = C_q + \left[(C_f) \times (1/Q_{dd}) \times (1/F) \right]$$

$$\frac{\text{cost for all services}}{\text{per container}} = \frac{\text{cost for quantity service}}{\text{per container}} + \left[\frac{\text{cost for collection service}}{\text{per week}} \times \frac{\text{1/container}}{\text{collection}} \times \frac{\text{1/collection}}{\text{per week}} \right]$$

$$= (\beta_2 + \gamma_1 + \gamma_2 + \gamma_3) + \left[(\beta_1 + \alpha_1 + \alpha_2)F \times 1/Q_{dd} \times 1/F \right]$$

$$= (\beta_2 + \gamma_1 + \gamma_2 + \gamma_3) + \frac{(\beta_1 + \alpha_1 + \alpha_2)}{Q_{dd}}$$

the private firm could be shifted from individuals to the local government with taxes raised to cover the costs. Three possible answers are, first, that there may be institutional barriers. This would require investigation. Second, if private firms charge on an incremental quantity basis, financing from general tax revenues would eliminate the effect of such pricing on amounts of waste to be handled, and might increase costs, thus offsetting the tax advantages. However, for the most part, private firms do not charge on an incremental quantity basis. Third, the advantages of deductions from income taxes may be more apparent than real.

Despite this latter consideration, it appears that the tax savings for homeowners can be substantial. At a 25-percent marginal Federal and State tax rate, the savings on these taxes alone would be an equivalent 25 percent on waste collection service. This would not include revenue-sharing benefits. Nor would it include possible savings on separate billing for services that would be avoided. Wertz (1976) concludes that, "From a local perspective the value of transfers foregone by pricing (to individual households on a quantity basis) may exceed the value of resources conserved in the public treatment of less refuse."

However, since conceptual optimum billing is composed of two parts, C_f and CgF, the C_f portion, which is not quantity based, could be covered out of general revenue without loss of system efficiency (not merely a loss from a local perspective). If this C_f portion were a major part of the total billing (that is of total costs), which may well be the case, a change to financing only the C_f portion out of general revenues would involve a loss of only a minor part of the tax and revenue sharing savings that may be available to households. Retaining general revenue financing of the C_f portion would, of course, reduce the potential for conserving through the public treatment of less refuse, as this might be impacted by fully quantity-based pricing. However, there would be no loss in overall system efficiency, that is, overall savings.

Demand Concepts

Demand for a service depends on its price and on various demand shifters such as prices of other related goods and services, including both substitutes and complements (cross-price effects), income, other characteristics of the household, and demographic variables. Own-price relationships can be looked on as the households' willingness to pay for different types and levels of services or as the response on the part of households in terms of types and levels of services taken to changes in price. The willingness to pay, or price-quantity relationship, may be shifted by various factors. The first step in developing the demand concepts below will be to consider price effects on each of the services. Both own-price and cross-price effects will be considered. First, some general points concerning these effects, and the role of substitutes and complements, will be made. Then the various price effects on the collection/disposal services will be considered one service at a time, beginning with the location of collection and ending with the quantity of different type wastes. This will be followed by consideration of the effects of income and other demand shifters.

Price Effects

In actual practice the price facing a household is frequently either zero, or, in effect, infinity. The household can get additional amounts collected at no added charge, and can get back door or a second weekly collection without added charge where those services are provided (that is, there is no credit for taking the refuse to the curb or setting it out only once a week where these services are provided). Or, the household can get only curb or once-a-week service, and cannot, at least from the regular community service, get back-door or twice-a-week service. Nevertheless, the relationships between price and what households would take still exist, and the relationships would apply to finite, non-zero prices as well as to the actual prices. (Of course, by definition, none of an infinitely-priced service would be taken.)

Price- and cross-price effects--Own-price changes will affect the quantity of a service demanded in two ways, through income effects and through substitution effects, the latter being the more quantitatively important. A price change will effect general substitution between the particular service and all other goods and services, but the main effects will be with close substitutes. There will also be major cross-price effects from changes in the prices of substitutes themselves. Finally, another cross-price effect, a change in the price of complementary goods and services, will affect the quantity of a service demanded by directly changing the cost of its use relative to the price of other goods and services, particularly close substitutes.

Consumer non-durables (as opposed to durables and services) and waste disposal are complements. Thus, an increase in the price of non-durables will tend to decrease the quantity of waste disposal services demanded (with, of course, all prices being in real terms, and changes being relative to other prices). Alternative or own disposal, such as by sink disposals or returning bottles, is a substitute for community collection/disposal. For avoiding the odors and nuisances of stored wastes, more frequent service, better containers (e.g., with screw-on lids), and alternative disposal, such as by sink disposals, are substitutes. For reducing space requirements for between-collection storage, frequency of service, alternative disposal, and home trash compactors are substitutes. For carrying wastes to the curb (or paying for this service if it is charged for on an incremental basis), alternative disposal, lighter containers (paper or plastic bags) are substitutes. Given these relationships, frequency of service, back-door service, and community collection/disposal are complements. That is, if the price of any one decreases, the use of all three will increase.

These relationships will be more fully developed in the following sections.

Demand for back-door collection--In this section, demand with respect to location of collection is considered. There would be some willingness to pay for back door as opposed to curb or alley collection because back-door service would substitute for own labor.* Conceptually, the service could be provided in one of three ways: 1) if it is provided at all, every household receives the service, 2) on an either/or basis, that is, the service would be optional to each household, but taken either on a regular continuing basis, or not at all, or 3) on a pay-as-you-take-it basis, optional to each household and at each collection.**

If the choice were optional at each collection, the total willingness to pay would increase at a decreasing rate, as shown in Figure 4a. The marginal willingness to pay (demand for services) would be the first derivative of this function, a declining function. The explanation of these decreasing rates and declining relationships is the usual one of declining marginal utility of a good or service as more is taken. Specifically, on some days there would be a high cost to the household to set refuse out on the curb (due to sickness or incapacitation, foul weather, or other pressing uses of time), and on others, low cost. Household utility would be maximized by receiving services on this basis, with back door collection service being taken by the household only when the households' utility cost of not receiving the service exceeded the cost of providing the service. (It should again be emphasized that in the final analysis, this cost should also include the cost of recording and billing for the service.)

For either/or service, the willingness to pay for service would be a fixed amount per collection, as shown in Figure 4b. Also shown is the effect on willingness to pay of having more or less refuse per collection. Obviously, the willingness to pay would tend to be greater the greater the average number of containers per collection. (This would also shift the curves of Figure 4a, as is discussed below.) (Figure 4b is also shown with an x axis representing distance to back door, comparable to the x axis for the supply function of back-door service previously discussed. This is further discussed below.)

The willingness to pay of Figure 4b can be derived from the parameters of Figure 4a. The willingness to pay in Figure 4a for 100 percent back-door collection service is the integrated sum of the households' marginal utility (marginal willingness to pay) for back door collection, or the area under the demand (marginal willingness to pay) curve, which is the total willingness to pay at 100 percent service. This divided by the number of collections per year is the willingness-to-pay per collection for either/or service shown in Figure 4b.

Figure 4b shows willingness to pay as a function of distance to back

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* According to the U.S. EPA (1976), approximately 60 percent of collections in the United States are curbside and alley, 40 percent backyard.

**Again, according to the U.S. EPA (1976), some communities provide a choice of curb or backyard service and charge a different rate for each. While not indicated, it might be assumed that most or all of this is on an either/or basis.

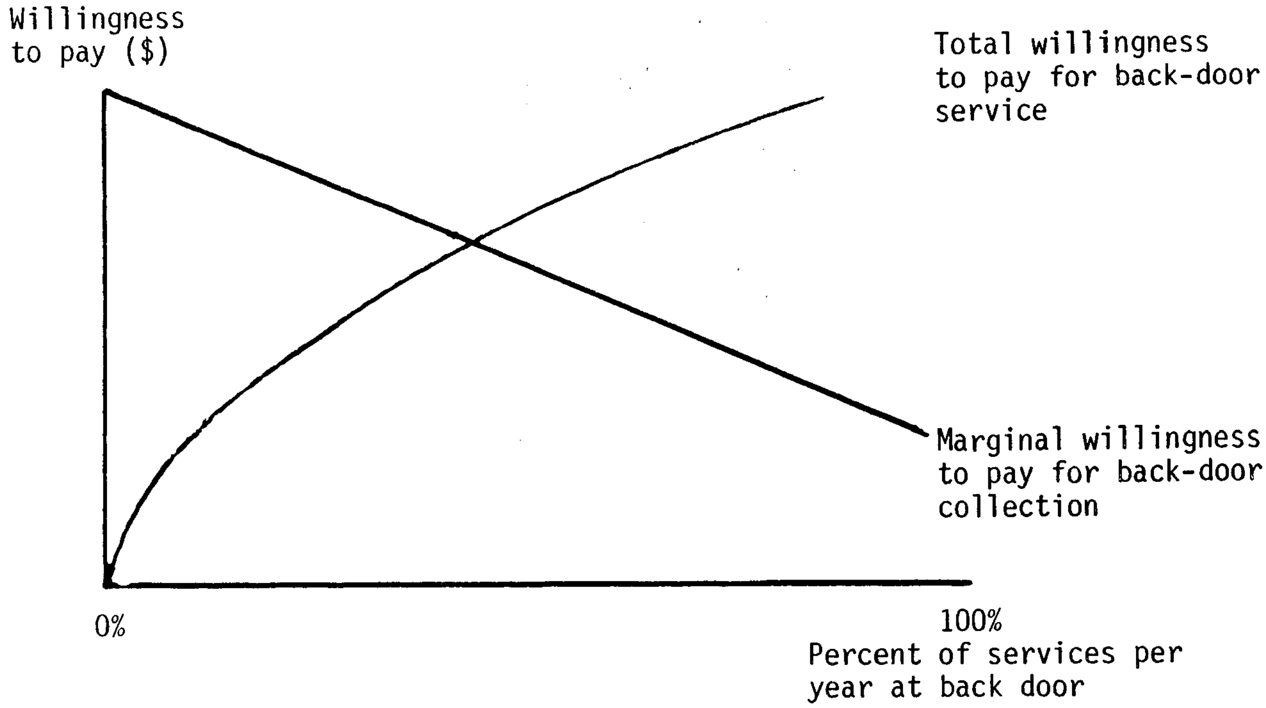

Figure 4a. Willingness to pay for back-door services on a pay-as-you-go basis.

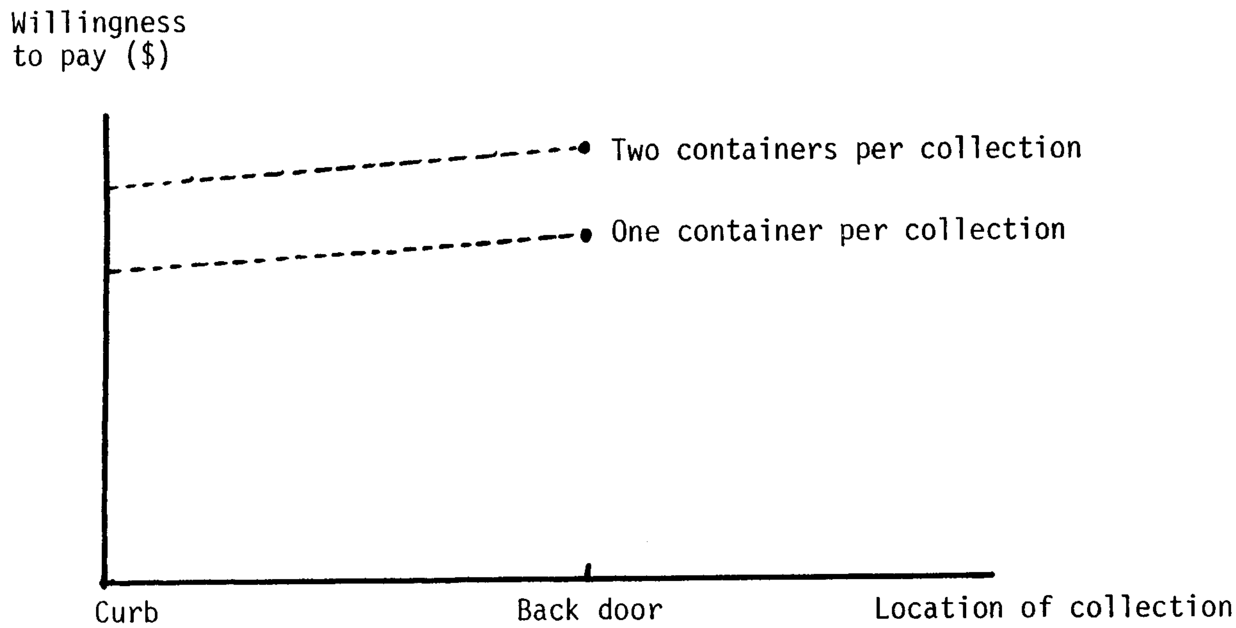

Figure 4b. Willingness to pay per collection for back-door service (on an either/or basis).

door. This is portrayed in this way mainly to make the relationship comparable to the cost function portrayed in Figure 1c. The cost relationship in that figure is shown as linear and proportional to distance, a reasonable assumption since it is time that is involved in cost, which is directly proportional to distance. However, for willingness to pay, there is probably a large fixed cost involved in going out and moving the refuse to the curb, unrelated to distance, as is indicated by the location of the functions in Figure 4b. Of course, variation in distance from back door to curb would shift the curves of Figure 4a, with total willingness to pay at 100 percent service equal to the willingness to pay at the actual back door distance if different from that indicated.

Before proceeding to the relationship between price and frequency of collection, the next service to be discussed, and between price and the amount of collection, which will follow, some preliminary discussion of possible relationships between location and amount of collection in the context of prices should be presented. Wertz (1976) states that a shift to curbside collection from collection at the permanent place of outdoor containers, usually in the backyard, decreases the marginal utility of commodities in proportion to their unit refuse weight and induces a decrease in refuse production because households must transport refuse to the curb on collection days and then return the containers to their permanent place. Thus, he states, a shift to curbside collection can reduce a municipality's outlays for refuse service not only because collectors spend less time transporting refuse but also because they collect less of it. On the first point, he cites Hirsch (1965) who, using St. Louis area data, found a significant positive relationship between backyard service and collection costs.

While Wertz makes a valid specific point, he fails to cover the more general point. The point is that where there is a marginal cost, however imposed, that is based on the volume of waste to be transported from the backyard to the curb (to the collection truck), there will be an inducement to produce less waste. This may be either where a household member transports the refuse himself, or when the service is provided if charges are based on marginal costs for the service according to the volumes transported.

Referring back to Figure 4b, a greater willingness to pay for two containers per pickup is shown than for one. However, the marginal willingness to pay, as suggested by the position of the curves, is seen to be decreasing. (That is, the willingness to pay for two containers per pickup is less than twice that for one, or equivalently, the willingness to pay for the second container is less than for the first.) This can be depicted as the percent of services per year at back door as shown in Figure 5.

The extent to which this marginal willingness to pay is a declining function depends on the alternatives open to the household, such as reducing the amounts of wastes generated, and alternative disposal options, such as garbage disposals. It would, of course, also depend on frequency of service. This point will be discussed later.

The relationship can be put in general mathematical form. First, the total willingness to pay for back-door service can be represented as

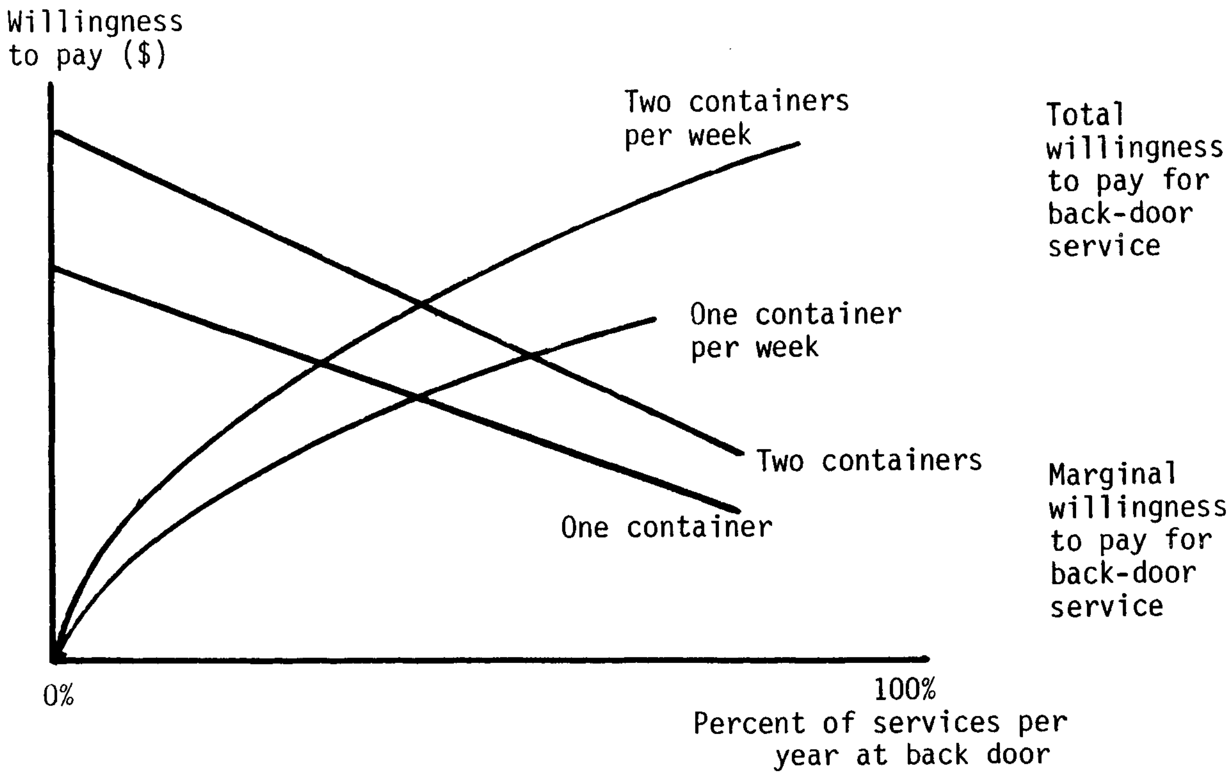

Figure 5. Marginal willingness to pay for percent back-door services as a function of number of containers per week.

$$W_T = \delta T - \tfrac{1}{2}\varepsilon T^2;$$

(with the -½ used for convenience)

marginal willingness to pay per collection is then,

$$W_T' = \delta - \varepsilon T\ ;$$

and total willingness to pay for back-door service on a regular basis (100 percent of time) is

$$W_{100} = \delta(100) - \tfrac{1}{2}\varepsilon(100)^2$$

where W_T = total willingness to pay

T = percent of collection in a year at back door, and

W_T' = marginal willingness to pay

δ and ε are parameters of the relationship

The total willingness to pay as a function of the distance from the back door to the curb is

$$W_{DT} = \zeta + \eta D$$

The ηD acts as a demand shifter. Thus, for a different distance from back door to curb from the one represented, the total willingness to pay for regular back-door service would be (by adding this demand shifter to the total willingness to pay for 100 percent back door service for the distance for which the parameters apply)

$$W_{D,100} = \delta(100) + \eta_{100}\hat{D} - \tfrac{1}{2}\varepsilon(100)^2$$

where η_{100} is the marginal effect of distance on willingness to pay for 100 percent service, and $\hat{D}$ is the distance difference. (Note that both the δ and η are likely to differ from time to time throughout the year. Indeed, it is these differences that give slope to the marginal willingness to pay function in Figure 4a. However, there will be an average δ and η for 100 percent service, which can be represented by δ_{100} and η_{100}.)

To represent the willingness to pay for a first, second, or more containers, the relationships can be taken to be

$$W_{C1} = \delta_1 T - \tfrac{1}{2}\varepsilon_1 T^2$$

$$W_{C2} = \delta_2 T - \tfrac{1}{2}\varepsilon_2 T^2$$

$$\vdots$$

$$W_{C\eta} = \delta\eta T - \tfrac{1}{2}\varepsilon\eta T^2$$

Then

$$W_C = \sum_{i=1}^{n} W_{Ci}T$$

$$= \sum_{i=1}^{n} \delta_i T - \tfrac{1}{2} \sum_{i=1}^{n} \varepsilon_i T^2$$

$$\text{and } W'_C = \sum_{i=1}^{n} \delta_i - \sum_{i=1}^{n} \varepsilon_i T$$

It has also been indicated that, for any given T, $W_{C1} > W_{C2} > \cdots W_{Cn}$.

Demand for frequency of collection--Consider next the demand for frequency of collection, or, stated alternatively, the interval between collections. The usual frequency of service that is provided appears to be once-a-week, with twice-a-week services a close runner up.*

Again, as with curb service, there would be some willingness to pay for more frequent service. More frequent service, by reducing the interval between collections, would reduce the buildup of odors, the breeding and hatching of insects,** the attraction to rodents, exposure to scattering by animals, and the pressure on space and facilities required for between-collection storage.

Again, the service could be provided (taken) on an either/or basis or on an optional-at-each-collection-offered basis. With respect to the latter, for example, if 3 times a week curb service were offered on Mondays, Wednesdays, and Fridays, one could choose not to set the refuse out on the curb on Wednesdays and in fact receive twice-a-week service. Or, if back-door service were provided, one could notify the agency not to collect on Wednesdays. In addition, there would also be some positive willingness to pay up to continuous, taking-the-wastes-away-as-produced services. However, if the nth weekly service were not offered, its price would in effect be infinity, and no one would choose to take it on an individual basis. Nevertheless, the individual household willingnesses to pay, which are based on the utility the households derive from more frequent service, would provide a guide to the agency or firm providing service with respect to what frequency should be provided.

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* According to the U.S. EPA (1976), approximately 50 percent of urban systems provide weekly service, about 45 percent (mainly in the South, particularly Southeast) twice weekly, and about 5 percent more frequent service.

** One source states that at least twice weekly service is needed to break the fly-breeding-hatching cycle. Thus, it is reasonable that more frequent service would be in higher demand in the South compared to the North. This should also be true for summer compared to winter.

Willingness to pay for frequency of service is shown in Figure 6a. The figure also shows that there may be a significant difference between summer and winter demands, with summer demands greater than winter. In summer, decomposition of wastes occur, whereas in winter there is an icebox effect. Flies and other insects breed in the summer, garden and yard waste add to waste storage problems in the summer, and the alternative of burning papers in the fireplace is not attractive in the summer (although outside burning is, if not prohibited by laws against open burning).

Figure 6 shows a declining marginal willingness to pay for collections per week. This ties in to the demand for services for collecting different type wastes and the alternatives for disposing of the different types. Thus, the demand for added frequency of collection also ties into the demand for quantity of collection.

If service were relatively infrequent, say once a week, there would be considerable inducement to dispose of wastes in alternative ways. Whether the alternative is easy or difficult, high cost or low cost, quickly adoptable or not, depends on the type waste. Buying and using sink disposals to dispose of garbage (and thus avoiding the fly and other insect-breeding problems, animal attraction, and odors), would be relatively more attractive with infrequent service. Buying returnable bottles, having Boy Scout newspaper and aluminum can collections, and buying compactors would become relatively more attractive with infrequent service to reduce storage needs. Back-yard composting, depositing of old clothes in the church rummage-sale bin, or finding a taker for old things would all become relatively more attractive. If, going to an extreme, regular collection were only once every 6 months, most households would in fact find such alternative "outlets" for almost all of their wastes. The point of the declining marginal-willingness-to-pay curve is that as frequency increases to the 2, 3, and more times a week rates, there is likely to be increasingly less avoiding of alternative outlets as these alternative options are dropped.

Now how can these functions be used to guide what services should be provided? Consider a waste collection agency providing twice-a-week service studying whether it should stay with this or go to once- or three-times-a-week service. (Again, it should be emphasized that it is assumed that households do not adopt polluting alternatives, such as littering, even though this is a definite alternative that would almost certainly be adopted when faced by extremes such as a 6-month collection frequency, particularly lower income groups that would find non-polluting alternatives taking a very substantial fraction of their budget.) Refer to Figure 6b, which is a detail of Figure 6a for service. If every individual along the route had the demand shown, the solution would be easy. If the average cost per household of service were greater than a, as shown on Figure 6b, but equal to or less than b, the agency should shift from twice- to once-a-week service. If the average cost were c or less, at least 3-times-a-week service should be provided. If greater than b, less than once-a-week service should be provided. Costs could be recovered by charging the average cost per customer, and since this average would not exceed marginal willingness to pay, costs would be covered. However, if different households have different demand functions, a complication arises. In this case, the costs cannot be

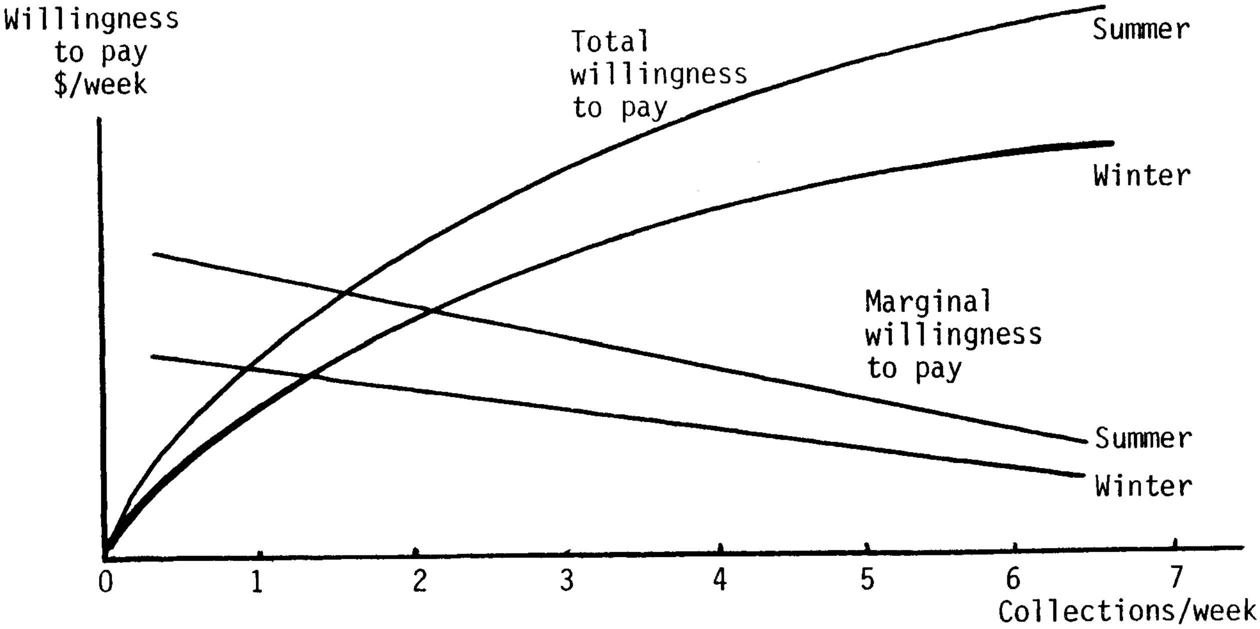

Figure 6a. Willingness to pay for frequency of collections showing summer winter difference.

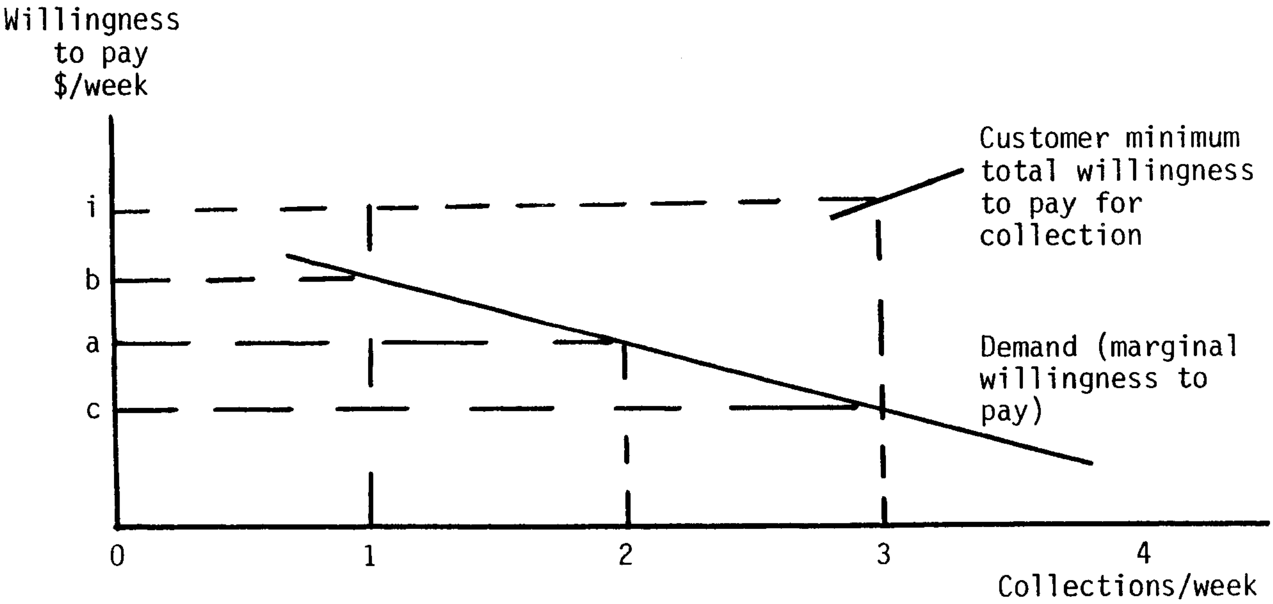

Figure 6b. Willingness to pay for frequency of service showing critical prices for shifting frequency.

recovered by charging the average cost if individual households have the option of not taking the full number of services per week and thereby avoiding the charge for added services.

This can be overcome in one of two basic ways. One is to make no charges for frequency of service directly to users, but to fund from taxes. Another is to charge the average cost to each household, but not give the option of avoiding charges for frequency of service. A non-setting-out of refuse on any of the added days of the week would be treated as a zero quantity on that day, not as a case of not receiving the third weekly service. (Or, if back yard service were provided, a notification by an individual not to collect on a particular day would be treated as a zero quantity, not as a case of not receiving back yard service on that day, that is, not as a case of not receiving the 3rd weekly service.)

Considering this latter case, if the only option for avoiding charges were to not receive waste collection service at all, the question would be whether everyone is better off with than without the service. For 3 weekly collections, as long as i, the total value to the household to whom services are worth the least, is equal to the total cost for the 3 collections per week (average cost for 1st, 2nd, and 3rd), then every household is better off. This is likely to be the case for all practical purposes.

Neither taxing or charging as suggested violates marginal conditions for maximizing household utilities. This is true because no non-optimum action is induced by such charges. "Taking" or "not taking" the third weekly service does not affect efforts or costs. The third service is there, once it has been decided upon, whether "taken" or "not taken" by the individual.*

Another question that might be asked is whether a denial of the third weekly service to those who might have a high marginal willingness to pay does not somehow impose an artificial, non-optimum restriction. If just a few along the route have high enough marginal functions, high enough so that the sum equals cost of the added collection cost, the service would be provided. At the extreme, this few could be one, but this would be a high cost service indeed if, also in the extreme, no others along the route found any marginal utility in the added service.

There is considerable support in the literature for frequency of service affecting quantity of wastes set out for collection. Probably the main empirical support for this comes from Quon et al (1968), who state that "the information on refuse quantity (from wards in the City of Chicago) when categorized with respect to collection interval, clearly reveals an increase in refuse production with greater frequency of service." Ernst (1975) supports the possibility of such a relationship in a footnote.

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*There could be a small incremental charge for the cost of a stop and start when refuse is set out for collection, avoidable when not set out. However, this would almost certainly be smaller than administrative cost of such a discrimination.

In his text, Ernst states that "it is unlikely that either of these components (collection location and frequency) is functionally related to the amount of waste collected," but in a footnote to this statement, he allows that "It is possible, though, that higher collection frequency increases the total amount of solid waste collected by providing fewer incentives to reduce waste generation." Obviously, Ernsts' thinking was for some reason narrowed on this point, not only because he made the point as a footnote, and as a "possible" exception, but because he failed to recognize the main ways in which this could occur. He places considerable emphasis in his report on distinguishing between amounts of waste collected and amounts generated. According to his definitions, wastes generated include, in addition to wastes collected, wastes disposed of by alternative means. It is thus surprising that he fails to consider the effect of frequency of service on the proportions of wastes generated that are collected and disposed of by other means. On this point, it is interesting to note that Quon et al suggest both reduced generation (less spring cleaning) and alternative means of disposal (outside burning) as possible explanations for reduced quantities collected where there is reduced frequency of service. Wertz (1976) also supports the point that increased frequency of service leads to increased wastes. He cites Quon et al for empirical evidence. Wertz, unlike Ernst, does indicate that alternative disposal may be important. He states, "That more (frequency of service) is preferred to less is evidenced by households' expenditure for sink disposals and trash compactors, devices that also reduce on-site accumulations of refuse or their undesirable properties." By the word "also", Wertz clearly means that frequency of service and various alternative disposal devices are substitutes for achieving the ends indicated. Wertz follows this discussion of the relationship between frequency of service and amounts collected through substitution of alternative disposal for greater frequency of service with a paragraph on the mathematics involved in the inducement to generate more wastes or to adopt fewer substitutes for disposing of wastes (garbage disposals) with more frequent service.

The mathematics of the demand for frequency of service can now be presented. The total willingness to pay for frequency of service is

$$W_f = \theta F - \tfrac{1}{2}\lambda F^2$$

and marginal willingness to pay per service per week is

$$W'_f = \theta - \lambda F$$

where W_f = total willigness to pay

W'_f = marginal willingness to pay, and

F = frequency of service per week.

θ and λ are parameters of the relationship.

The willingness to pay for more frequent service is related to demand for quantity of service through the demand for cleanliness/spaciousness, as suggested by Wertz.

Now, there exists a demand function for cleanliness/spaciousness, which can be visualized as beginning at some low-level-of-cleanliness/spaciousness point where the marginal willingness to pay is very high, and as crossing the axis at a point near perfect cleanliness/spaciousness where the marginal value is zero.

In addition, there exists a production function which represents the technical means using various combinations of inputs (substitutes) for producing cleanliness/spaciousness. For any given level of cleanliness/spaciousness, and for any given set of prices of the inputs for producing it, there exists a least-cost combination of inputs. These costs over the range of outputs represent the cost function. The household willingness to pay/cost functions are shown in Figure 7.

While there is a cost attached to each input option, there is (under the arguments presented above) no marginal cost to the individual household for providing or receiving an additional collection per week if offered. Marginal costs of obtaining various degrees of cleanliness/spaciousness to the individual would, however, shift with a change in collection frequency, for example, downward and to the right in going from 2 to 3 collections per week, as shown in Figure 8. Of course, the slope of the total cost function will decrease. However, if average costs of the firm providing the collection services, which will increase in going from 2 to 3 collections, are charged to the household, the level of the total cost function will rise, but not necessarily above the level for 2 collections per week, as shown in Figure 8.

There will be a consumer surplus associated with going from 2 to 3 collections a week. This should equal the marginal utilities previously discussed, and, if this area is greater than the increase in total costs to households (increment a on Figure 8), shifting from 2 to 3 collections per week would be justified (assuming the household depicted is the average.)

By depicting the demand and supply in the above way, it can be more clearly seen what the utilities are that the households receive in going from 2 to 3 collections per week. First, the households get more cleanliness/spaciousness. Second, they may avoid higher-cost means of disposing wastes, such as by use of disposals, or of providing space, such as by use of trash compactors, or for cleanliness by use of better containers (for example with screw-on lids)--all of which are alternatives for frequency of service. In addition, they may shift their buying to a higher-utility producing more waste intensive buying pattern.

Figure 9 shows that this tendency to avoid alternative means of disposal and shift buying to more waste intensive goods will, when going from 2 to 3 collections/week, shift the demand for quantity of service upwards and to the right. Here again, a consumer surplus is shown, representing the marginal value of the shift (the difference in total value between 3 and 2 collections per week). This, too, should equal the marginal utilities and consumer surplus discussed above. Note that if price b is charged per

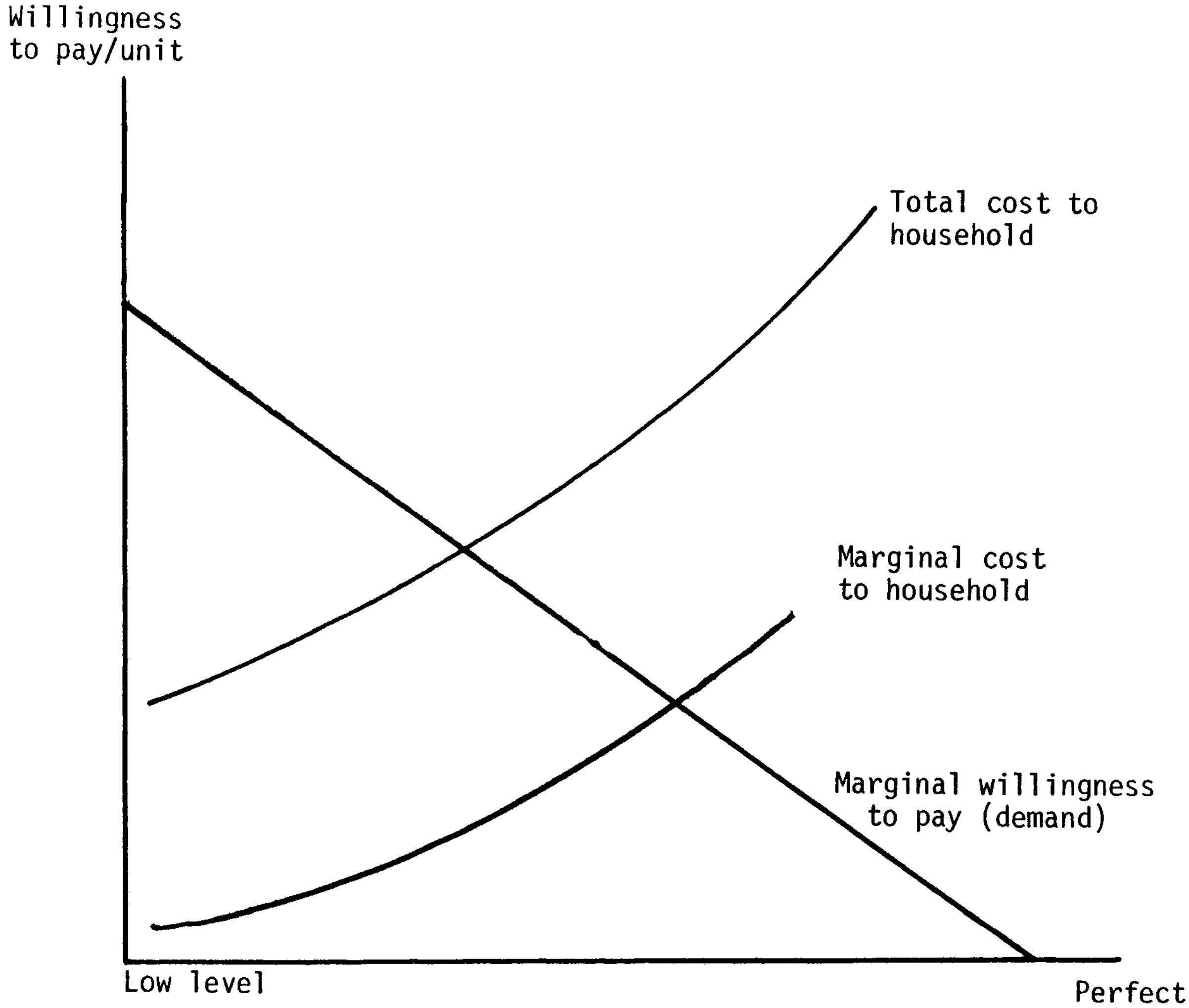

Figure 7. Supply and demand functions for cleanliness/spaciousness.

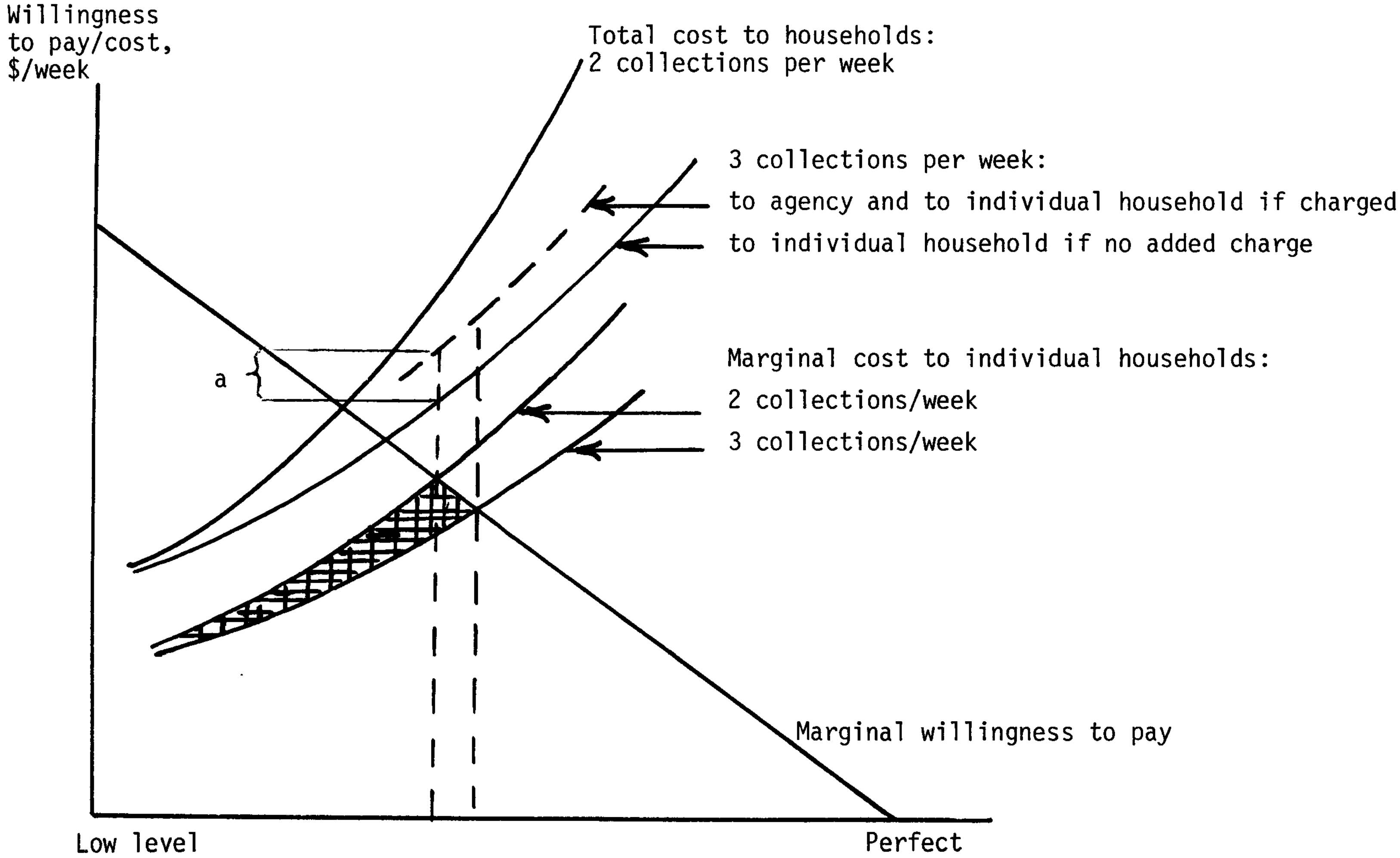

Figure 8. Shift in cleanliness/spaciousness supply function with change in collection frequency.

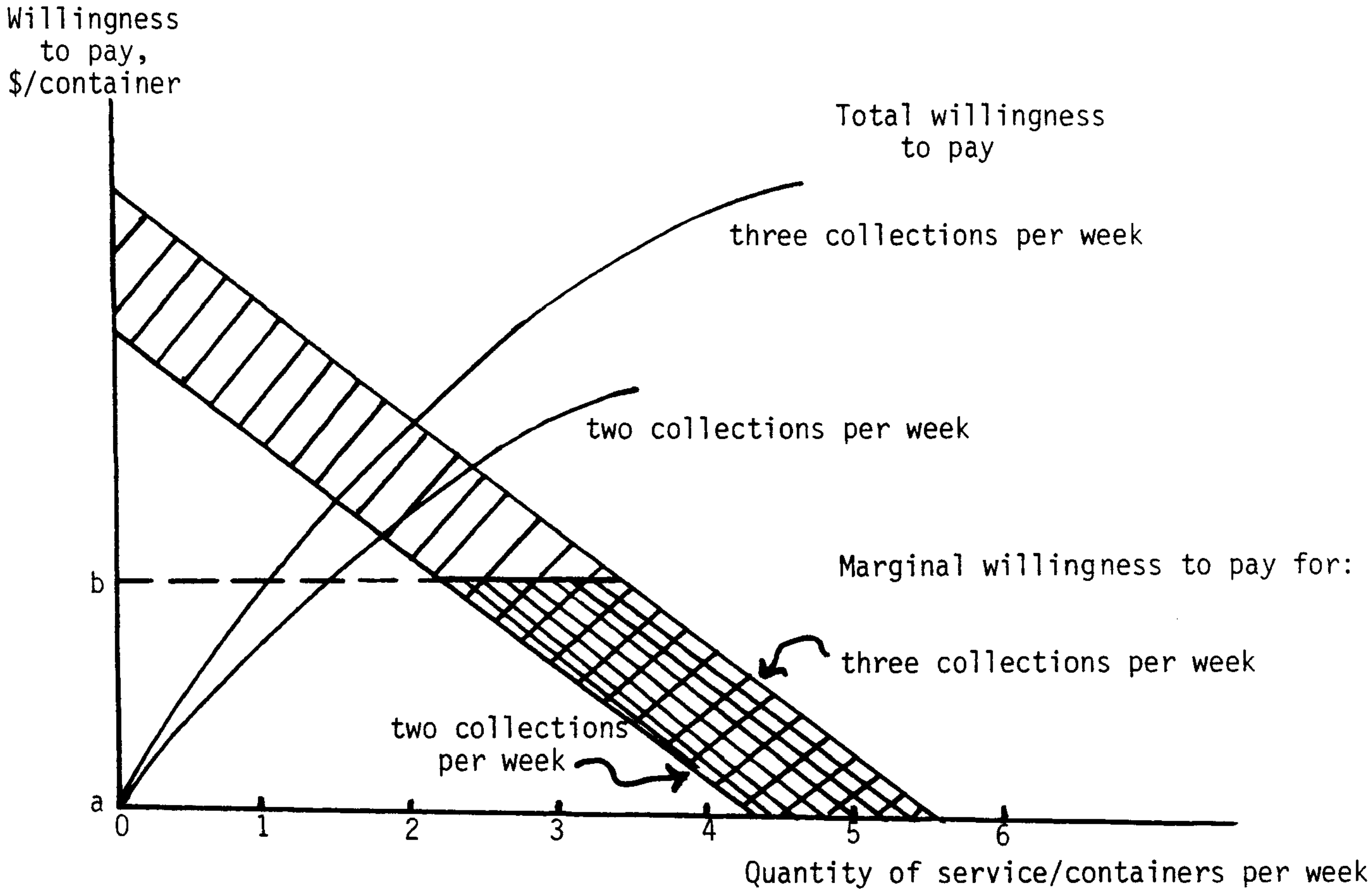

Figure 9. Shift in demand for quantity of service when collection frequency is increased.

container the consumer surplus is the slashed area, but if there is no incremental user charge, it includes the cross-hatched area. Under conceptual optimum pricing, price b should be charged, and all incremental utilities or surpluses in going from 2 to 3 collections per week would be net of the added cost for added containers. If not, however, this cost would have to be included in the total (and average) cost of the added collection.

<u>Demand for quantity collected</u>--The willingness to pay for quantity collected for two different frequencies of service is depicted in Figure 9. The demand for the service is the marginal willingness to pay, a declining function. The number of containers at zero marginal willingness to pay would be the quantity of service demanded under the usual flat charge (no incremental quantity charge) system.

In equation form, total willingness to pay,

$$W_q = \nu Q - \tfrac{1}{2}\xi Q^2 ,$$

and marginal willingness to pay,

$$W'_q = \nu - \xi Q$$

The relationships among location, frequency, and quantity are symmetrical when viewed from the standpoint of one or the other, and since the relationships have been viewed from the standpoint of location and frequency, they need not be repeated here.

<u>Demand for collection of different type wastes</u>--As has been previously indicated, there are two reasons for considering the demand for collection of different type wastes. One is based on a supply side factor. Different type wastes may involve different handling costs or provide different salvage values and households may face different supply price functions for separated wastes. If wastes are separated, advantage can be taken of these differences. The second reason is that households may have different demands for the collection/disposal of different type wastes, based either on differences in storage/nuisance problems avoided or alternative disposal options open for the different type wastes. The two reasons may go together for a particular type waste.

The willingness to pay on the part of a household for collection/disposal by the community collection agency of two separated wastes would be less than the demand for unseparated disposal because of the cost to the household of separation. To otherwise make separation worthwhile, there would have to be a positive value to the household, such as nuisance avoidance, from the act of separation and separate storage. This does not seem likely. Thus, the sum of the supply prices for separated wastes must be lower by enough to offset the decrease in separated-waste demand prices (the cost of separation to households.) This would depend on the extent of reduced handling cost/increased net salvage values, as seen by the collector, for separated wastes as opposed to combined wastes.

Where one part of the wastes is disposed by alternative means (own disposal), and the residual is deposited for collection and collected by the community collection service, the reason is likely to be a positive value of separated wastes and alternative disposal resulting in the avoidance of space/nuisance problems. Here, the algebraic sum of the decrease in the supply price for residuals collection/disposal compared to total-wastes collection/disposal (if there is in fact any change, one way or the other) and the space/nuisance avoidance values achieved must offset the costs of separation and alternative disposal of the separated wastes.

Income Effects

The effects of income levels on the quantity of goods and services demanded, and the application of these theories to demand for services in the solid wastes collection/disposal field, have been fairly well developed and presented in both words and equation form, as well as supported through empirical analysis, both in the original Sheaffer-Tolley study and in subsequent studies. It is believed that little needs to be added in this extension. The main extension here, which is new empirical analysis using more recent data, is reported in Section III of this report. That extension supports earlier conclusions concerning the likely direction and range of income effects. Both conceptual and empirical extensions by others are reported in Section II, where studies by others are reviewed and critiqued.

Nevertheless, a brief restatement of the theory of income effects and their application in the solid wastes field, along with a few added or rephrased theoretical points, is in order.

Because prices attach to various goods and services that produce utilities, income restricts the total size of the bundle of priced goods and services that can be purchased. Optimum allocation of income among priced goods and services requires that marginal utilities (incremental utilities per incremental dollar of income) be equal among all allocations. For goods and services that are not priced, amounts are taken to the point where their marginal utilities are zero.* This also places a limit on the amount of services, in this case of free services, that will be taken. Since, in the usual case, and in the Chicago area of study reported here and in the 1971 Sheaffer-Tolley study in particular, prices (incremental-quantity user charges) do not apply, it is this zero marginal utility amount which is the usual limiting amount.

This limit comes about in one way because of complementary relationships (in the household-utilities production function) between the quantity of community waste collection services and the quantity taken by households of other goods and services that are limited by income. In particular, the quantities of goods purchased, particularly consumer non-durables, or

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* In general, goods and services are taken to the point where their marginal utilities equal their marginal costs. For priced goods and services, this is the marginal opportunity cost of other goods and service (their marginal utilities), and for non-priced goods and services, zero.

size of lawns kept, which produce wastes, are limited by income/price, thus limiting the demand for community waste collection services. (Households do not fill their garbage cans with sand merely to take greater advantage of a free service. This costs something, that is, has a negative marginal utility.)

The phenomenon of less wastes at lower incomes through lower consumption appears to be a complex one. Lower consumption at lower incomes is reasonable. However, just what the effects of lower income on collected wastes are are not clear. Studies by Richardson and Havlicek (1976, 1975, 1974) and Saleh and Havlicek (1975), reported in Section III, have indicated that yard wastes and newspaper wastes do increase with income, but not food or clothing wastes.

The simple explanation of lower income persons not producing more food and clothing wastes could be that they do not really (to any extent) eat or wear less. However, as earlier pointed out, lower income families may tend to eat more leftovers, use scraps to feed the dog rather than buy dogfood, wear clothes out more and make patchwork quilts, and otherwise "save string" and "mine" wastes. They may do so because the alternative value of their labor, used in mining and converting wastes to reusable products, is lower, and because this may represent their best alternative for increasing their incomes. At higher incomes, more goods are purchased, and, not violating the law of conservation of matter, more wastes should be produced from these goods at a faster rate. Or, as Tolley has stated it, to maintain a desirable quality of life commensurate with income, consumers have incentives to scrap earlier and buy a new item as incomes increase. Thus, lower income families may generate less food and clothing wastes. However, as Havlicek and his coauthors have pointed out, the effects of such higher scrapping rates on quantities of collected wastes may be offset by greater use of alternative disposal at higher income, such as use of sink disposals and finding takers for old clothes.

The extension of the theory in this paper suggests that there are other complementary relationships that may limit the quantities of waste collection services demanded. One is moving-the-waste-to-the-curb, which involves either an own cost for moving the containers to the curb, or purchased back-door service. To the extent that income restricts the amount of back-door service purchased (in a broader sense, also, to the extent that the availability of own household labor, which is a form of income, restricts this "service"), less of the complementary quantity-of-wastes-for-community-collection will be taken. Also, to the extent that income restricts the frequency of collection service taken, less of the complementary quantity of service will be taken.

Ernst (1975) further suggested that at lower incomes, the general quality of waste collection service taken (provided) may be lower, and thus less attractive for use. This is the same point, extended beyond location/frequency attributes.

Marginal utilities of various goods and services, including those of non-priced goods and services, may change as income and total spending change. Thus, the same proportions of added income, compared to base income, may not be spent on the various goods and services. The 1971 Sheaffer-Tolley study revealed a positive income elasticity of demand for community waste collection (indicating that the service was not an "inferior good")* but one of less than 1.0, specifically between 0.3 and 0.7, indicating that less than a proportional amount of waste collection is demanded as incomes rise. This is reasonable, as Ernst confirms, on at least two grounds. First, the marginal propensity to consume with respect to income is less than 1.0. This is certainly true with respect to transitory income, and the data used include transitory elements. Second, the proportion of added income spent on non-durables tends to decrease as income increases. Thus, proportionally less wastes would be produced as incomes rise.

Other Effects on Demand

In addition to price and income, there are a number of factors that may affect quantity of services demanded. These may include, but are not limited to, population density and lot size, season of the year, working and eating-away-from-home status of members of the household, race, age structure and education levels of household members, region of the country (climate), ownership of alternative disposal facilities (sink disposals) or means-of-saving-leftovers facilities (home freezers). Laws on bottle return, use of sink disposal practices, and customs in certain areas may affect quantity. Population or number of households will affect total quantities for a community, and household size may affect both per-household and per-capita amounts. The theory of these relationships is more or less obvious. The extent of the effects can be determined by regression analysis. Additionally, some information might be obtained from production function analysis.

Integration of Supply and Demand Through Price

Price is the integrating factor between supply and demand. This role has been largely covered in discussing supply and demand themselves. The economic efficiency role of price is to avoid social losses from under- or over-pricing. Without considering the costs of administering a pricing system or of externalities, this means marginal cost pricing based on quantities of services provided.

Where solid waste services are not quantity-priced, the price for more or less of the services to the household is zero. To the extent that the use of service is responsive to price, more of the services are used than would be used if prices were set to reflect the costs of more or less services. This is true because the services are worth less than their cost. The net social loss from zero pricing (flat charging) is measured by the cost of services provided they cost more than they are worth, less the value of these services. Marginal cost pricing would avoid this net social loss.

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* Less is not taken (to keep its marginal utility equal to its marginal cost) as incomes rise.

However, there are administrative costs involved in quantity pricing. First, the quantity must be measured, and second, billing becomes more complex. (There may, of course, be offsets from better record keeping.) In addition, as has been discussed, there may be external costs, such as littering, resulting from pricing, and, from an individual community point of view, loss of tax and revenue-sharing advantages. Thus, the total net benefits of pricing may not be positive. Whether or not incremental charge systems based on marginal costs should be instituted would depend on whether or not the net total benefits are positive in each particular case. This involves a benefit-cost analysis. Apparently no empirical studies of such benefits and costs have been undertaken (see Section II).

EXTENSION OF THE THEORY OF DEMAND FOR RESIDENTIAL SOLID WASTE COLLECTION/ DISPOSAL TO INCLUDE PUBLIC GOOD CONSIDERATIONS (ENVIRONMENTAL EXTERNALITIES)

Community cleanliness, which involves sanitation, health, and safety and a sense of neatness and orderliness, is a public good. A principal input for achieving the desired level of community cleanliness is the non-polluting collection/disposal of all community solid wastes. Where individuals do not "automatically" use non-polluting services for collection/ disposal of their solid wastes, the public-good aspects of solid waste collection/disposal must be considered in developing the theory of demand.

Non-polluting collection/disposal involves, first, the community having a regular collection/disposal service; second, rules for its use, particularly rules prohibiting alternative polluting disposal, such as littering, open burning, and dumping; and third, observation of the rules by members of the community.

There are certain economic aspects of this community waste collection/ disposal input for achieving community cleanliness. These include the demand for cleanliness, mainly litter control, the alternatives for achieving it, and optimum solutions. Goddard (1975) has developed a comprehensive "complete pricing model" for taking these considerations into account in pricing solid waste collection/disposal pricing. This model is discussed in Section II of this study. Others have also presented and discussed models, including McFarland's empirical model (1972), and Ernst (1975). Rather than repeat what Goddard and others have already done, these economic aspects are taken up in a series of numbered discussion points that are presented below.

1. If the rules for use of collection/disposal service are fully observed by households and others (and if the collection/disposal service itself meets certain standards for preventing scattering of wastes along routes and for proper disposal), essentially 100 percent control of solid wastes effects on community cleanliness will be maintained.

2. With respect to this 100-percent control, it is almost univerally assumed that the marginal public benefits, in terms of community cleanliness, of observation of the rules (and certainly public plus private benefits) are greater than the marginal private costs

of observation up to the full observation of the rules. Thus, if there could be full observation of the rules at essentially no public cost, there would be no question of the optimum level of control of solid wastes effects on community cleanliness. It would be 100 percent.

3. While costs probably do tend to rise (for example, it requires more effort to not-litter while in a public place the farther the litter basket) and while benefits may tend to decline as 100-percent control is approached, there appears to be little if any reason, either on judgmental or empirical grounds, to substantially question the above assumption. (This does not necessarily apply to disposal itself according to standards. Standards for sanitary-land-fill and other disposal methods, for both typical residential wastes and those including hazardous elements, are included as an area for needed research in Section IV.)

4. On private grounds alone, there may be reason for less than 100-percent observation of rules. Littering and dumping or other own-disposal that pollutes may be privately less costly than use of the community service for certain wastes, at certain times, or in certain places. There are, it is emphasized, two aspects of this, the private costs of the community service and the private costs of the alternatives.

5. Because there are these two sides, there are two approaches to reducing or eliminating the littering and dumping itself, one is that of encouraging the use of the community service, which means lowering its cost to the user, and the second that of discouraging use of alternatives, which means raising the cost of alternatives to the user.

6. The costs that are subject to modification are not limited to monetary costs, although price and monetary considerations may play an important role and may be directly involved in non-monetary considerations.

    a. On the side of encouraging greater use there are first, of course, price considerations. The marginal charge for collection/disposal could be less than cost by any amount to encourage use. Flat charges, that is zero marginal charges, are typical, probably because these avoid any accounting and have tax advantages, not strictly because zero (flat) charges are the optimum price. Better, more frequent service with back-yard collection would in effect also reduce costs of use, as would providing free containers. All of these approaches may involve encouraging greater generation of wastes in addition to greater relative use of community collection facilities to reduce or eliminate littering. This is a price paid for encouraging use of community facilities, which must be compared to the benefits achieved.

b. On the side of discouraging alternatives, one cost may be the conscience cost--knowledge that in littering and dumping, one is breaking the golden rule and stealing environmental quality from one's neighbors, and where there are laws, that one is breaking laws. For those without, or with insufficient, conscience, there is the cost attached to the probability of getting caught and paying a fine. Again, there may be a cost associated with promoting greater observation of the golden rule and the laws, and with enforcement of the law, which costs must be compared with benefits achieved by such promotions and enforcement, as indicated below.

7. In addition to reducing littering and dumping itself, the effects of littering and dumping on community cleanliness can also be reduced by increased community litter collection and general street and public place cleaning.

8. Where the rules for use of solid waste collection/disposal are _not_ observed 100 percent, there _is_ the question of how much community cleanliness is wanted. The marginal benefits of different levels of cleanliness, and thus demand for cleanliness, would vary with community income and other characteristics.

9. The actual degree of cleanliness demanded will also depend on the marginal costs of achieving cleanliness through the various approaches, that is, the cost for added units of cleanliness, as measured by some index, in the various approaches--subsidizing use of the community system; advertising, education, promoting and enforcing greater observation of rules and laws; and cleanup.

10. The optimum program for "cleanliness management" would, of course, be one that equated the marginal costs in each of the approaches to obtaining cleanliness to the marginal benefits of cleanliness.

SECTION II

REVIEW AND CRITIQUE OF PRIOR STUDIES OF DEMAND FOR RESIDENTIAL SOLID WASTE COLLECTION/DISPOSAL SERVICE

In this section, prior studies of demand for residential solid waste collection/disposal service are reviewed and critiqued, with particular emphasis on empirical results related to price and income elasticities, as called for in the EPA request. The section is organized into four parts. The first three cover effects of various factors on the quantity of solid waste collection/disposal services, first price, second income, and third other factors as reported in the literature. The fourth section discusses studies dealing with environmental effects. Because of this organization around topics rather than around studies, particular studies may be discussed in more than one part.

PRICE EFFECTS

Effects of Price on Quantity of Service Demanded and Price Elasticity of Demand Estimates

Effects on Quantity Collected

No regression analysis has been uncovered in the literature of the effect of price on quantity of solid wastes collected, and only one empirical estimate of any kind has been discovered, an estimate by Wertz (1976). Wertz, averring that "there is one place among the largest American cities to find a clue about the predicted decline (in quantity of waste collection as price increases), San Francisco," compared pounds per capita collected in those sections of the San Francisco area where prices were charged on a per container basis (699 pounds per capita in 1970) with pounds per capita collected in all San Francisco urban areas, where general revenue financing predominated (937 pounds per capita). Wertz, after estimating the price per pound from given price per container, estimated "an arc-elasticity of -0.15," but stated that this "does not exactly represent the independent effect of price of service upon refuse quantities--because of variations in income, frequency of service, weather conditions, etc.---" In general, these points are certainly correct (although it is not clear why weather variation within a single metropolitan area should be important). Regression analysis, covering all important variables, and using cross-section, time-series, or combined analysis appears definitely called for to extend this analysis. Furthermore, although Wertz seems to suggest that the search should be limited to large American cities, it is not clear why. A number of smaller American communities, including but not limited to suburbs of larger cities, employ incremental-quantity charges. The quantities in these communities could be compared with the quantities in nearby areas where flat charges are employed to give insights into price effects just as well as in large American cities. The need for such extensions is covered in Section IV on areas of needed research.

McFarland et al (1972), using a "price proxy," ran a regression analysis for estimating the "effect" of this price proxy and per capita income and population density on per capita pounds of wastes collected. However, as Ernst (1975) suggests, this proxy variable, which was average revenue per household, was not a price variable in the true sense "since no solid waste management in the analysis used pricing (on a quantity basis)." Even so, McFarland et al obtained significant and negative correlation coefficients between pounds per capita of wastes collected and average revenue per household, the result that would be expected if average revenue were a true price proxy. Ernst provides some interesting speculation concerning other-than-price effects that may have brought about the relationship. As Ernst suggests, price effects if any should be extremely small under flat charge systems which relate charges to average community rather than individual actions. In any event, the findings in the McFarland study cannot be taken as estimates of price effects.

In addition to empirical studies, other studies have focused on developing concepts and models of pricing. Goddard (1975) develops a model for user charges. The model includes submodels for 1) demand and supply in collection and disposal, 2) demand and supply of litter control: individual preferences, 3) demand and supply of litter control: collective preferences, and 4) production conditions: litter control. Goddard's focus is thus on pricing in a context where litter control or externalities are a primary concern. Goddard's model specifies in equation form the various considerations for pricing and for determining associated quantities. Ernst (1975) also presents models for pricing taking externalities into consideration.

Effects of Back-Door Service and Frequency of Collection

Stevens (1977) found the frequency of service demanded was significantly and negatively related to the price for frequency of service, and significantly and positively related to the quantity of pickup, measured either in tons or cubic yards. She found that frequency was also significantly related to pickup location (with quantity measured in tons) but not significantly related to income. She found that backyard pickup service was significantly and negatively related to price for backyard service, and significantly and positively related to the frequency of service, household income, and number of persons in the household. Savas (1977) concluded that the frequency and mode of pickup were not associated with the form of payment for collection services, tax, flat, or quantity variable.

Effect of Pricing (Methods of Financing) on Costs of Service

There is a need for analysis of how incremental pricing, or other methods of financing, affect costs as well as quantities demanded. Incremental pricing can affect costs in different ways. It can reduce quantities taken, thereby reducing costs. It can be administratively more expensive, thereby increasing costs. It can also reduce costs indirectly through improvement in management, for example, improved record keeping through increased cost consciousness, improved technology, etc. These effects need to be analyzed separately under various circumstances. One analysis, in which multiple regression techniques were used, has been discovered in the literature on the subject of the effect on costs of type of financing. Clark et al (1971), using Ohio data, regressed average annual budgeted cost of residential refuse collection per pickup unit against a number of potential cost factors. They found collection frequency, collection location, and nature of financing arrangement to be significant. For financing arrangement, a zero-one variable was used, zero when a user charge is assessed, one for other method of payment. It was not stated whether the user charge was defined as an incremental charge or merely a direct charge to user as opposed, for example, to taxes. User charges added $8.17 to annual budgeted costs per pickup unit (customer).

Because of failure to report the definition of user charges, and because of limited information and analysis in general, it is impossible to draw any conclusions from this result. It should certainly not be taken to mean that administrative costs of pricing more than offset cost savings due to quantity reductions.

The need for further analysis along these lines is recommended in Section IV.

Effects of Costs on Price and Quantity of Service Demanded

Where prices are charged for individual waste collection/disposal services based on costs, the quantity of the services demanded will ultimately be a function of their individual costs. There is a considerable literature on the costs of the various services and of the various technologies and management approaches in providing these services. Two in particular have been previously cited (Clark, 1971; and Hirsch, 1965). Unfortunately, most such studies are not oriented toward supply/demand/price analysis, and their number is too great for individual review and critique in this paper. The U.S. Environmental Protection Agency (Larsen, 1976) has prepared a bibliography of studies and reports in the solid wastes field, and this bibliography cites a number of such studies.

In addition, rate information is available in the literature. Rates tend to reflect costs, and descriptions of the services and the basis for charge will indicate whether prices or flat rates are charged. As an example, a 1965 University of Oregon study, prepared in cooperation with the League of Oregon Cities, Refuse Collection and Disposal - A Survey of Practices in 164 Oregon Cities, provides information on the character of service and rate schedules for residential and commercial service. Among the data supplied are city population, normal residential charge per month, type of disposal, distance to disposal site, and rate schedule information for residential and commercial collection by amount and frequency of service, and other information on cost factors for particular cities.

As examples of the information provided, Portland and Corvallis offered once-a-week service, with charges per month based on number of cans per week.

For Portland, the charge was $1.75 for 1, $3.00 for 2, and $4.00 for 3 30-gallon cans. For Corvallis, it was $1.50 for 1, $2.25 for 2, and $3.00 for 3 35-gallon cans. Eugene offered either once- or twice-a-week service, for once a week $1.50 for 1, $2.25 for 2, and $3.00 for 3 32-gallon cans per week. The twice-a-week pickup charge was just twice as much per can, except for 3 cans where the charge was slightly less on a per-can basis. Springfield added extra charges for its per-can pickup rate in less-developed areas and in areas farther from the dump. Hillsboro added an extra charge if the 30-gallon cans' weight exceeded 100 pounds. Empire had one rate for cans under 30 gallons (using a standard 27-gallon can), a higher rate for cans 30 gallons or over ($1.50 for one can under 30 gallons, $1.75 for one can over 30 gallons). Redmond had no limit on the number of cans. It offered a standard $1.45-a-week fee for once-a-week collection, as long as the cans contained household refuse. Port Oxford had a standard fee for cans at the curb, a higher fee for cans "on lot." This report provides a good example of the kinds of services provided and the pricing practices employed, as well as some indication of costs based on charges.

INCOME EFFECTS, AND INCOME ELASTICITY OF DEMAND ESTIMATES

Studies providing estimates of income effects are more numerous than price, though still only a very few. In addition to the 1971 Sheaffer-Tolley study and the updated analysis reported in Section III of this report, these studies include Wertz (1976); Downing (1975); results from studies covering two areas in Indiana, one for Indianapolis reported in Richardson and Havlicek (1976, 1975, and 1974) and one for Lafayette reported in Saleh and Havlicek (1975); and McFarland et al (1972).

As has been previously indicated, the 1971 Sheaffer-Tolley study revealed income elasticities of demand between 0.3 and 0.7. In the McFarland et al (1972) study, no significant effect of income was found, a result Ernst found surprising in the light of the Sheaffer-Tolley Chicago findings. More recent studies, as cited above, tend for the most part to support the existence of significant positive effects of income, with elasticities less than 1.0.

Wertz, using cross-section analysis and data from 10 Detroit suburbs, found an implied income elasticity of 0.279. In a second analysis, using data from 6 different Detroit-area communities, he found an elasticity of 0.272. Both studies produced significant estimates. He compared these results with an income elasticity estimate by Downing, 0.39, based on observations made in Riverside, California.

Saleh and Havlicek (1975), in a study of food consumption and the food wastes components (garbage and food and beverage containers) of solid wastes in the Lafayette/West Lafayette, Indiana metropolitan area, found a significant positive effect of income on the value of food consumed at home. Their estimated elasticity was 0.19. However, income did not have a significant effect on the total food component of solid waste. As an implied explanation, based on higher income households owning garbage disposals, it was reported that the availability of a garbage disposal unit channeled 3.337

lb./household/week into the sewage system, out of an average 4.626 lbs./household/week of garbage (primarily food wastes), and out of 11.337 lbs./household/week total food-waste components (the difference being food-and-beverage containers).

Richardson and Havlicek, in studies of the components and seasonality of solid wastes in the Indianapolis area, found a significant positive linear relationship between total annual wastes collected and income. They found this relationship both when using income alone and income and income squared as independent variables. They did not find a significant relationship between income squared and either total annual collections or collections for any of the 13 four-week periods of the year analyzed. The authors explain that they may not have had sufficient observations at the higher-income levels to obtain significant results. Regressions were not run in double-log or semi-log forms, and no test was made of whether income elasticity varied with income.

In their analysis of income effects on the quantities of different type wastes, Richardson and Havlicek found both positive and significant relationships for 4 of 11 components. Grass was the most responsive to income. Other solid waste components with positive significant relationships were newspapers, green glass, and aluminum. Significant negative relationships were found for textiles, plastics, and garbage-and-other (food wastes, dirt, ashes, and miscellaneous). Regarding textiles, Richardson-Havlicek speculated that higher income houses may dispose of clothing through goodwill institutions, and regarding garbage-and-other, that higher income households may have garbage disposal units. Significant seasonal effects on quantities were found, with lowest amounts in the winter. Income was found to have a significant positive effect on quantities in all of 13 four-week periods in the year except one, a mid-winter period. This was the case where the income squared term was retained in the regression. Where it was not, collections for 3 additional winter periods and one fall period, a total of 5 of 13 periods, showed insignificant relationships with income (unsquared).

OTHER EFFECTS

Estimates of the effect of a few factors other than price and income on residential solid wastes quantities collected have been reported in the prior literature. These include effects of season and of household size, race, and age distribution, reported by Richardson and Havlicek (1976, 1975, and 1974); population density, reported by McFarland et al (1972); and for the food component of solid wastes, sex and age of family head (neither found significant), housewife's education, and ownership of a garbage disposal, reported by Saleh and Havlicek (1975).

Richardson and Havlicek found that total solid waste amounts collected were significantly related to household size. All components were also positively related and at a significant level for 7 of 11 components of waste. Each added household member added 8.8 pounds per week to total solid wastes. For race, percent black was used. A negative, but not significant, effect was found for total wastes, but significant negative race effects were found for three components, paper other than newspapers, plastics, and brown glass. Percent of household members 18 to 61 was found to have a significant positive effect, each percent adding almost one pound per week to household solid wastes. As previously reported, Richardson and Havlicek found a significant seasonal effect.

McFarland et al found that population density had a significant negative effect. This could be due to less yard and garden wastes at higher population densities. It might also be speculated that population density was negatively correlated with income and that population density was partially picking up an income effect. This could be an explanation of the fact, reported above, that McFarland et al found no significant income effect on solid waste collection amounts.

Saleh and Havlicek found that housewives' education had a significant positive effect on total-food solid waste, with an elasticity of 0.56 for average weekly pounds with respect to years of schooling. They found a significant negative relationship with respect to ownership of a garbage disposal, with a unit, as previously indicated, reducing collection by 3.337 pounds per household per week.

ENVIRONMENTAL EFFECTS

Goddard (1975) cites Gueron's (1972) conclusion "that collection should not be sold; an efficient price is a zero marginal price." Gueron based this conclusion on assumptions of "an increase in litter, burning, etc., and not a reduction in waste generation" with pricing, and "that the social cost of any unrestricted own disposal exceeds the direct cost of collective handling." However, as Goddard points out, the conclusions cannot be reached on a priori grounds, and Goddard further states that the two assumptions are most likely not valid. McFarland (1972) includes street sweeping costs with collection costs in her 1972 analysis. She found that such costs are higher in communities with positive marginal waste collection charges, $14.05 per person annually compared to $9.15. The inference was that pricing leads to increased littering. As Goddard (1972) points out, "because of several shortcomings to this empirical analysis---it is not possible to reach such conclusions within a reasonable margin of doubt." Goddard discusses various reasons for this, including the fact that street sweepings are only partially litter and that "the sample includes cities in both northern and southern California, with the possible result that the presence of deciduous vegetation in the former has biased the estimates." In addition, Goddard discusses lack of control of income, race, and other socioeconomic factors. No other empirical studies of the environmental effects of pricing have been discovered.

SECTION III

FACTORS AFFECTING RESIDENTIAL SOLID WASTES IN CHICAGO

PURPOSE

The purpose of this section is to update the findings of the Sheaffer-Tolley (1971) study dealing with the demand for solid wastes in the City of Chicago. That study specified and tested various econometric models in the course of investigating the nature of the relationship between the demand for solid waste collection and various socioeconomic factors. The same regression models are now tested using more recent and more satisfactory data. In this manner, the reliability of the previous econometric models, as well as the earlier findings, are evaluated. The results are also compared with results from other studies reported in the literature.

SOLID WASTES DISTRIBUTION IN CHICAGO

This study is based, as was the earlier study, on data collected by the Bureau of Sanitation of the City of Chicago. The data collected provide, on a weekly basis and by fifty political wards, the pounds of solid wastes collected by municipal trucks. The Department of Streets and Sanitation collects refuse only from residential buildings with four dwelling units or less, and it does so free of charge. Approximately one half of all solid wastes accruing in the City of Chicago are covered by these services. The fifty political wards are shown in Figure 10.

The earlier study used 1968-1969 solid waste collection data. The data used in this study cover the period 1970-1971. Only a fraction of the data was available for 1970, with the majority of the weekly data used covering the 1971 period. Where weekly data for 1971 were missing, 1970 data were used to obtain representative data for each period.

In Figure 11, weekly pounds of solid waste collection, on a per dwelling unit basis, are shown for both 1968-1969 and 1970-1971. In the 1970-1971 period, the average weekly pounds per dwelling unit is higher than in 1968-1969. Otherwise, the data show similar patterns. In both time periods, a seasonal pattern is evident. The demand for solid waste collection services was comparatively low in the first few months of the year. It reached a peak in April, and fluctuated around a high level until around Labor Day weekend, after which time it began a decline to relatively low levels.

In both 1968-1969 and 1970-1971, solid waste collection in pounds per dwelling unit varied substantially from ward to ward. Table 2 shows the 1970-1971 waste collection in pounds per dwelling unit for the 50 political

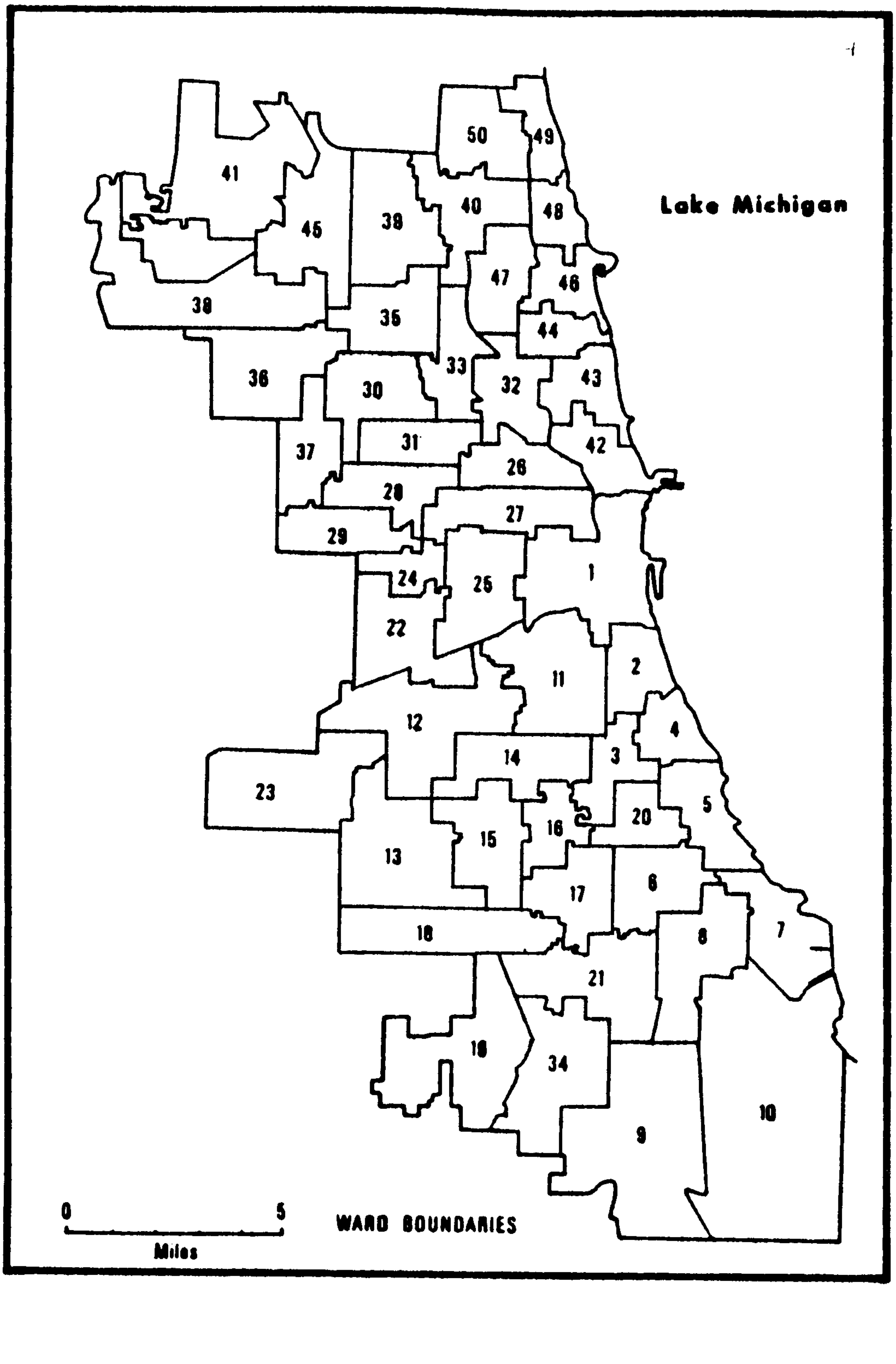

Figure 10. Ward map of Chicago.

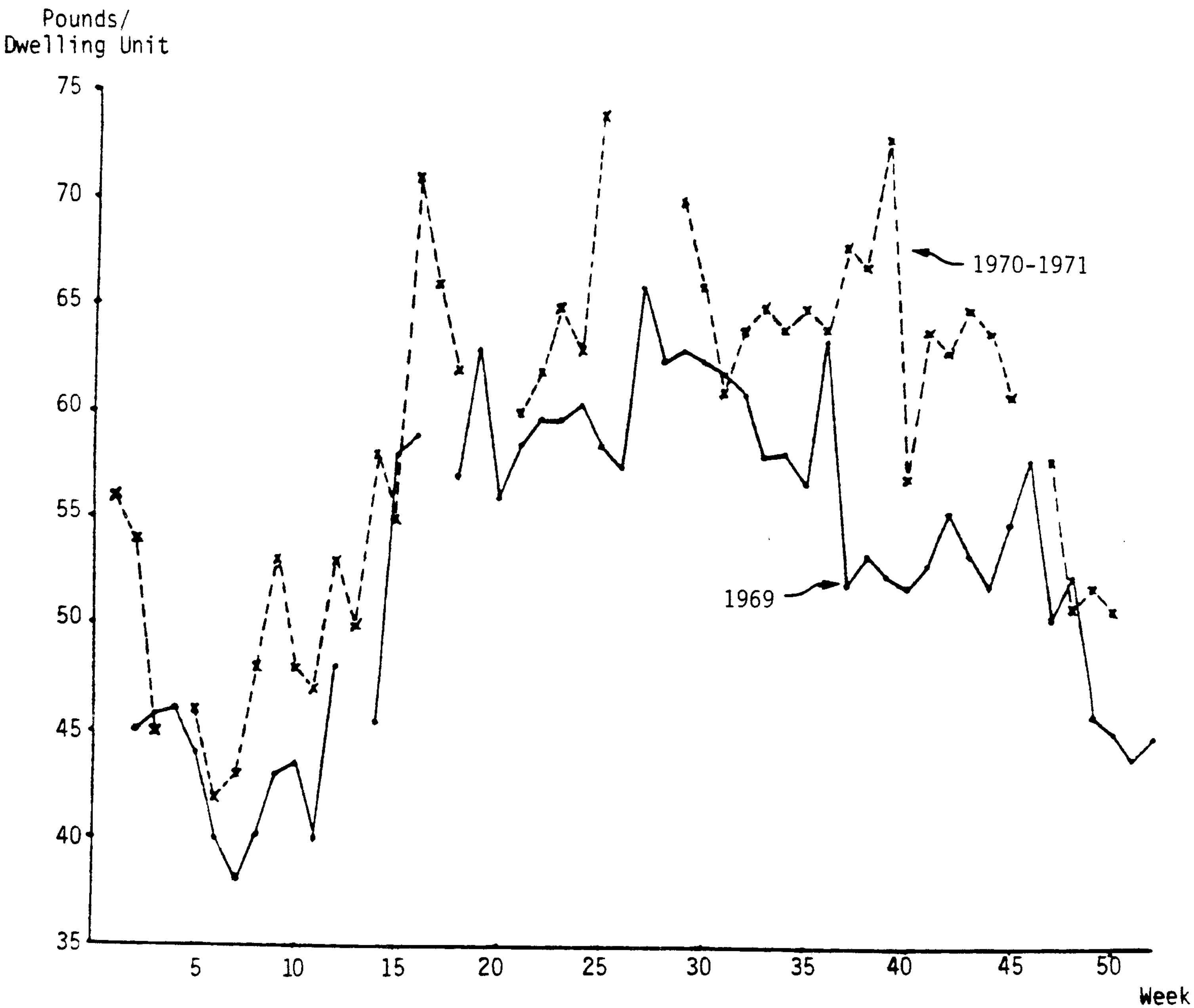

Figure 11. Average pounds of solid waste collection per dwelling unit by weeks, 1969 and 1970-1971.

TABLE 2. SOLID WASTE COLLECTION IN POUNDS PER DWELLING UNIT, BY POLITICAL WARD

Ward	Week 7 (1971)	Week 21 (1971)	Week 32 (1971)	Week 50 (1970)
1	79.8	93.3	106.5	73.3
2	32.6	52.4	49.9	48.1
3	43.5	57.6	68.8	28.6
4	31.4	41.2	49.8	28.5
5	15.5	24.6	19.7	12.2
6	38.8	58.3	58.1	39.0
7	38.0	54.0	54.2	38.1
8	44.5	69.2	64.1	63.2
9	36.3	58.2	57.4	52.7
10	44.9	77.4	70.2	57.0
11	60.2	83.2	88.2	55.9
12	41.4	66.0	63.6	44.1
13	54.1	82.9	81.4	73.7
14	41.9	61.4	57.9	41.5
15	41.6	60.8	55.0	37.9
16	47.4	70.9	68.7	63.0
17	45.2	72.4	73.7	49.1
18	44.4	78.4	68.3	68.4
19	43.4	74.1	65.5	65.2
20	25.1	33.2	35.8	41.1
21	44.6	75.6	76.6	87.8
22	42.5	63.6	63.1	42.2
23	49.0	86.2	78.2	69.6
24	41.8	67.4	71.6	37.4
25	60.6	82.7	85.6	69.2
26	52.4	72.0	69.6	43.7
27	49.7	69.5	73.0	43.0
28	43.7	66.1	61.9	54.3
29	48.8	64.0	74.2	52.1
30	43.3	66.7	58.4	34.9
31	44.1	56.2	58.3	44.3
32	49.8	66.8	66.3	44.6
33	39.8	55.0	54.3	46.3
34	54.0	87.0	85.2	52.0
35	37.9	59.8	54.5	38.5
36	38.6	71.5	61.7	43.2
37	42.6	62.4	59.2	39.3
38	42.8	70.6	65.7	56.8
39	27.3	43.0	37.1	30.6
40	37.7	50.9	48.0	41.7
41	45.6	87.7	73.3	63.5
42	53.8	72.6	74.9	44.5
43	81.2	108.2	101.8	88.4
44	40.4	53.0	49.5	45.8
45	40.9	71.9	60.2	53.3
46	32.9	41.1	38.0	62.6
47	38.4	50.0	52.6	43.1
48	26.3	33.3	33.0	18.7
49	30.0	40.0	37.0	37.2
50	40.0	50.4	48.8	52.5

wards in selected weeks, 7, 21, and 32 of 1971 and 50 of 1970. The medians are 45.2 pounds in week 7, 42.7 in week 21, 66.0 in week 32, and 62.5 in week 50. As an example of the difference between wards, in week 32, for Ward 5, the pickup was 19.7 pounds per dwelling unit, in Ward 1, 106.5 pounds.

As was the case in 1968-1969, for the 1970-1971 period the relative positions that the various wards held within the distribution shifted dramatically over the year. For 1970-1971, this can be seen by an examination of Table 3, which shows the ranking of the fifty political wards according to their solid waste yield for the 4 selected weeks. Certain wards kept a relatively stable position within the waste distribution (Wards 5, 7, 43, and 48). Others shifted dramatically in rank (Wards 8, 18, and 45). Some wards such as the 8th and 16th ranked high in the winter, while others ranked low in the winter (11th, 24th, 35th). An indication of the changes in ranks throughout the distribution can be obtained by examining the Spearman correlation values between weeks:

Spearman Correlation Coefficients

Week 7	0.88	0.93	0.65
Week 21		0.93	0.71
Week 32			0.63
	Week 21	Week 32	Week 50

The correlation between Week 7 (beginning 2/13/71) and Week 21 (beginning 5/21/71) is 0.88 and between Week 7 and Week 32 (beginning 8/6/71) is 0.93, both high. The correlation between the two winter weeks, 7 and 50 (beginning 12/11/70) is relatively low, 0.65. The correlation between the two spring-summer weeks (21 and 32) is quite high (0.93). The spring-summer weeks 21 and 32 have a rank order correlation with winter week 50 of 0.71 and 0.63 respectively. From this, it can be concluded that seasonal factors do have a substantial effect on the relative positions the wards hold, just as was revealed to be the case in the 1971 study.

EXPLANATORY VARIABLES

The earlier study used intercensal estimates for the explanatory variables. The explanatory variables in the present study were either obtained directly from or derived from the 1970 U.S. Census. Thus, the explanatory variables for this study were measured close in time to the dependent variable, waste collection in 1970-1971. Also, because these were either directly taken or derived from those in the Census, they are relatively free of estimation error. Derivation of the explanatory variables for the present study is described below. Estimates of the explanatory variables are presented and these estimates are compared with estimates in the earlier study.

Median Income

The median income for each ward for this study was obtained by

TABLE 3. RANK ORDER OF WEEKLY WASTE COLLECTION IN POUNDS PER DWELLING UNIT, BY POLITICAL WARDS

Ward	Week 7 (2/13/71)	Week 21 (5/21/71)	Week 32 (8/6/71)	Week 50 (12/11/70)
1	2	2	1	4
2	44	40	40	23
3	22	35	17	47
4	45	45	41	48
5	50	50	50	50
6	36	33	32	39
7	39	38	38	41
8	18	21	23	10
9	42	34	34	18
10	16	10	15	13
11	4	6	3	15
12	31	26	24	29
13	5	7	6	3
14	28	30	33	36
15	30	31	35	42
16	13	18	18	11
17	15	14	11	22
18	19	9	19	7
19	23	12	22	8
20	49	49	48	37
21	17	11	8	2
22	27	28	25	34
23	11	5	7	5
24	29	22	14	43
25	3	8	4	6
26	8	15	16	30
27	10	20	13	33
28	21	25	26	16
29	12	27	10	20
30	24	24	30	45
31	20	36	31	28
32	9	23	20	26
33	35	37	37	24
34	6	4	5	21
35	40	32	36	40
36	37	17	27	31
37	26	29	29	38
38	25	19	21	14
39	47	44	46	46
40	41	41	44	35
41	14	3	12	9
42	7	13	9	27
43	1	1	2	1
44	33	39	42	25
45	32	16	28	17
46	43	46	45	12
47	38	43	39	32
48	48	48	49	49
49	46	47	47	44
50	34	42	43	19

averaging the median 1970 family income of all census tracts that fall within a given ward. The median family income estimates for each ward are shown in Table 4. (No estimates of income by season were made.)

Table 5 shows for each ward the relative median family income rank from the earlier study and for the present study. A comparison of rankings reveals that while many wards did not shift very much in rank, others did, some quite dramatically. For instance, Wards 5, 34, 39, and 40 moved up significantly in the rankings. On the other hand, Wards 7, 15, 18, 37, and 38 moved down in rank. The change in rankings between wards is further demonstrated by the Spearman correlation coefficient which is 0.83. While there is still a high correlation between the ward rankings, the impacts of movements up and down the ranking order on the correlation are reflected in the Spearman correlation coefficient.

In Figure 12, median ward income is plotted against the percentage of residential dwelling units served by municipal waste collection in the various wards. A positive relationship between income and percent served can be seen by inspection of this figure. This is the same relationship revealed in the earlier study. As was indicated in the earlier study, this finding indicates that the higher income groups receive the greater advantage of a municipal service free of charge.

Variance of Income

One of the findings of the earlier study was that, using regression analysis, median income explained the main impact of incomes on the volume of solid wastes, but not all. Income variance explained some of the impact. To elaborate on this point, suppose that families in a ward with extremely low or high incomes produce more or less solid wastes than the average family produces, based on the income-waste relationship. Then, for a given median family income, a ward will produce more or less solid wastes the higher the variance of the income distribution. Consequently, in a multiple regression analysis, the variance may have a positive or negative coefficient. Therefore, when significant coefficients for the variance (σ^2) are found in a cross section analysis, the indication is that the response of households to income is different for households with extremely high or low incomes from that of households with incomes closer to the center of the income distribution.

There is one income distribution for each political ward. Let it be lognormal with parameters μ and σ^2. Median income (i.e., the geometric mean income of the population, y, is then given by $\bar{y} = e^{\mu}$. The parameter σ^2 represents the variance, or the inequality of the income distribution.

The estimate of the income distribution for each ward was obtained following Aitchison and Brown (1957). Aitchison and Brown pointed out that, if the income distribution is lognormal, then the fractions of households with an income of more than y_i form a straight line when plotted on lognormal probability paper against log y_i. Using the fact that quartiles of order 16 percent and 50 percent are given by

TABLE 4. ESTIMATES OF MEDIAN FAMILY INCOME BY WARD, 1970

Ward	Median Family Income ($)	Ward	Median Family Income ($)
1	8,794	26	8,315
2	7,689	27	6,015
3	6,090	28	7,384
4	7,138	29	8,415
5	12,046	30	10,863
6	8,407	31	8,490
7	10,261	32	8,936
8	12,181	33	10,003
9	8,821	34	11,821
10	11,450	35	11,216
11	9,042	36	11,762
12	11,078	37	11,013
13	12,532	38	12,144
14	10,297	39	12,804
15	10,497	40	12,334
16	7,947	41	13,577
17	9,378	42	11,553
18	12,058	43	10,971
19	14,763	44	9,963
20	7,343	45	12,308
21	11,130	46	9,717
22	9,468	47	10,554
23	12,522	48	10,227
24	6,681	49	11,549
25	7,941	50	13,983

TABLE 5. MEDIAN FAMILY INCOME RANK, BY WARD

Ward	Rank, 1971 Study	Rank, Present Study	Ward	Rank, 1971 Study	Rank, Present Study
1	46	37	26	41	41
2	49	44	27	50	50
3	48	49	28	37	45
4	45	47	29	40	39
5	42	12	30	21	23
6	36	40	31	28	38
7	7	27	32	35	35
8	11	9	33	25	29
9	22	36	34	26	13
10	16	17	35	18	18
11	33	34	36	19	14
12	23	20	37	13	21
13	9	5	38	5	10
14	29	26	39	8	4
15	14	25	40	15	7
16	34	42	41	2	3
17	39	33	42	43	15
18	4	11	43	30	22
19	1	1	44	24	30
20	44	46	45	6	8
21	20	19	46	27	31
22	32	32	47	17	24
23	10	6	48	31	28
24	47	48	49	12	16
25	38	43	50	3	2

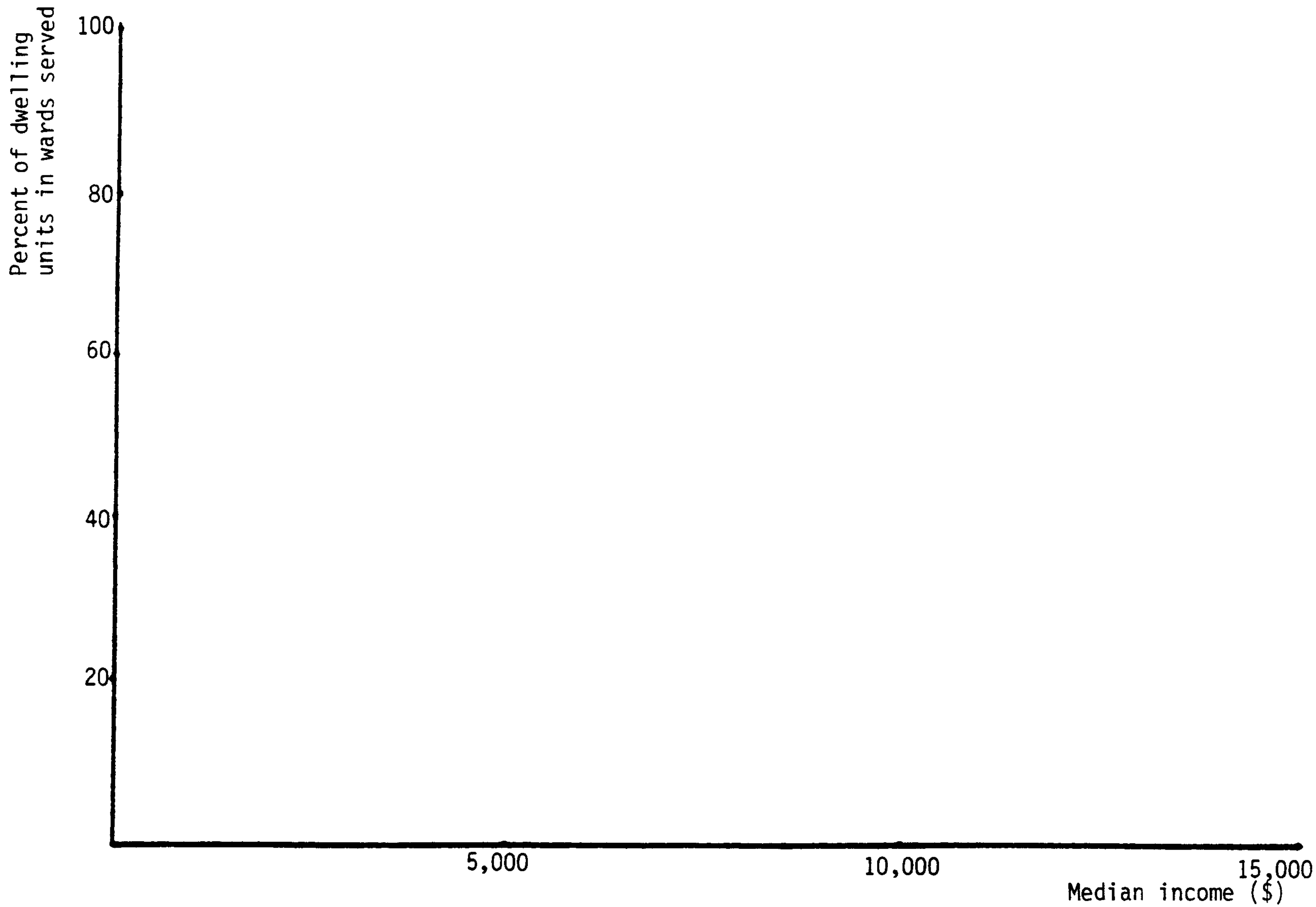

Figure 12. Relationship between ward median family income and percentage of dwelling units served by municipal waste collection.

$$\zeta\ 16\% = e^{\mu + \sigma}$$

$$\zeta\ 50\% = e^{\mu}$$

$\bar{\mu}$ and σ were determined by graphical means. This method was shown in the earlier study to be a close approximation to estimates derived using more sophisticated techniques. The estimates derived using this method are shown in Table 6 along with estimates from the previous study. It can be seen that in certain wards the variance increased from those in the earlier study (Wards 1, 20, 28, and 48), in some it decreased (Wards 19, 23, 27, and 41), and in others it remained fairly stable (Wards 9, 11, 16, 22, 32, and 33). The average variance for the 50 weeks did not change much, being 0.59 in the earlier study and 0.63 in the present study.

<u>Population, Household Size, and Percentage Blacks</u>

The remaining explanatory variables used in the previous study, which were also used in this study, were population, household size, and percentage black (non-white). Population was used to calculate solid wastes per capita. The population figures in the previous study were based on adjustments to update them from 1960 whereas the current study used directly the close-in-time Census figures. The 1970 figures are presented in Table 7. Household size was included as an explanatory variable when using waste collections per household as the dependent variable because larger households are expected to produce more pounds of waste per household than smaller ones by virtue of the fact that more people live in them. The percentage black was used because consumption habits could differ between black and other families with equal incomes. The household size and percent black figures in the earlier study were also updated from 1960 Census figures. The ones used here are from the close-in-time 1970 Census. The data for household size and percent black are shown in Table 8.

MODEL SPECIFICATION

The econometric analysis of waste collection was carried out using two alternative dependent variables. The first dependent variable, D_i, was the pounds of solid waste collected per dwelling unit per week in the i^{th} ward. The second dependent variable, C_i, was the pounds of solid wastes collected per capita per week.

The explanatory variables, as discussed earlier, were:

Y_i = the median family income of the i^{th} ward

B_i = the ratio of blacks to the total population in the i^{th} ward

S_i = average household size of the i^{th} ward

V_i = variance of the income distribution in the i^{th} ward.

As indicated above, the average household size, S_i, was used only when D_i was the dependent variable.

TABLE 6. FAMILY INCOME VARIANCES BY 50 POLITICAL WARDS

Ward	Estimates from 1971 Report	Estimates Derived from 1970 Census	Ward	Estimates from 1971 Report	Estimates Derived from 1970 Census
1	0.68	1.18	26	0.64	0.79
2	0.78	0.76	27	0.75	0.59
3	0.74	0.86	28	0.63	1.19
4	0.75	0.86	29	0.64	0.79
5	0.77	1.00	30	0.55	0.67
6	0.63	0.79	31	0.51	0.55
7	0.60	0.67	32	0.53	0.55
8	0.54	0.41	33	0.51	0.55
9	0.57	0.55	34	0.49	0.42
10	0.53	0.41	35	0.48	0.67
11	0.56	0.55	36	0.50	0.42
12	0.50	0.67	37	0.53	0.67
13	0.45	0.25	38	0.49	0.42
14	0.51	0.67	39	0.52	0.42
15	0.50	0.67	40	0.55	0.42
16	0.61	0.59	41	0.47	0.14
17	0.69	0.98	42	0.95	0.98
18	0.46	0.25	43	0.72	0.67
19	0.56	0.25	44	0.63	1.02
20	0.69	1.19	45	0.50	0.42
21	0.54	0.44	46	0.66	0.55
22	0.56	0.55	47	0.50	0.67
23	0.44	0.24	48	0.68	1.02
24	0.73	0.86	49	0.59	0.42
25	0.60	0.79	50	0.57	0.25

TABLE 7. WARD POPULATIONS, 1970

Ward	Population	Ward	Population
1	68,932	26	68,555
2	75,506	27	67,795
3	68,979	28	69,274
4	68,528	29	67,004
5	66,906	30	65,752
6	67,695	31	66,854
7	68,036	32	67,692
8	65,971	33	68,503
9	66,925	34	67,944
10	67,072	35	65,418
11	66,535	36	68,086
12	66,382	37	66,970
13	56,759	38	64,060
14	66,630	39	68,747
15	67,495	40	65,531
16	65,872	41	66,923
17	68,504	42	69,336
18	67,717	43	69,159
19	66,875	44	66,558
20	69,486	45	67,071
21	67,167	46	65,222
22	68,267	47	68,264
23	66,424	48	67,979
24	67,359	49	68,531
25	66,122	50	66,997

TABLE 8. HOUSEHOLD SIZE AND PERCENT BLACKS BY WARD, CHICAGO, 1970

Ward	Persons Per Household Unit	Percent Black	Ward	Persons Per Household Unit	Percent Black
1	2.3	35.76	26	2.6	8.98
2	2.5	91.88	27	2.7	83.35
3	3.2	98.99	28	3.2	83.35
4	2.5	91.04	29	3.6	88.60
5	2.6	57.78	30	2.4	0.11
6	2.7	97.73	31	3.0	1.42
7	2.4	26.91	32	2.5	3.85
8	2.9	77.84	33	2.4	0.30
9	2.9	28.32	34	3.2	66.30
10	3.0	9.16	35	2.3	0.01
11	3.0	11.26	36	2.4	0.02
12	2.6	5.31	37	2.4	12.49
13	2.8	0.02	38	2.6	0.51
14	2.6	6.20	39	2.4	0.65
15	2.6	8.26	40	2.3	0.14
16	3.6	95.31	41	2.7	0.01
17	3.5	97.63	42	2.1	39.17
18	3.1	28.23	43	1.9	4.93
19	2.8	2.18	44	2.1	0.75
20	2.3	97.45	45	2.4	0.02
21	3.1	86.44	46	1.9	2.63
22	2.6	0.01	47	2.3	0.08
23	3.1	98.59	48	1.9	2.72
24	3.8	36.25	49	2.0	1.20
25	3.0	4.71	50	2.4	0.17

The regression analyses were run using three functional forms. The first form specified a linear relationship between the dependent and independent variables. The second form specified a semi-log relationship. In this relationship, natural logarithms are taken of the independent variables only. Finally, a double-log form was specified. In this relationship, natural logarithms are taken of both the dependent and independent variables.

To bring out the implications of these different specifications, consider a two-variable model describing pounds of wastes per dwelling unit, D, as a function of the median income, Y. Disregarding the disturbance term, the linear specification is then:

$$(1) \quad D = \alpha + \beta \underline{Y}$$

$$(2) \quad \frac{dD}{dY} \cdot \frac{Y}{D} = \beta \frac{Y}{D} = \frac{\beta Y}{\alpha + \beta \underline{Y}} = \frac{1}{1 + \alpha/\beta Y}$$

Some of the characteristics of this form are that the income elasticity is positive and less than unity when α and β are both positive, approaching unity as $\underline{Y}$ increases. That is, income elasticity is less for low-income households than it is for well-to-do households, but always less than unity for finite incomes. For a negative α, income elasticity is greater than unity but likewise approaches unity as $\underline{Y}$ increases.

If $\underline{Y}$ were to increase exponentially with rate g in a time series context, then the income elasticity would follow a logistic curve.

$$(3) \quad \frac{dD}{dY} \cdot \frac{Y}{D_t} = \frac{1}{1 + \alpha/\beta Y_0 e^{gt}}$$

The semi-log form is:

$$(4) \quad D = \alpha + \beta \log Y$$

$$(5) \quad \frac{dD}{dY} \cdot \frac{Y}{D} = \frac{\beta}{D} = \frac{\beta}{\alpha + \beta \log Y} = \frac{1}{\log Y + \alpha/\beta}$$

The income elasticity is thus positive if both α and β are positive. In this case, it is not necessarily less than unity but decreases as D increases; in fact, it approaches zero as D goes to infinity. As income increases, the same is true. In other words, the income elasticity is higher for low-income households than it is for well-to-do families, but instead of approaching unity as in the linear specification, it approaches zero as income rises.

The double-log specification is:

$$(6) \quad \log D = \alpha + \beta \log Y$$

$$(7) \quad D = e^{\alpha} Y^{\beta}$$

$$(8) \quad \frac{dD}{dY} \cdot \frac{Y}{D} = \frac{e^{\alpha} \beta Y^{\beta-1}}{D} Y = \frac{e^{\alpha} \beta Y^{\beta}}{e^{\alpha} Y^{\beta}} = \beta$$

The income elasticity is thus equal to β and is constant as income increases. In other words, the same income elasticity applies to all households regardless of the level of their actual income.

REGRESSION RESULTS

Weighted vs Unweighted Regressions

The regression analyses were run both with unweighted and with weighted observations. Weighting was undertaken to reflect the fact that the solid waste data do not cover wastes from the entire population of a political ward. The City of Chicago collects solid wastes only from housing units containing 4 households or less. However, the explanatory variables cover the total population of each ward. The question arises, How to control for the differences? One way, as discussed in the earlier study, was to include only those wards in which some minimum percentage of the total population was served. However, any such method would be arbitrary in terms of what the minimum fraction should be. In the earlier study, weighted regressions were used. If a high fraction of the ward were served by municipal collection, then that particular ward entered the regression with a high weight. If the fraction were low, the observation was given a small weight. The squared fraction of household units receiving municipal service was used in the earlier study. As explained, squaring had the effect of further accentuating wards for which the values of explanatory variables were highly representative. The same weighting scheme was used in this study for two reasons. First, it makes the two studies comparable on this point. Second, the weighting scheme still appeared to be reasonable, based on comparison of alternative schemes, as discussed below. The basic weighting figures are shown in Table 9.

The earlier study found that the use of regressions weighted by the squared fraction of residential dwelling units municipally served was best by the R^2 criterion. The present study also carried out the regression analysis (a) unweighted, (b) weighted by the fraction of residential dwelling units municipally served, F_i, and (c) weighted by $(F_i)^2$.

The results verified that (c) was uniformly best by the R^2 criterion. For illustrative purposes, Table 10 shows the results for Week 32 (beginning August 6, 1971). The results are shown using the two dependent variables (D_i, C_i), and the three functional forms. In each case, both the R^2 and the F values are highest when the $(F_i)^2$ weights are used. Furthermore, the parameter estimates also become sharper as indicated by the smaller standard errors, and hence the increasing significance levels of the parameters. The results shown in the rest of the text are those of type (c).

Functional Form and Best Dependent Variable

Table 10 indicates that for both dependent variables, D_i and C_i, the

TABLE 9. RATIO BETWEEN MUNCIPAL AND TOTAL COLLECTION OF HOUSEHOLD SOLID WASTES, BY POLITICAL WARD

Ward	Fraction of Household Refuse Collected by City of Chicago	Ward	Fraction of Household Refuse Collected by City of Chicago
1	0.661	26	0.657
2	0.414	27	0.593
3	0.348	28	0.674
4	0.241	29	0.663
5	0.230	30	0.806
6	0.654	31	0.791
7	0.632	32	0.762
8	0.817	33	0.852
9	0.953	34	0.815
10	0.936	35	0.854
11	0.683	36	0.943
12	0.943	37	0.743
13	0.957	38	0.956
14	0.850	39	0.845
15	0.919	40	0.772
16	0.870	41	0.973
17	0.652	42	0.336
18	0.908	43	0.564
19	0.963	44	0.566
20	0.461	45	0.940
21	0.955	46	0.487
22	0.848	47	0.670
23	0.976	48	0.285
24	0.546	49	0.397
25	0.736	50	0.702

TABLE 10. RESULTS OF WEIGHTED AND UNWEIGHTED REGRESSIONS WEEK 32 (8/6/71)

Weights Used	Dependent Variable	$\hat{\alpha}$	$\hat{\beta}$	Explanatory Variable	R^2	F
--	D_i	70.039 (12.05)	-0.000730 (0.0012)	Y_i	0.0082	0.399
F_i	D_i	54.278 (6.08)	0.001102 (0.000746)	Y_i	0.0434	2.18
$(F_i)^2$	D_i	56.404 (4.51)	0.00103 (0.00065)	Y_i	0.0503	2.54
--	D_i	130.20 (103.17)	-7.342 (11.20)	log Y_i	0.0089	0.430
F_i	D_i	-11.525 (41.51)	8.401 (4.70)	log Y_i	0.0624	3.20
$(F_i)^2$	D_i	10.491 (22.75)	6.179 (2.68)	log Y_i	0.0993	5.29
--	log D_i	5.516 (1.85)	-0.1541 (0.201)	log Y_i	0.0121	0.588
F_i	log D_i	2.394 (0.731)	0.1930 (0.083)	log Y_i	0.1019	5.44
$(F_i)^2$	log D_i	2.908 (0.395)	0.1410 (0.047)	log Y_i	0.1600	9.14
--	C_i	55.687 (8.94)	0.000172 (0.000857)	Y_i	0.0008	0.040
F_i	C_i	4.0735 (1.31)	0.00139 (0.000161)	Y_i	0.6079	74.40
$(F_i)^2$	C_i	7.080 (0.929)	0.00125 (0.000133)	Y_i	0.6474	88.14
--	C_i	-67.272 (32.97)	8.88 (3.58)	log Y_i	0.1138	6.16
F_i	C_i	-65.020 (8.81)	9.022 (0.997)	log Y_i	0.6303	81.84
$(F_i)^2$	C_i	-32.424 (4.38)	5.574 (0.517)	log Y_i	0.7074	116.07
--	log C_i	-2.878 (3.23)	0.5911 (0.351)	log Y_i	0.0559	2.84
F_i	log C_i	-4.784 (0.873)	0.8334 (0.099)	log Y_i	0.5968	71.05
$(F_i)^2$	log C_i	-1.895 (0.415)	0.5295 (0.049)	log Y_i	0.7082	116.50

-- indicates unweighted.

double-log, or constant elasticity, specification was usually best by the R^2 and F criteria, and the semi-log specification between the linear and double-log specification. This is more clearly shown in Table 11, showing typical relationships between alternative forms taken from Table 10. (C_i in the example shown, the double-log formulation was only slightly preferable to the semi-log formulation based on the R^2 as well as F criteria.)

As for dependent variable, the per capita model performs significantly better than the dwelling unit model. This was a tendency that, as will be seen, was found in most of the regression models used in this study. In the discussion that follows, emphasis is given to R^2 values in comparing results. However, in all cases, where R^2 values were highest F values were also highest.

Income

In Table 12, the empirical solid waste income relationship is given for nine weeks studied. For both dependent variables, R^2 and F statistics are reproduced. (Standard errors are given in parentheses.) For comparison purposes, the linear version for the dwelling unit approach is given, even though it is never the best specification by either the R^2 or F criterion.

The double-log specification turns out to be best on a dwelling unit basis for all of the weeks studied. On a per capita basis, the double-log specification is best in six weeks, and the semi-log form is best in three weeks. Thus, in both cases, the double-log form is the dominant one. The semi-log form is slightly better on a per capita basis in Weeks 26 (in June) and 36 and 37 (in September). (Compare R^2 values for the semi-log form in Table 12 with R^2 values for the double-log form in Table 21.) Consequently, in those weeks the income elasticity is higher for low income as opposed to higher income persons. In all cases, the income variable has a positive sign, and the per capita formulation dominates the per dwelling unit specification.

How do these results compare with those from the earlier study? An indication can be obtained by comparing the results shown in Table 12 with comparable results from the earlier study, shown in Table 13. In both cases, the income variable had a significantly positive sign. The differences which have emerged are in terms of which specification is best. Whereas the double-log form was the dominant one in the current study, generally the linear specification was best on a dwelling unit basis and the double-log form was best on a per capita basis in the previous study. Additionally, as shown in Table 13, in the earlier study the linear per dwelling unit specification dominated the per capita formulation while, as shown by Table 12, the per capita formulation was better than the per unit specification in the present study. In comparing the amount of explained variation, the results from the earlier study, shown in Table 13, have higher R^2 on a per unit basis than on a per capita basis, whereas the opposite is true for the present study. In 1970, the R^2's for the per capita double-log formulation were much higher than for alternative formulations, as shown in Table 12, with at least 70 percent of the variation being explained by income.

Income elasticity may have followed a slight seasonal pattern in 1970. Figure 13 shows the nine per capita double-log formulation coefficients. The

TABLE 11. THE TYPICAL RELATIONSHIP BETWEEN ALTERNATIVE SPECIFICATIONS (WEEK 32, 1971)

Dependent Variable	$\hat{\alpha}$	$\hat{\beta}$	Explanatory Variable	R^2	F
D_i	56.40 (4.51)	0.00103 (0.00065)	Y_i	0.0503	2.54
D_i	10.49 (22.75)	6.18 (2.68)	log Y_i	0.0993	5.29
log D_i	2.91 (0.39)	0.1410 (0.05)	log Y_i	0.1600	9.14
C_i	7.08 (0.93)	0.00125 (0.00013)	Y_i	0.6474	88.14
C_i	-32.42 (4.38)	5.57 (0.52)	log Y_i	0.7074	116.07
log C_i	-1.90 (0.42)	0.5295 (0.05)	log Y_i	0.7082	116.50

TABLE 12. SOLID WASTE - INCOME RELATIONSHIP, 1970-1971

Week	Dependent Variable	$\hat{\alpha}$	$\hat{\beta}$	Explanatory Variable	R^2	F
7	log D_i	2.75	0.1172	log Y_i	0.1369	7.61
		(0.360)	(0.042)			
	log C_i	-2.05	0.5056	log Y_i	0.7439	139.43
		(0.363)	(0.428)			
	D_i	41.34	0.000345	Y_i	0.0120	0.584
		(3.15)	(0.00045)			
19	log D_i	2.98	0.1296	log Y_i	0.1558	8.86
		(0.369)	(0.043)			
	log C_i	-1.82	0.5180	log Y_i	0.7294	129.37
		(0.386)	(0.045)			
	D_i	55.90	0.000851	Y_i	0.0375	1.87
		(4.34)	(0.00062)			
21	log D_i	2.50	0.1922	log Y_i	0.3231	22.91
		(0.340)	(0.040)			
	log C_i	-2.30	0.5806	log Y_i	0.7999	191.88
		(0.355)	(0.042)			
	D_i	52.12	0.00202	Y_i	0.1966	11.75
		(4.12)	(0.00059)			
26	log D_i	2.76	0.1675	log Y_i	0.2301	14.35
		(0.374)	(0.044)			
	C_i	-37.99	6.386	log Y_i	0.7544	147.46
		(4.45)	(0.526)			
	D_i	58.49	0.00153	Y_i	0.0956	5.07
		(4.76)	(0.00068)			
32	log D_i	2.91	0.1410	log Y_i	0.1600	9.14
		(0.395)	(0.047)			
	log C_i	-1.89	0.5295	log Y_i	0.7082	116.50
		(0.415)	(0.049)			
	D_i	56.40	0.00103	Y_i	0.0503	2.54
		(4.51)	(0.00065)			
36	log D_i	2.80	0.1574	log Y_i	0.1748	10.17
		(0.418)	(0.049)			
	C_i	-34.31	5.861	log Y_i	0.7245	126.23
		(4.41)	(0.522)			
	D_i	58.26	0.00111	Y_i	0.0473	2.38
		(5.03)	(0.00072)			
37	log D_i	2.86	0.1643	log Y_i	0.2110	12.84
		(0.388)	(0.046)			
	C_i	-1.87	8.884	log Y_i	0.7359	133.77
		(25.47)	(3.01)			
	D_i	63.68	0.00156	Y_i	0.0862	4.53
		(5.11)	(0.000732)			
43	log D_i	1.90	0.2523	log Y_i	0.3821	29.69
		(0.392)	(0.046)			
	log C_i	-2.90	0.6408	log Y_i	0.8617	299.03
		(0.314)	(0.037)			
	D_i	43.49	0.00265	Y_i	0.2471	15.75
		(4.66)	(0.00067)			
50	log D_i	1.81	0.2414	log Y_i	0.3389	24.61
		(0.41)	(0.049)			
	log C_i	-3.00	0.6300	log Y_i	0.8582	290.56
		(0.31)	(0.037)			
	D_i	37.93	0.00189	Y_i	0.1972	11.79
		(3.84)	(0.00055)			

TABLE 13. SOLID WASTE - INCOME RELATIONSHIP, 1969

Week	Dependent Variable	$\hat{\alpha}$	$\hat{\beta}$	Explanatory Variable	R^2
7	log D_i	0.763 (0.811)	0.320 (0.090)	log Y_i	0.2100
	log C_i	-0.879 (1.10)	0.376 (0.121)	log Y_i	0.1674
19	D_i	35.98 (7.15)	0.00352 (0.00082)	Y_i	0.2792
	log C_i	-1.312 (1.06)	0.4822 (0.117)	log Y_i	0.2614
	log D_i	0.330 (1.01)	0.426 (0.112)	log Y_i	0.2312
21	D_i	31.94 (6.50)	0.0034 (0.0007)	Y_i	0.3068
	log C_i	-1.40 (1.06)	0.483 (0.117)	log Y_i	0.2613
	log D_i	0.200 (0.988)	0.432 (0.109)	log Y_i	0.2458
32	D_i	36.71 (6.95)	0.00295 (0.00080)	Y_i	0.2238
	log C_i	-0.93 (1.06)	0.432 (0.117)	log Y_i	0.2219
	log D_i	0.72 (1.02)	0.376 (0.113)	log Y_i	0.1873
36	D_i	29.56 (6.53)	0.00436 (0.00075)	Y_i	0.4150
	log C_i	-2.156 (1.022)	0.5768 (0.1130)	log Y_i	0.3516
	log D_i	-0.513 (0.936)	0.5204 (0.1034)	log Y_i	0.3453
37	D_i	25.05 (6.15)	0.00340 (0.00070)	Y_i	0.3279
	log C_i	-1.940 (1.12)	0.5293 (0.123)	log Y_i	0.2770
	log D_i	-0.297 (1.04)	0.473 (0.115)	log Y_i	0.2603
50	D_i	-121.24 (33.75)	18.61 (3.73)	log Y_i	0.3412
	log C_i	-1.714 (1.10)	0.4889 (0.122)	log Y_i	0.2509
	log D_i	-0.071 (0.797)	0.433 (0.088)	log Y_i	0.3345

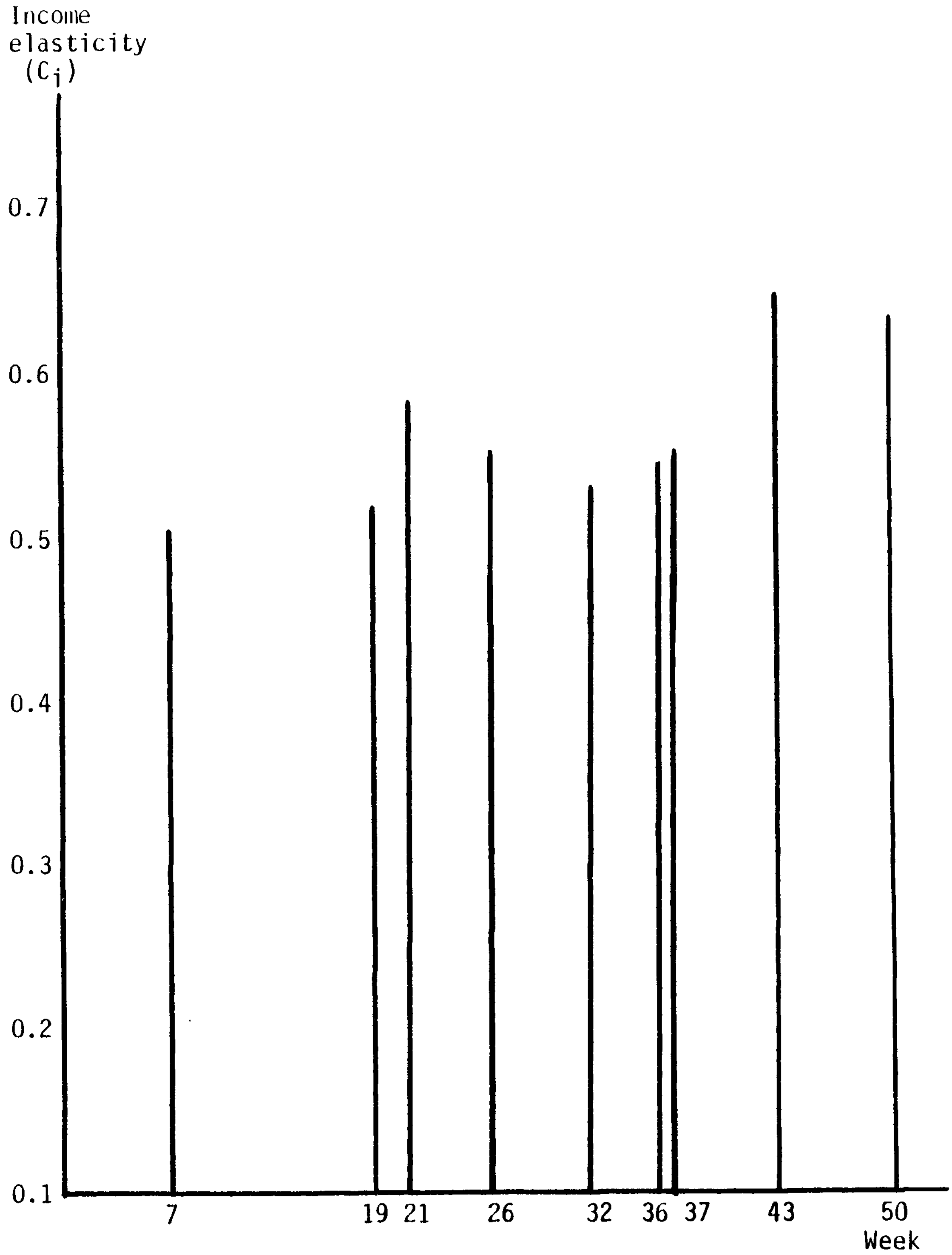

Figure 13. Income elasticity of the demand for solid waste.

elasticities were about average in the summer months when the volume of solid wastes collected was relatively high (Figure 11), was highest in the fall and early winter months when the volume of solid wastes collected was moderately low, and low in mid-winter when volumes collected were lowest. However, since in the summer and early fall the semi-log specification was dominant, in those months the income elasticity was higher for the lower income groups. If there is a basic volume of solid waste that is generated throughout the year, and in the summer months there is an additional waste component arising from increased consumption of soft drinks, beer, fruits, etc., then this component is more sensitive to income of those in lower than higher income brackets. During the hottest part of the summer (August), this consumption is relatively less sensitive to income. Seasonal variation in income, with high earnings in mid-summer among low income groups, could also cause this seasonal variation. (However, as previously indicated, no estimates of seasonal income were made.) While based on relatively sparse information, if there is such seasonal variation in income elasticities, there is a possible policy implication: pricing can be used to dampen seasonal variation in solid waste amounts. Summer would remain a problem, for which additional incentives for reducing amounts, such as greater incentives for using returnable beer and soft drink bottles, might be required.

The Variance of the Income Distribution

The variance of the income distribution was significant in all cases with the double-log formulation, and the double-log formulation was best both on a dwelling unit and per capita basis. In no case was the linear or semi-log form better. The results for the double-log specification on both a per household and per capita basis are shown in Table 14. A positive relationship was found between the amount of solid waste generated and the amount of variance in the income distribution. That is, the greater the inequalities in income in a ward, the greater the solid wastes in that ward. This finding was different from that of the previous study where a negative sign was found with respect to the income variance variable. Variance as an explanatory variable does better than income in explaining solid waste variation on a dwelling unit basis, while income does better on a per capita basis.

The combined effects of income and the variance of the income distribution are shown in Table 15. The per capita model always does better in terms of the explained variance with the R^2 ranging from 0.574 to 0.8698. The income and variance variables, when they are significant, both have a positive sign. On a per dwelling unit basis, in no single week are the income and variance variables both significant. The income variable is significant in Weeks 21, 43, and 50 whereas the variance is significant in Weeks 7, 19, 36, and 37. However, on a per capita basis, both variables are significant with the exception of Weeks 43 and 50 when the variance, though positive, is insignificant. In the other seven weeks, both income and variance are positive and highly significant. Thus, on a per capita basis, as incomes and the variance of the income distribution increases, the total amount of solid waste generated also increases. In the earlier study, this was not generally true since the variance became insignificant when income and variance are both included as independent variables.

TABLE 14. SOLID WASTE - VARIANCE RELATIONSHIP, 1970-1971

Week	Dependent Variable	$\hat{\alpha}$	$\hat{\beta}$	Explanatory Variable	R^2	F
7	$\log D_i$	4.00 (0.084)	0.1960 (0.051)	$\log V_i$	0.1970	11.77
	$\log C_i$	3.02 (0.115)	0.6117 (0.078)	$\log V_i$	0.5601	61.11
19	$\log D_i$	4.36 (0.086)	0.2114 (0.056)	$\log V_i$	0.2133	13.02
	$\log C_i$	3.38 (0.120)	0.6270 (0.082)	$\log V_i$	0.5500	58.64
21	$\log D_i$	4.44 (0.086)	0.2395 (0.058)	$\log V_i$	0.2582	16.71
	$\log C_i$	3.47 (0.132)	0.6552 (0.090)	$\log V_i$	0.5240	52.84
26	$\log D_i$	4.50 (0.089)	0.2415 (0.061)	$\log V_i$	0.2462	15.67
	$\log C_i$	3.53 (0.129)	0.6571 (0.088)	$\log V_i$	0.5370	55.68
32	$\log D_i$	4.40 (0.092)	0.2259 (0.063)	$\log V_i$	0.2111	12.84
	$\log C_i$	3.42 (0.126)	0.6416 (0.086)	$\log V_i$	0.5349	55.21
36	$\log D_i$	4.47 (0.098)	0.2566 (0.066)	$\log V_i$	0.2392	15.09
	$\log C_i$	3.49 (0.127)	0.6723 (0.085)	$\log V_i$	0.5572	60.39
37	$\log D_i$	4.60 (0.089)	0.2641 (0.061)	$\log V_i$	0.2805	18.71
	$\log C_i$	3.63	0.6797	$\log V_i$	0.5608	61.29
43	$\log D_i$	4.36 (0.108)	0.2509 (0.074)	$\log V_i$	0.1944	11.58
	$\log C_i$	3.39 (0.147)	0.6666 (0.100)	$\log V_i$	0.4797	44.26
50	$\log D_i$	4.17 (0.111)	0.244 (0.076)	$\log V_i$	0.1787	10.44
	$\log C_i$	3.19 (0.144)	0.6601 (0.098)	$\log V_i$	0.4849	45.19

TABLE 15. SOLID WASTE - INCOME, VARIANCE RELATIONSHIP, 1970-1971

Week	Dependent Variable	$\hat{\alpha}$	$\hat{\beta}$ Explanatory Variables Log Y	Log V	R^2	F
7	log D_i	3.60	0.0410	0.1574	0.2061	6.10
		(0.546)	(0.056)	(0.078)		
	log C_i	-0.7019	0.3848	0.2498	0.7948	91.04
		(0.514)	(0.052)	(0.073)		
19	log D_i	3.87	0.0501	0.1643	0.2260	6.86
		(0.559)	(0.057)	(0.079)		
	log C_i	-0.4305	0.3938	0.2567	0.7796	83.13
		(0.551)	(0.056)	(0.078)		
21	log D_i	0.309	0.1400	0.1079	0.3516	12.74
		(0.527)	(0.054)	(0.075)		
	log C_i	-1.21	0.4837	0.2003	0.8266	112.01
		(0.523)	(0.053)	(0.074)		
26	log D_i	3.60	0.0992	0.1541	0.2845	9.36
		(0.572)	(0.053)	(0.081)		
	log C_i	-0.7050	0.4366	0.2465	0.7882	87.46
		(0.573)	(0.055)	(0.081)		
32	log D_i	3.83	0.0583	0.1711	0.2260	6.86
		(0.601)	(0.061)	(0.085)		
	log C_i	-0.4688	0.4020	0.2635	0.7574	73.36
		(0.600)	(0.061)	(0.085)		
36	log D_i	3.88	0.0697	0.1993	0.2534	7.98
		(0.630)	(0.063)	(0.090)		
	log C_i	-0.4229	0.4047	0.2917	0.7710	79.13
		(0.598)	(0.061)	(0.085)		
37	log D_i	3.95	0.0670	0.2011	0.2996	10.05
		(0.580)	(0.051)	(0.082)		
	log C_i	-0.3490	0.4107	0.2935	0.7777	82.21
		(0.594)	(0.060)	(0.084)		
43	log D_i	2.04	0.2402	0.0250	0.3832	14.60
		(0.621)	(0.063)	(0.088)		
	log C_i	-2.26	0.5840	0.1174	0.8698	156.98
		(0.482)	(0.049)	(0.069)		
50	log D_i	1.98	0.2260	0.0319	0.3406	12.14
		(0.652)	(0.066)	(0.093)		
	log C_i	-2.32	0.5697	0.1243	0.8676	153.98
		(0.479)	(0.049)	(0.068)		

Household Size

Household size was included in the analysis where the dependent variable was on a dwelling unit basis. The expectation was that the larger the average family size in a ward, the more solid wastes per households would be generated, thus the greater would be the volume of solid waste collection per household. However, the results of the earlier study did not bear this out. In that study, household size alone turned out to be insignificant in all weeks except Week 32. However, the results of the current analysis indicate that household size is indeed positively related to the volume of solid wastes collected. Table 16 shows the results in double-log form, which was again best by the R^2 criterion.

The impact of controlling for income is shown in Table 17. The double-log specification is shown since it was the best, as was the case where household size was used as a single explanatory variable. In every case, where the income variable was significant, so was household size. This was the case for the summer and early fall months (Weeks 19, 32, 36, and 37). In these months, the income variable had a negative sign while household size had a positive sign. Consequently, when controlling for household size as income increases, the amount of solid waste generated decreases. (See, however, the last paragraph of this section in which it is concluded that the positive effect of income on waste volume is confirmed.) Additionally, in three weeks (7, 21 and 26), income was insignificant whereas household size had a positive sign. During those weeks, household size was a better predictor than income of the amounts of solid waste generated. For two weeks, (43 and 50) both income and household size were insignificant. This may give more credence to the notion that during the winter months there is a basic volume of solid waste that is generated that is fairly insensitive to both income and household size. In the earlier study, household size was also insignificant, but income was significant, as well as positive. For Week 50, in December 1968, the relationship was:

$$D_i = \underset{(8.44)}{29.57} + \underset{(0.00054}{0.00152}\,Y_i + \underset{(2.15)}{1.07}\,S_i \qquad R^2 = 0.1462 \quad F = 4.02$$

However, comparing 1970 results with 1968 results, from Table 17 it is evident that for Week 50 in 1970, both explanatory variables were insignificant. The linear formulation for that week gave:

$$D_i = \underset{(4.08)}{34.46} - \underset{(0.000121)}{0.000347}\,Y_i + \underset{(5.42)}{11.11}\,S_i \qquad R^2 = 0.2631 \quad F = 8.39$$

Thus, when the linear specification was used, it appears from the current analysis results that household size was a relatively more important factor in the winter. This again suggests that there is a basic amount of solid waste which is tied more to the number of persons in a family than to their income.

The results of the regressions using solid wastes collected per household as the independent variable and household size and income as the dependent variables must be compared with the results using solid wastes collected per capita as the dependent variable and income as the independent variable. As can be seen by comparing Table 17 with Tables 12 and 15, the

TABLE 16. SOLID WASTE - HOUSEHOLD SIZE RELATIONSHIP, 1970-1971

Week	Dependent Variable	$\hat{\alpha}$	$\hat{\beta}$	Explanatory Variable	R^2	F
7	log D_i	3.71 (0.352)	0.1503 (0.043)	log S_i	0.2057	12.43
19	log D_i	4.04 (0.035)	0.1795 (0.042)	log S_i	0.2734	18.06
21	log D_i	4.08 (0.032)	0.2296 (0.039)	log S_i	0.4217	35.00
26	log D_i	4.13 (0.035)	0.2183 (0.042)	log S_i	0.3577	26.73
32	log D_i	4.06 (0.037)	0.1972 (0.045)	log S_i	0.2859	19.21
36	log D_i	4.09 (0.039)	0.2180 (0.047)	log S_i	0.3067	21.23
37	log D_i	4.21 (0.036)	0.2248 (0.043)	log S_i	0.3613	27.16
43	log D_i	3.98 (0.039)	0.2729 (0.047)	log S_i	0.4086	33.16
50	log D_i	3.79 (0.041)	0.2659 (0.049)	log S_i	0.3757	28.89

TABLE 17. SOLID WASTE - INCOME, HOUSEHOLD SIZE RELATIONSHIP, 1970-1971

Week	Dependent Variable	$\hat{\alpha}$	$\hat{\beta}$ Explanatory Variables Log Y	Log S	R^2	F
7	log D_i	4.77 (0.930)	-0.1293 (0.1127)	0.2764 (0.112)	0.2273	6.91
19	log D_i	5.98 (0.891)	-0.2350 (0.108)	0.4088 (0.113)	0.3401	12.11
21	log D_i	4.88 (0.851)	-0.0970 (0.103)	0.3242 (0.108)	0.4324	17.90
26	log D_i	5.87 (0.900)	-0.2099 (0.109)	0.4230 (0.114)	0.4046	15.97
32	log D_i	6.27 (0.942)	-0.2680 (0.114)	0.4587 (0.119)	0.3609	13.27
36	log D_i	6.44 (0.989)	-0.2850 (0.120)	0.4961 (0.125)	0.3812	14.47
37	log D_i	6.51 (0.894)	-0.2789 (0.108)	0.4969 (0.113)	0.4403	18.50
43	log D_i	3.41 (1.04)	0.0690 (0.127)	0.2056 (0.132)	0.4123	16.48
50	log D_i	3.52	0.0333 (0.132)	0.2334 (0.138)	0.3766	14.19

per capita formulation is far superior based on the R^2 criterion. The R^2 values range from 0.2273 to 0.4403 in Table 17, and from 0.7082 to 0.8617 in Table 12. This even more strongly confirms that waste volume is heavily tied to the number of persons. However, in the per capita results, the importance of family income as an explanatory variable is confirmed. It appears that household size is strongly correlated with family income, and, in the per capita formulation, could be used as a proxy for income. However, this was not tested.

Race

When the fraction of blacks was used as a single explanatory variable, the general results were insignificant both on a per dwelling unit and per capita basis. The F values for the overall equation were insignificant. This was true for the linear, semi-log, and log-log formulations. In this case, the double-log specification did not do significantly better. However, there were three exceptions to the general results. All of the exceptions were found using a linear specification with the dependent variable defined on a dwelling unit basis. The three weeks are shown below.

Week 37/1971: $D_i = \underset{(3.19}{68.87} + \underset{(0.138)}{0.3126}\, B_i$ $\quad R^2 = 0.0964 \quad F = 5.12$

Week 43/1971: $D_i = \underset{(3.22)}{55.37} + \underset{(0.139)}{0.3005}\, B_i$ $\quad R^2 = 0.0884 \quad F = 4.65$

Week 50/1971: $D_i = \underset{(2.54)}{45.75} + \underset{(0.110)}{0.2627}\, B_i$ $\quad R^2 = 0.1060 \quad F = 5.69$

The three weeks were all in the fall or winter months. The relationship was a positive one indicating that for these three weeks, the higher the percentage of blacks, the higher the total amount of solid wastes. The dominance of the linear formulation for the three weeks indicated that the elasticity of waste yields with respect to the percentage of blacks was higher, the greater the percentage of blacks in a ward in those weeks. In the previous study, race by itself was a better predictor than in this study, being significant in most cases. However, the relationship there was a negative one.

When both income and the percentage of blacks were used to explain the solid waste yield by ward, then the influence of the percentage of blacks in a ward became apparent in the double-log specification. The double-log formulation again yielded the highest R^2 values in all cases. In the linear specification, the percentage of blacks was insignificant in most cases. Income, however, was generally statistically significant. In the semi-log formulation on a dwelling unit basis, the percentage black was generally insignificant during the fall and winter months but significant during the remainder of the year. This could seem to indicate that race is not a very important factor during the winter months whereas it is during the rest of the year. In the semi-log form, income was significant in all cases irrespective of whether the dependent variable was defined on a dwelling unit or per capita basis.

Table 18 shows the results for the double-log formulation. The explanatory power of the model was found to be much higher on a per capita basis than on a per dwelling unit basis. On a per capita basis, the average R^2 was 0.79, compared to 0.31 on a dwelling unit basis. The income variable was positive and significant in all cases. The percentage of blacks variable was also positive and generally significant. The exceptions were Weeks 7 (in February) and 43 (end of October) when race was insignificant.

In analysis of the effects of income and race in the earlier 1971 study, the linear formulation was generally better than logarithmic versions, and the dwelling unit approach was better than the per capita approach. Both the percentage of blacks and income variables had a positive sign. The best results for comparable weeks from the earlier study are shown in Table 19. The dwelling unit basis was best in all cases. Furthermore, in all but two weeks (7 and 50) the linear formulation was best. Additionally, these were the weeks in which the race variable was insignificant. As in the present study, race was an insignificant factor during winter months in terms of the amounts of solid waste generated. During the rest of the year, race was significant in determining the volume of solid wastes generated, especially during the summer months. Thus, both the 1971 and current studies provide support for the differentiation of solid wastes into a "basic" and "excess" component.

If the results of the previous and current analysis are compared in terms of the amount of variance explained, the current study does better. In the earlier study, the R^2 values of the best specification were generally around 0.40 as compared to around 0.80 in the present study. A significant portion of this may be due to the availability of more current data which has minimized the need for ad hoc estimation procedures.

Income, Income Variance, and Race Combined

It has been pointed out that one of the differences between the results of this study and the earlier 1971 study was the effect of the income variance variable. In the earlier study, the variance was generally insignificant when income was also included in the equation, whereas it was significant with a positive sign in the current analysis.

A set of regressions was run with income, income variance, and the percentage of blacks as the independent variables. The results on a per capita basis using a log-log specification are shown in Table 20. Both income and variance were significant in all cases. However, the race variable, although still positive in each week tested, was not significant in any week. It is probable that, in the analyses with just two variables, income and income variance and income and race, the income variance variable was in part picking up the influence of race in the former and the race variable in part picking up the variance effect of the latter. The correlation between percent black and the income variance was 0.47 indicating that the higher the percentage of blacks in a ward, the higher the income variance.

TABLE 18. SOLID WASTE - RACE, INCOME RELATIONSHIP, 1970-1971

Week	Dependent Variable	$\hat{\alpha}$	$\hat{\beta}$ Explanatory Variables: Log B_i	$\hat{\beta}$ Explanatory Variables: Log Y_i	R^2	F
7	log D_i	2.57 (0.368)	0.02290 (0.013)	0.1366 (0.043)	0.1876	5.43
	log C_i	-2.21 (0.373)	0.0208 (0.013)	0.5232 (0.044)	0.7561	72.85
19	log D_i	2.73 (0.366)	0.0325 (0.013)	0.1571 (0.043)	0.2511	7.88
	log C_i	-2.06 (0.388)	0.0304 (0.014)	0.5437 (0.045)	0.7538	71.94
21	log D_i	2.31 (0.344)	0.0253 (0.012)	0.2135 (0.043)	0.3773	14.24
	log C_i	-2.48 (0.362)	0.0231 (0.013)	0.6002 (0.042)	0.8122	101.65
26	log D_i	2.50 (0.370)	0.0338 (0.013)	0.1960 (0.043)	0.3209	11.10
	log C_i	-2.28 (0.397)	0.0316 (0.014)	0.5826 (0.046)	0.7705	78.90
32	log D_i	2.63 (0.3919)	0.0350 (0.014)	0.1707 (0.046)	0.2558	8.08
	log C_i	-2.15 (0.417)	0.0329 (0.015)	0.5573 (0.049)	0.7348	65.10
36	log D_i	-2.49 (0.411)	0.0397 (0.015)	0.1910 (0.048)	0.2830	9.27
	log C_i	-2.29 (0.419)	0.0376 (0.015)	0.5776 (0.049)	0.7467	69.29
37	log D_i	2.55 (0.376)	0.0404 (0.014)	0.1984 (0.044)	0.3348	11.83
	log C_i	-2.24 (0.416)	0.03826 (0.015)	0.5851 (0.049)	0.7542	72.12
43	log D_i	1.71 (0.401)	0.0244 (0.014)	0.2730 (0.047)	0.4168	16.80
	log C_i	-3.07 (0.318)	0.0223 (0.012)	0.6596 (0.037)	0.8718	159.78
50	log D_i	1.57 (0.417)	0.0305 (0.015)	0.2673 (0.049)	0.3916	15.12
	log C_i	-3.22 (0.309)	0.0284 (0.011)	0.6539 (0.036)	0.8752	164.77

TABLE 19. BEST SPECIFICATIONS FOR INCOME AND RACE, 1969

Week	Linear (L), Semi-log (SL) or Double-Log (DL)	Pounds of Waste Per Household (D) or Per Capita (C)	$\hat{\alpha}$	$\hat{\beta}_1$ Y	$\hat{\beta}_2$ B	R^2	F
7	DL	D	0.048 (0.957)	0.404 (0.108)	0.014 (0.010)	0.2405	7.44
19	L	D	14.95 (9.09)	0.0056 (0.00097)	17.98 (5.44)	0.4153	16.69
21	L	D	11.56 (8.14)	0.0054 (0.0009)	17.42 (4.87)	0.4554	19.65
24	L	D	12.74 (8.95)	0.00563 (0.00095)	14.47 (5.35)	0.4392	18.41
32	L	D	13.20 (8.58)	0.00596 (0.00091)	13.99 (5.13)	0.4950	23.04
37	L	D	14.28 (8.40)	0.00446 (0.00089)	9.20 (5.02)	0.3728	13.97
43	L	D	-10.27 (7.67)	0.00816 (0.00082)	11.88 (4.58)	0.7256	62.13
50	SL	D	-145.62 (40.11)	21.47 (4.52)	-4.86 (0.435)	0.3583	13.12

TABLE 20. SOLID WASTE - INCOME, RACE, VARIANCE RELATIONSHIP, 1970-1971

Week	Dependent Variable	$\hat{\alpha}$	$\hat{\beta}$ Explanatory Variables: Log Y	Log B	Log V	R^2	F
7	log C_i	-0.7321 (0.611)	0.3877 (0.061)	0.00134 (0.014)	0.2462 (0.085)	0.7949	59.41
19	log C_i	-0.7222	0.4218 (0.065)	0.0129 (0.015)	0.2214 (0.089)	0.7831	55.34
21	log C_i	-1.42 (0.619)	0.5039 (0.062)	0.00933 (0.014)	0.1748 (0.085)	0.8282	73.89
26	log C_i	-1.06 (0.673)	0.4702 (0.068)	0.0155 (0.016)	0.2041 (0.092)	0.7926	58.61
32	log C_i	-0.8174 (0.706)	0.4354 (0.071)	0.0154 (0.016)	0.2213 (0.096)	0.7620	49.08
36	log C_i	-0.8426 (0.701)	0.4450 (0.070)	0.0186 (0.016)	0.2409 (0.096)	0.7773	53.52
37	log C_i	-0.7836 (0.695)	0.4524 (0.070)	0.0192 (0.016)	0.2409 (0.095)	0.7843	55.76
43	log C_i	-2.640 (0.563)	0.6200 (0.056)	0.0166 (0.013)	0.0721 (0.077)	0.8742	106.53
50	log C_i	-2.859 (0.549)	0.6212 (0.055)	0.0237 (0.018)	0.0594 (0.075)	0.8769	109.18

The correlation between income and income variance was -0.64. The higher the income in a ward, the lower the income variance. The three-independent-variable analysis suggests that the much more significant variable is income variance, and probably not race per se. The lower income fraction of the families in a ward contribute more wastes than are indicated by the income relationship based on median ward incomes. This fraction is predominantly black, but it is income variance that has the greatest explanatory power.

SUMMARY OF RESULTS, COMPARISON WITH 1971 STUDY AND WITH OTHER RESULTS IN THE LITERATURE, AND CONCLUSIONS

In this subsection, the results of this study are first summarized. The results are then compared with results from the 1971 Sheaffer-Tolley study and with results from other solid waste socioeconomic studies that have appeared in the literature. Finally, conclusions are summarized.

Summary of Findings

In general, the findings of the current study are that solid waste volume can be best explained on a per capita basis using a double-log formulation for regression equations. The per capita double-log formulation is generally best by both R^2 and F statistics criteria. The double-log formulation implies a constant elasticity with respect to explanatory variables. Income has a strong positive effect, as does income variance. However, percent black has no significant effect when income, income variance, and percent black are considered together. In the 3 explanatory variable regressions, income elasticities range between about 0.4 and 0.6 and income variance elasticities between about 0.06 and 0.24 for the 9 weeks tested. R^2 value, the percent of solid waste collection variance explained, ranges from 0.76 to 0.88.

The results in somewhat more specific detail are as follows:

1. Solid waste volume collected by the City of Chicago is best explained on a per capita basis. In all cases, this was superior to explanation on a per household basis, even with household size included as an explanatory variable.

2. In most cases, waste volume is best explained using a double-log formulation for regressions. This formulation implies a constant waste volume elasticity with respect to esplanatory variables over their range of variation.

3. On a per capita basis, significant positive relationships were always found between waste volume and ward median family income. The results, for both simple income regressions and for multiple regressions, with income variance and percent black as the other explanatory variables, are presented in Table 21, and are shown in Figure 14. Elasticities range between 0.38 and 0.66. Since these elasticities are based on cross-sectional data, they tend to be long-run elasticities. The range thus does not cover short-run elasticities, which would probably tend to be lower.

TABLE 21

PER CAPITA WASTE VOLUME ELASTICITIES WITH RESPECT TO FAMILY INCOME, β(log Y), FROM SIMPLE AND MULTIPLE REGRESSIONS 9 WEEKS TESTED

	Income Only		Income & Variance		Income & Race		Income, Variance & Race	
Week	β(log Y)	R^2	β(log Y)	R^2	β(log Y)	R^2	β(log Y)	R^2
7	0.5056	0.7439	0.3848	0.7948	0.5232	0.7561	0.3877	0.7949
19	0.5180	0.7294	0.3938	0.7796	0.5437	0.7538	0.4218	0.7831
21	0.5806	0.7470	0.4837	0.8266	0.6002	0.8122	0.5039	0.8282
26	0.5559	0.7139	0.4366	0.7882	0.5826	0.7705	0.4702	0.7926
32	0.5295	0.7207	0.4020	0.7574	0.5573	0.7348	0.4354	0.7620
36	0.5458	0.7245	0.4047	0.7710	0.5776	0.7467	0.4450	0.7773
37	0.5527	0.7359	0.4107	0.7777	0.5851	0.7542	0.4524	0.7843
43	0.6408	0.8617	0.5840	0.8698	0.6596	0.8718	0.6200	0.8742
50	0.6300	0.8582	0.5697	0.8676	0.6539	0.8752	0.6212	0.8769

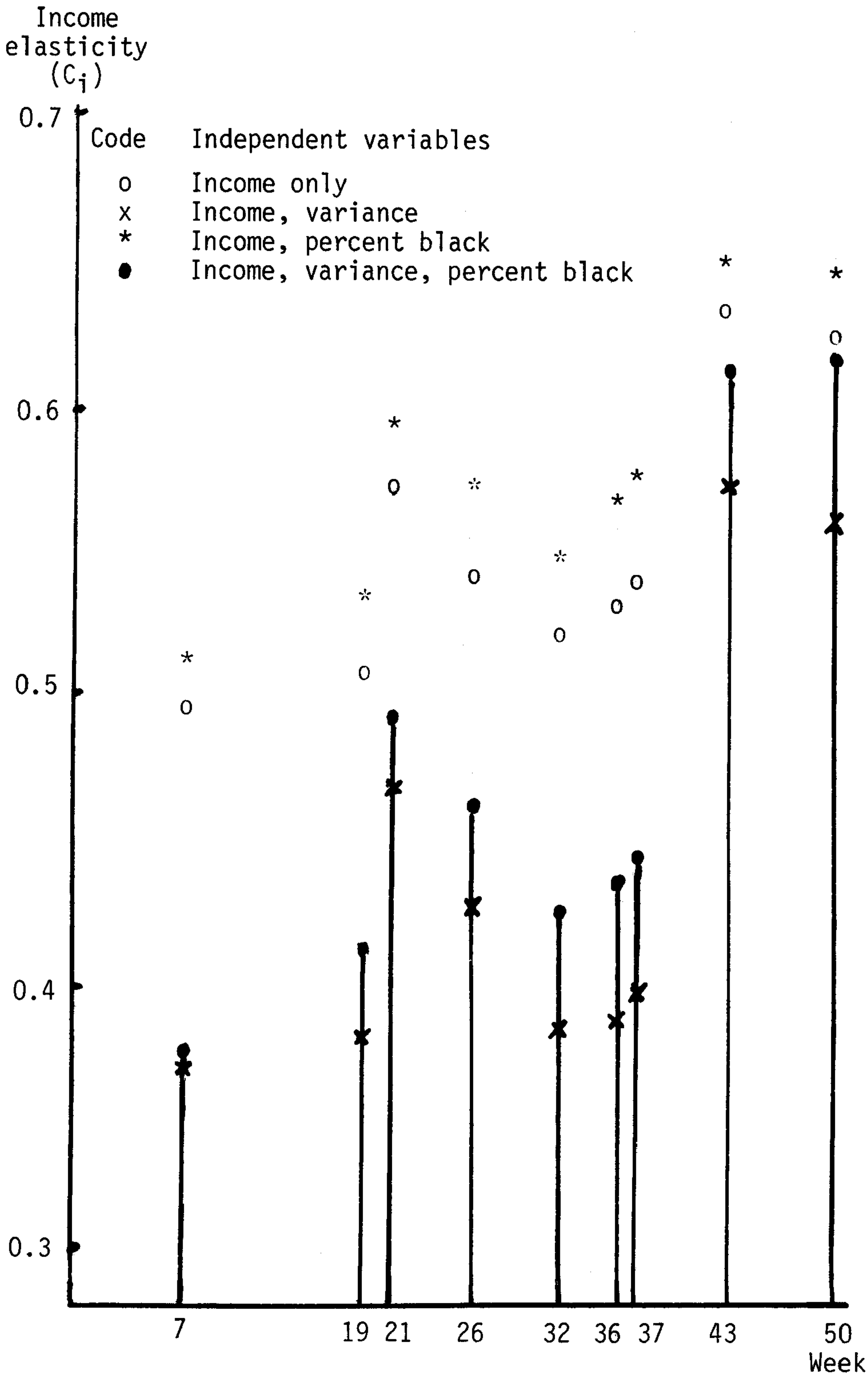

Figure 14. Per capita waste volume elasticities with respect to family income from simple and multiple regressions for 9 weeks tested.

a. When regressing solid waste volume on income only, on a per capita basis the double-log formulation was best in 6 of 9 weeks analyzed, and the semi-log formulation was best in 3. R^2 values, measures of the proportion of variation explained, range from 0.71 to 0.86 and income elasticities from 0.48 to 0.64.

b. When regressing per capita volume on income and income variance, the double-log formulation was best in all weeks. R^2 values ranged from 0.76 to 0.87 and income elasticities from 0.38 to 0.58.

c. When regressing per capita volume on income and race, the double-log formulation was always best in terms of R^2, with the R^2 values ranging from 0.73 to 0.88 and income elasticities from 0.52 to 0.66.

d. When regressing per capita volume on all three variables, income, income variance, and percent black, the same pattern emerged. R^2 values for the double-log formulation ranged from 0.76 to 0.88, and income elasticities ranged from 0.39 to 0.62.

4. On a per household basis, the double-log formulation explained best in all of the 9 weeks tested, both when regressing per household volume on income only and when regressing per household volume on income and household size. However, income had a positive effect only in the simple regression, and the R^2 values were consistently lower than in regressions on a per capita basis.

   a. When regressing per household volume on income only, a significant positive income effect was found in each week, but R^2 values ranged from 0.14 to 0.38 compared to 0.71 to 0.86 for the regression of per capita volume on income only.

   b. When regressing per household volume on income and household size, in 7 of the 9 weeks, including the 4 weeks when the income effect was significant, the income effect was negative. However, it was concluded that this was a spurious result, probably due to correlation between the independent variables income and household size. The R^2 values in these household regressions were considerably lower than in the per capita volume against income regressions, where income had a highly significant positive effect. The R^2 values ranged from 0.71 to 0.86 for the per capita regressions, compared to 0.23 to 0.44 for these household regressions.

5. On a per capita basis, income elasticities were highest in the fall and late fall/early winter (October and mid-December), low in mid-winter (February), and lower in the summer than in the spring and fall. It appears that this may represent a seasonality in income elasticities, particularly since this tends to repeat a pattern appearing in the 1968-1969 results, to be discussed in the next subsection in which results are compared. The low mid-winter volume may suggest that there is a basic, year-round volume of wastes, represented by the mid-winter volume, that is relatively less sensitive to

income than "excess" volumes in other parts of the year, except possibly mid-summer.

6. Both on a per capita and per household basis, significant, positive relationships were always found between waste volume by ward and ward income variance. Also, the double-log formulation was always best in terms of explanatory power. These results were obtained when regressing waste volume on income variance only, and when regressing waste volume on income and other variables. The elasticities with respect to income variance for both simple and multiple regressions are reproduced in Table 22.

   a. When regressing volume on income variance only R^2 values for the per capita, double-log formulation ranged between 0.48 and 0.56. The elasticity of volume with respect to income variance ranged between 0.61 and 0.68.

   b. When regressing volume on income variance and income, R^2 values, as reported under 3b above, ranged between 0.76 and 0.87, but the income variance elasticities were reduced considerably, ranging between 0.12 and 0.29.

   c. When regressing volume on all three variables, R^2 values, as reported under 3d above, ranged between 0.76 and 0.88, and the income variance elasticities ranged between 0.06 and 0.25.

7. When it alone was the explanatory variable, percent black was a significant explanatory variable in only 3 of 9 weeks. In these weeks, it showed a positive effect on per household waste volume in the linear formulation. It became significant in 7 of 9 weeks for explaining per capita volume when both income and percent black were used as the explanatory variables in the double-log formulation, with a positive effect on both per capita and per household volume in all weeks. However, percent blacks, though still positive in its effect, was not a significant variable in any week when income variance, which was positively correlated with percent black, was added to the regression equations. The per capita elasticities for the two multiple regressions in the double-log form are reproduced in Table 23.

Comparison with 1971 and Other Study Results

The current study confirms the 1971 Sheaffer-Tolley study in at least one major respect. Income has a major effect on per capita waste volume. Much higher R^2 values were obtained for the simple relationship between income and per capita waste volume in 1970-1971 than in 1968-1969, ranging from 0.71 to 0.86 for the weeks tested in 1970-1971 compared to 0.12 to 0.57 for the weeks tested in 1968-1969. The median income elasticity was about 0.5 in the earlier study, about 0.55 in this study. The comparative results are provided in Table 24 and are shown graphically in Figure 15.

The higher R^2 values are attributed to having better socioeconomic data,

TABLE 22

PER CAPITA WASTE VOLUME ELASTICITIES WITH RESPECT TO INCOME VARIANCE, β(log V), FROM SIMPLE AND MULTIPLE REGRESSIONS FOR 9 WEEKS TESTED

	Variance Only		Variance & Income		Variance, Income, & Percent Black	
Week	β(log V)	R^2	β(log V)	R^2	β(log V)	R^2
7	0.6117	0.5601	0.2498	0.7948	0.2462	0.7949
19	0.6270	0.5500	0.2567	0.7796	0.2214	0.7831
21	0.6552	0.5240	0.2003	0.8266	0.1748	0.8282
26	0.6571	0.5370	0.2465	0.7882	0.2041	0.7926
32	0.6416	0.5349	0.2635	0.7574	0.2213	0.7620
36	0.6723	0.5572	0.2917	0.7710	0.2409	0.7773
37	0.6797	0.5608	0.2935	0.7777	0.2409	0.7843
43	0.6666	0.4797	0.1174	0.8698	0.0721	0.8742
50	0.6601	0.4849	0.1243	0.8676	0.0594	0.8769

TABLE 23

PER CAPITA WASTE VOLUME ELASTICITIES
WITH RESPECT TO PERCENT BLACK, β(log B),
FROM MULTIPLE REGRESSIONS FOR 9 WEEKS

	Percent Black Income		Percent Black, Income, Variance	
Week	β(log B)	R^2	β(log B)	R^2
7	0.0208	0.7561	0.00134	0.7949
19	0.0304	0.7538	0.0129	0.7831
21	0.0231	0.8122	0.00933	0.8282
26	0.0316	0.7705	0.0155	0.7926
32	0.0329	0.7348	0.0154	0.7620
36	0.0376	0.7467	0.0186	0.7773
37	0.03826	0.7542	0.0192	0.7843
43	0.0223	0.8718	0.0166	0.8742
50	0.0284	0.8752	0.0237	0.8769

TABLE 24

PER CAPITA WASTE VOLUME ELASTICITIES WITH RESPECT TO INCOME, β(log Y), AND R^2 VALUES, SIMPLE REGRESSION RELATIONSHIPS

	1968		1969		1970-1971	
Week	β(log Y)	R^2	β(log Y)	R^2	β(log Y)	R^2
7			0.376	0.1674	0.5056	0.7439
19			0.4822	0.2614	0.5180	0.7294
21	0.6977	0.4369	0.483	0.2613	0.5806	0.7999
24	0.6723	0.3789	0.542	0.3222		
26					0.5559	0.7544
32	0.2911	0.1229	0.432	0.2219	0.5295	0.7082
36	0.5213	0.3383	0.5768	0.3516	0.5458	0.7245
37	0.4712	0.2298	0.5293	0.2770	0.5527	0.7359
43	0.7278	0.4281			0.6408	0.8617
46			0.9840	0.5745		
50	0.3367	0.1246	0.4889	0.2509	0.6300	0.8582

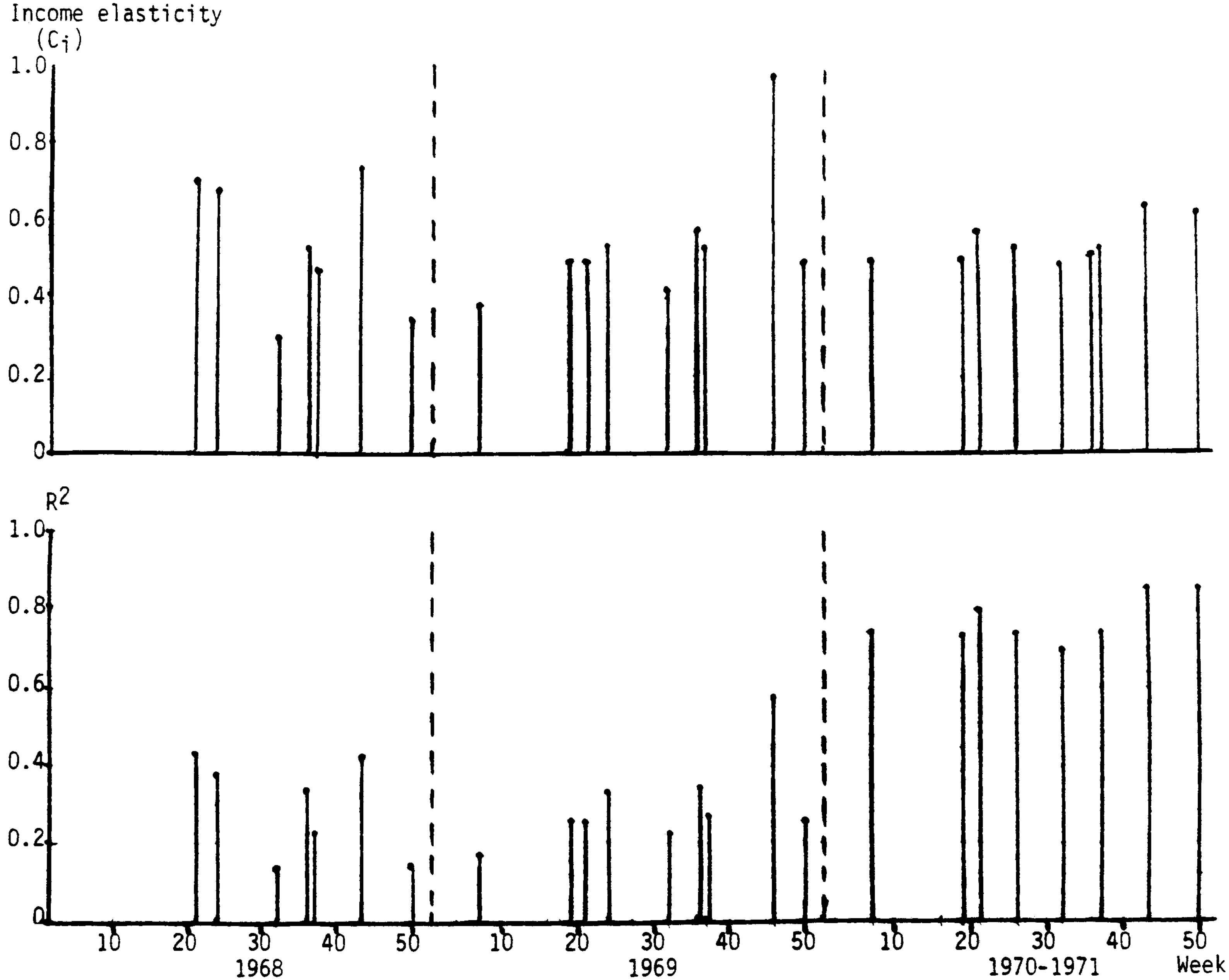

Figure 15. Per capita waste volume elasticities with respect to income and R^2, 1968, 1969, and 1970-1971.

that of the close-in 1970 Census, for the analysis using 1970-1971 waste volume. However, while the 1970 socioeconomic data were better, the data for the two studies revealed similar general characteristics with respect to ward population, percent of households served, family income, income variance, and percent black, with some shifting among wards. (Percent black, the race variable reported in the 1970 Census, rather than percent non-white as reported in the 1960 Census, was used in this study. The difference is taken to be negligible in comparing results.)

In addition, the waste volume data, while showing somewhat higher collection rates per capita in 1970-1971 than in 1968-1969 (to be expected with increasing incomes given the strong income-waste volume relationship), revealed similar patterns in the two periods, generally high collection volumes in the summer, low in the winter.

The 1970-1971 study also tends to confirm a seasonality in income elasticities, with waste volume more sensitive to income in the spring and fall, and less sensitive in mid-winter and mid-summer. This tends to confirm an hypothesis put forth in the 1971 study that there is a basic year-round volume of wastes, represented by the mid-winter volume, that is, less sensitive to income than is "excess" wastes, except possibly in mid-summer. The seasonal pattern can be seen in Figure 15.

There were, however, some major differences between this study and the 1971 study results. There were differences in signs, statistical significance, and seasonal patterns of effects, and in the unit basis (per capita or per household) and form (log-log, semi-log, or linear) of the relationships that best explained the variance in waste collection. The differences are described and possible reasons for the different results are discussed below.

Differences in Sign, Significance, and Pattern

The variance of income distribution, taken as a single explanatory variable, was significant in most cases in the 1971 study, and its effect on volume was negative. In the current study, its effect was significant in all cases, but positive. In the 1971 study, the effect of variance became insignificant in most weeks when both income and variance were taken together in regressions, though still negative. In this study, when income was added, the effect of variance was reduced, but its effect remained significant and positive.

The percent black variable when taken alone in the current study was usually insignificant, but in 3 weeks in which it showed a significant effect, this effect was positive. In the 1971 study, on the other hand, the percent nonwhites taken alone generally showed a negative impact. This was attributed to the relationship between income and race. (Possible reasons for differences between the studies are discussed below.) Both studies showed that when income and race were taken together, the effect of race tended to be positive. Finally, the current study showed the effect of race to be insignificant in all cases when income, income variance, and race were all taken together. The earlier study did not proceed to this point. The earlier study showed, for both 1968 and 1969, a seasonal pattern in income and race sensitivity of weekly waste output. The income and race patterns were similar. There were low or negative race effects in the winter, high positive race effects in the rest of the year. These race effect patterns, however, did not repeat, at least in any clear-cut way, in the current study results, although, as indicated earlier, this seasonal pattern tended to repeat with respect to income.

In the current study, household size alone had a significant positive effect on per household waste collection. In the earlier study, significant effects, which were positive, were found in only 2 of 16 weeks. In the current study, when income was added as a variable, the effect of household size on waste collection remained positive, but was significant in only 4 of 9 weeks. In the 1971 study, the addition of income tended to increase the significant positive relationship between waste collection and household size. In the current study, when income was added, its effect on per household waste collection was negative in 7 of 9 weeks, and negative in the 4 weeks when significant. In the 1971 study, the effect of income remained positive, and, indeed, for the weeks reported, showed higher positive effects than when taken alone.

Differences in Basis and Form

In the current study, solid waste collection variation was always better explained on a per capita than on a per household basis. In the 1971 study, explanation was generally better on a per household basis. In the current study, the log-log formulation explained waste collection variation best in all cases where per household collection was the independent variable, and in all multiple regressions and in most simple regressions where per capita collection was the independent variable. The exceptions were in 3 of 9 weeks for simple per capita waste-income regressions, when the semi-log formulation was best, and in 3 weeks when there was a statistically significant relationship between race and per capita waste volume. In the race regressions, it was the linear form that showed the significant relationships. In the earlier study, the linear form was generally best.

Possible Reasons for Differences

The fact that solid waste collection volume was always explained better on a per capita basis in this study, whereas the opposite was generally true in the 1971 study, and the higher R^2 values can be explained by the fact that better data, particularly on ward population, were available for the current study. Better data may also be one explanation for the fact that the double log formulation was almost always better in the current study.

The one striking difference in the effect of independent variables, the positive rather than negative or insignificant effect of income variance, could be due to transitory income effects. Variance was highly negatively correlated with income. It could be that the low incomes were due more to transitory factors in 1970-1971 than in 1968-1969. This could be due to business cycle factors or to better data on transitory factors applicable to the analyzed data. Since waste volume would tend to vary more with permanent rather than transitory income, a positive relationship between volume and income variance would result when transitory factors were overriding. A policy implication would be that in forecasting demand, the reasons for any projected income variance as an explanatory variable would have to be considered. There is an alternative way of looking at essentially the same explanation. The current study showed that percent black and income variance in the current study picked up what appeared as a percent black effect in the 1971 study, and, possibly for the same transitory income reason.

Comparison with Results Reported Elsewhere in the Literature

As reported in Section II of this paper, Wertz (1976) and Downing (1975) both found positive effects of income on waste collection, with elasticities less than 1.0. The elasticities were somewhat lower than found in this study, 0.279, 0.272, and 0.39 compared to a median of a little over 0.5 in the current, and about 0.5 in the previous 1971 study of Chicago collection data. Richardson and Havlicek also (1976, 1975, and 1974) found a positive relationship between income and waste collection. McFarland et al (1972), on the other hand, found no significant effect of income. Except for this 1972 study, the finding of a positive income elasticity, generally of less than 1.0, tends to be confirmed.

Richardson and Havlicek found that waste collection was significantly related to household size. This confirms the same finding in this study. They also found that for total wastes, the effect of percent black was insignificant, the same finding as in this study when controlling for income and income variance. They further found that income had a less significant effect on waste volume in the winter than in the rest of the year. This may tend to confirm the finding of a similar seasonal pattern with respect to income elasticity in this and the 1971 study, with low elasticities in midwinter.

Conclusions

The main conclusion that can be reached from this study is that differences in median family income can explain most of the variation in per capita solid waste collection. The added explanatory value of other variables tested were found to be relatively minor. These include income variance and percent black, as well as an alternative mode of explanation, using per household collection as the dependent variable and income and household size as explanatory variables. When the three independent variables for explaining per capita waste collection were taken together, percent black was not a significant explanatory variable. Income factors, median income and income variance with the latter relatively minor, were indeed the only significant explanatory variables.

The income effect on per capita waste volume is best explained using a constant elasticity formulation. The elasticity is less than 1, ranging between about 0.4 and 0.6, indicating that waste generation increases less than proportionally with income.

There still appears to be a seasonality in income elasticity, with lower elasticities in mid-winter and mid-summer and higher elasticities the rest of the year. The low winter values may suggest that there is a basic year-round volume of waste generation that is less sensitive, except in mid-summer, to income than are excess volumes generated in the rest of the year. The low mid-summer elasticity might be explained as a weather effect, with soft drink, beer, and fruit consumption less affected by income during very hot weather. Another explanation could be that income varies seasonally, with earnings among low income groups at a high level in mid-summer.

SECTION IV

AREAS OF NEEDED RESEARCH AND RECOMMENDATIONS FOR RESEARCH PROCEDURES AND METHODOLOGY

In this section, areas of needed research in the economics of solid and hazardous waste management are identified, and recommendations are made for procedures and methodologies in this research. These needs are described, and, in addition, the promotion of programs for improving the general data base for both research and waste management itself is recommended.

RESEARCH NEEDS

Based on purposes to be served, two kinds of research are needed in the solid waste management field. One is research of general applicability to various solid waste management systems, and another is research of specific applicability to the management and operation of particular systems. The two are not always distinct in practice, since results of specific research on specific systems are often needed for generalization, or since such results can often be generalized. Nevertheless, the discussions and recommendations in this section will focus on needs for research on the economics of solid and hazardous waste management of general applicability, keeping in mind that such research, to be useful, must always be directed toward ultimate specific applicability. It should provide guidance to system managers concerning where the payoffs might be, what modifications should be made in the quantity and quality of services offered and in the financing of these services, what records should be kept, and the procedures for specific research to make specific determinations.

Most of the general areas of research needs have been indicated, and in some cases discussed, in the preceding sections of this paper. This section largely reorganizes these needs under one heading. However, some new ideas are introduced.

For the purpose of recommending areas of needed economic research, it is not enough to merely enumerate the economic questions that solid waste managers might have or might need to ask and answer. What is needed is a set of priorities. The priorities depend on what the major questions are, answers to which would have the highest payoff.

One important question, and a question of major concern, deals with the rising costs of solid waste collection/disposal. Can there be a payoff in holding down these costs in ways that take into account the economic considerations of more than a strictly engineering nature in providing solid wastes management services? The rising costs are largely associated with rising input costs, particularly labor, the real cost of which continues to rise, and rising wastes volumes. However, in addition, the costs themselves are affected by the character of the services rendered, including frequency of service, which adds to costs both directly and by increasing volumes, and by demands for a better environment. It is recommended that a high priority be placed on determining the possible quantitative and other effects of various economic approaches for reducing these volumes and associated costs, and to reducing these costs in ways that would increase the net value of the overall services to the households and to the community served. For answering these questions, it is recommended that solid-waste-service demand and supply functions be estimated, relating quantities of service to price and to other factors that affect demand and supply. In this research, guides would be developed for application of the research results to research and to decisions in specific areas. In addition, guides would be provided for systematically collecting the needed research data.

Volumes of wastes collected and associated waste management services can only be substantially decreased if there are alternatives to waste generation and/or alternatives to community collection for waste disposal. The shape of the demand functions for collection/disposal depend on these alternatives. These alternatives include using returnable bottles, sink disposals, and the like. Thus, in addition to research in the area of demand/supply for waste collection/disposal, it is recommended that research be conducted in the area of supply functions for these alternatives and other matters with respect to alternatives. Presently, the supply price for returnable containers other than returnable soft drink bottles and possibly a few others (containers for moving vans are returnable) is in effect infinity. The household can't find returnable food jars, returnable other-beverage or pharmaceutical bottles, or returnable shoe boxes. With rising collection/disposal costs, would other returnable containers be economic?

A sink disposal decreases not only volume but also frequency-of-service needs. Households with lower incomes and receiving twice-a-week collection service might not install sink disposals because they do receive twice-a-week service and thus have a reduced need for sink disposals, and twice-a-week service may be provided because the households do not have disposals. This cycle might be broken if the community were to fund the installation of disposals and amortize this investment through savings achieved by being able to go to once-a-week service where sink disposals are installed. There are advantages of liquid disposal of wastes, particularly of food wastes, to the community as well as to individuals, and these advantages could be "used" to justify partial subsidizing of disposals. These advantages would, of course, have to be compared with added sewer and sewage treatment system costs.

Additional areas of research that are recommended for priority consideration include: estimation of demand functions for community cleanliness, estimation of supply functions for achieving community cleanliness, benefit cost estimation of a change from flat to other forms of financing, including full marginal cost pricing, and estimation of the supply functions and demand functions (environmental damage functions) for various solid wastes disposal requirements, or stated alternatively, the determination of the benefits and costs of existing and modified standards. Of particular concern would be the potential benefits of greater control over possible effects of hazardous wastes that might be introduced into residential solid wastes, estimated from hazardous waste damage functions.

In estimation of demand functions for community cleanliness, it might be possible to develop and assign measures of cleanliness, for example, using an index ranging from 0 for a continuous mess to 100 for an essentially litter-free community, and determine by multiple regression analysis if and to what extent this measure has an effect on land values. Such a land-value methodology has been used in developing demand functions for air quality. In estimation of supply functions for achieving community cleanliness, relationships between an index of cleanliness and various measures of input, such as expenditures, to achieve and maintain cleanliness might prove rewarding. The interactions among various inputs in the production function would be important.

All of the above priority economic research needs can be restated in an outline of questions requiring research that can be asked by solid wastes system managers. Since the focus of research should be on ultimate applicability, it is deemed useful to suggest such an outline:

a. What collection services and level of collection services should be provided?

  (1) What frequency of service should be provided? Should this be decided on a systemwide or individual collection area basis?

  (2) Should curb or back-door service be provided? If back door, should it be optional, and if optional, should it be optional at each collection?

  (3) Should unlimited-quantity service be provided, or should consideration be given to approaches that might limit or reduce quantities to be collected?

  (4) Should combined, same frequency, and location of collection be offered for all residential solid wastes, or should separate collection be offered?

b. What degree of community cleanliness, in terms of freedom from litter and other pollution from solid wastes, is demanded, and how is this best achieved?

  (1) What are the marginal benefits (what is the demand function for) different degrees of cleanliness?

  (2) What are the various means for achieving cleanliness and what are the marginal cost functions (cost per unit of cleanliness achieved) of the various means?

  (3) What is the optimum level of cleanliness and what are the

optimum levels of input of the various means, given these demand and cost functions?

c. What disposal services and level of services should be provided?

(1) Should there be processing of wastes prior to ultimate disposal (e.g. incineration)?

(a) What are the benefits of processing in terms of reducing transportation, ultimate disposal, or other costs?

(b) What are the costs of processing, including economic costs (net of any energy values obtained) and environmental costs (air pollution)?

(2) What are the options for ultimate disposal? What is the least-cost alternative, considering environmental costs? For sanitary land-disposal, are the standards set for this disposal optimum?

(a) What are the marginal environmental benefits of added efforts to protect against environmental damages from the disposal operation? These might include benefits from:

(i) More frequent covering or burying of wastes.

(ii) More careful site selection, for example, to find less permeable soils.

(iii) More remote sites, for example, to remove the site farthur from population centers, or to remove farther from groundwater sources.

(iv) More care to separate off and neutralize the possible health and safety effects of potentially hazardous wastes that might be introduced into residential solid wastes.

(b) What are the marginal costs associated with achieving the marginal benefits?

d. How should collection/disposal services be financed?

(1) What are the alternative ways of financing collection/disposal services? These may include:

(a) Flat charges based on average costs of services actually rendered over a period of time.

(b) Incremental user charges, based on the incremental costs of various collection/disposal services rendered.

(c) Some combination of flat and incremental charges.

(2) What are the advantages/disadvantages (benefits-costs) of alternative financing methods compared to existing financing methods, for example incremental compared to flat charge methods?

(a) What are the estimated changes in the amounts of the various services in shifting to incremental user charges?

(b) What are the direct benefits (estimated direct cost savings) from reducing these amounts?

(c) What are the direct costs to households (estimated loss in benefits) from reducing these amounts?

(d) What are the indirect costs from shifting to incremental charges?

(i) What are the added (or reduced) costs of administering such charges?

(ii) What are the added environmental cleanliness costs?

(iii) What are the tax/revenue sharing costs?

e. How can service requirements be best projected for planning and decision purposes?

(1) What are the various projection methodologies and how would they be implemented?

(2) Which projection methodologies are the more reliable in terms of accuracy? Which in terms of greater flexibility for different conditions or different modes of operation?

(3) Which projection methodology or methodologies should be used for the particular system? If more than one, could there be irreconcilable differences in results, and how would this be handled?

f. What specific-system research is needed to make all of the above determinations?

(1) What are the specific questions to be asked and answered?

(2) What are the research procedures?

(3) What are the data needs?

RECOMMENDATIONS FOR RESEARCH PROCEDURES AND METHODOLOGY

There are three basic research approaches that can be used in economic research. These are analysis of data from existing and operating systems, controlled experimentation, and simulation analysis (or production function estimations from cost information). The basic approach in analyzing data from existing systems is regression analysis.

For reasons given below, regression analysis is recommended as the generally preferred research approach for determining relationships in the solid wastes field. Controlled experimentation and simulation analysis can be used as alternative or supplementary approaches, particularly where insufficient data are available for obtaining significant regression results. The analysis of basic relationships would be followed, for some management questions, with benefit-cost analysis.

Regression analysis and controlled experimentation have the advantage of equal applicability to demand and cost function estimation. In addition, they are equally applicable to the estimation of other relationships, such as between weight and volume as measures of quantities of solid waste. On the other hand, while simulation analysis can be applied in cost function estimations, it is severely limited in its applicability to demand estimation. It is applicable where demand for a service is limited by the availability of alternative means for achieving the same ends. These means can sometimes be simulated from cost information, and their effects on demand for the service can thus be estimated. However, this approach cannot fill the total needs for estimating demand.

With respect to the relative merits of regression analysis and controlled experimentation, where sufficient data are available, regression analysis has an advantage over controlled experimentation in that the data needed for analysis are generated from the whole world of actual "experiments". Generally, a controlled experiment, which is budget and time constrained, cannot produce the variation in and quantity of data that the "real world" experiments tend to produce. In controlled experiments, there may be a real problem in obtaining enough variation and quality of data to produce comprehensive and significant results. On the other hand, to obtain significant results from regression analysis, sufficient data must be available.

In the solid wastes field, even where there have been "real world" experiments, regression analysis tends to face the problem that needed data generally have not been collected. This has tended to limit the data base for general research. It also tends to preclude the application of general research results to particular systems since the particular systems lack needed data. Therefore, it is strongly recommended that programs for regular collection of and maintenance of records on quantities and costs be promoted. Until such general data are available, general research projects will, to a large extent, have to include specific data collection programs as a part of the projects.

As for procedures, there are basically three general regression procedures: cross-section analysis, time-series analysis, and combined cross-section/time-series analysis. It is recommended that first emphasis be placed on cross-section analysis. For time-series analysis, a period of years would be needed in which to collect the data required. The basic research methodologies to be considered would include ordinary least-squares multiple regression analysis, particularly for supply/demand analysis. In determining whether a particular action should be taken, such as shift from flat charges to incremental charges or the setting of a standard, benefit-cost analysis would be essential followup to supply/demand analysis.

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16. ABSTRACT

The study provides an extension of the theory of demand, with specific application to collection and disposal services for household solid waste. The empirical investigation involving several socioeconomic variables (income, race, household size) repeated the analysis of an earlier study, using more recent (1970) Census data. The current findings supported the earlier results indicating a strong positive effect and a seasonal pattern for waste volume and income elasticity. There was less evidence of racial influence and household size on the quantity of solid waste for municipal collection and disposal.

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