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Solid and Hazardous Waste

EPA

Economics of Municipal Solid Waste Management

The Chicago Case

RESEARCH REPORTING SERIES

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August 1978

ECONOMICS OF MUNICIPAL SOLID WASTE MANAGEMENT

THE CHICAGO CASE

by

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DISCLAIMER

This report has been reviewed by the Office of Research and Development.

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

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

CONTENTS

FIGURES

Number | Page

TABLES

Various officials of the City of Chicago

SECTION I

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

INTRODUCTION

General

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

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-Talley report, Talley 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 [redacted]

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 [redacted] from such services. It was pointed out in the 1971 study that a comprehen-

[illegible]

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, [illegible]

[illegible]

is-demanded will be discussed. The what-is-demanded listing and discussion [illegible]

[illegible]

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

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 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

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 [illegible]

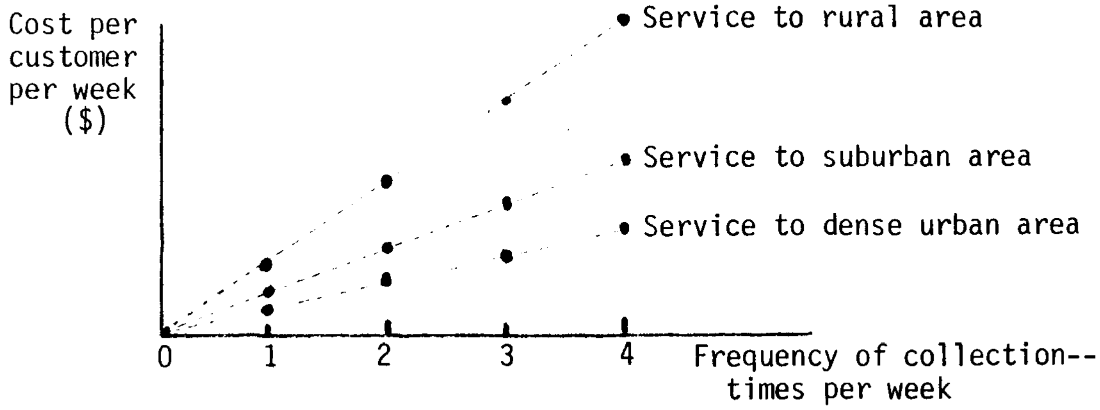
[illegible] These trucks compact wastes

as collected and thereby also hold down the collection and transportation [illegible]

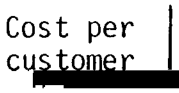
In any event, these possible solutions appear impractical, and are in fact not used, and in the presentation of concepts below, number of containers is used as the measure of quantity. This is done despite the fact that [redacted]

all empirical analysis to date has been in weight terms. It has all been in [redacted]

A. Frequency of collection

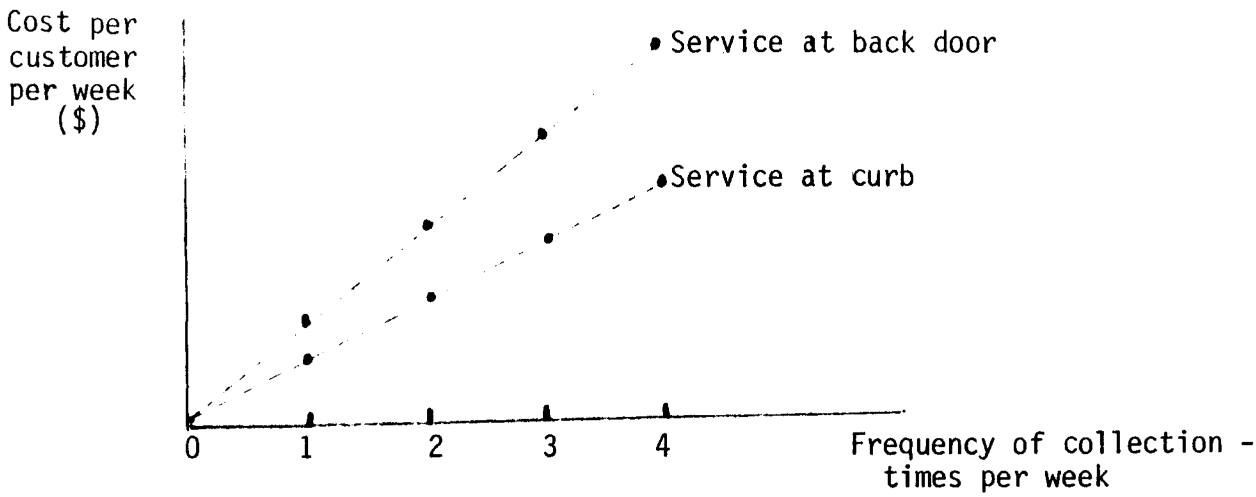


B. Amount of collection



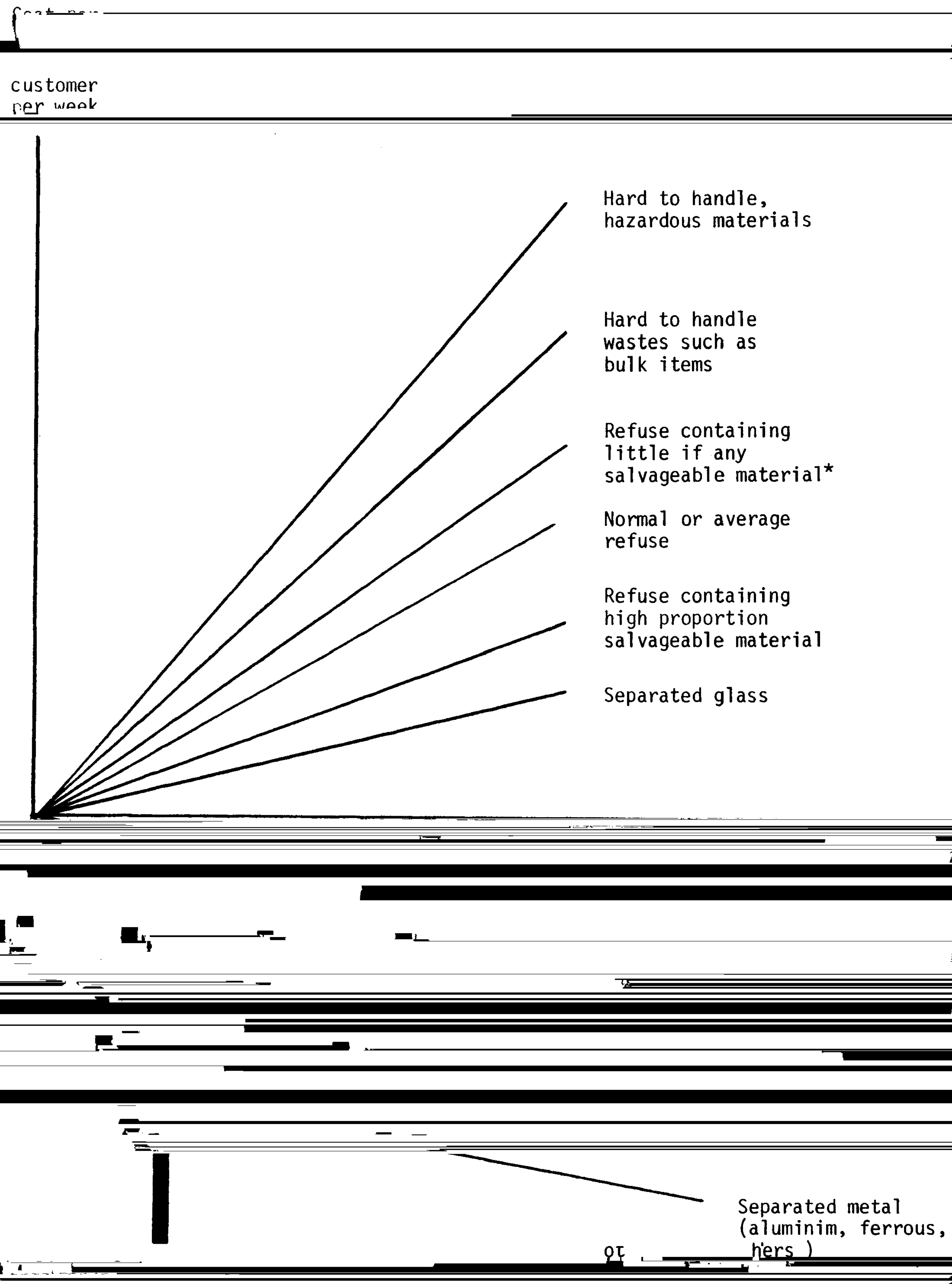
of these three services. Note that in the depiction, it is the total cost

A. Frequency of collection



B. Amount of collection

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


customer
Hard to handle, hazardous materials
Hard to handle wastes such as bulk items
Refuse containing little if any salvageable material*
Normal or average refuse
Refuse containing high proportion salvageable material
Separated glass
Separated metal (aluminim, ferrous,

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

Specifically, for those shifters discussed, we have α_1, the urban density 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:

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

[illegible]

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

[illegible]

basis, made up of the variable cost for quantity and a charge, distributed
on a quantity basis, for service, as follows:

TABLE 1.   COST FUNCTIONS FOR SOLID WASTES COLLECTION SERVICES

1. Basic Nature of Collection Cost Functions

[illegible]

Total cost of a collection service

Without shifters

$$C_f = \beta_1 \times F$$

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

[illegible]

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.)

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

[illegible]

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.)

TABLE 1 (continued)

3. Optimum Cost (Billing) Functions

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

$$B = C_f + C_q(F)$$

$$= P_{fs}F + P_{qs}\,QF$$

[illegible]

TABLE 1 (continued)

Combined charge with rates for all services on a weekly basis

[illegible]

[illegible]

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.

TABLE 1 (continued)

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

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

the private firm could be shifted from individuals to the local government

pay for back door as opposed to curb or alley collection because back door

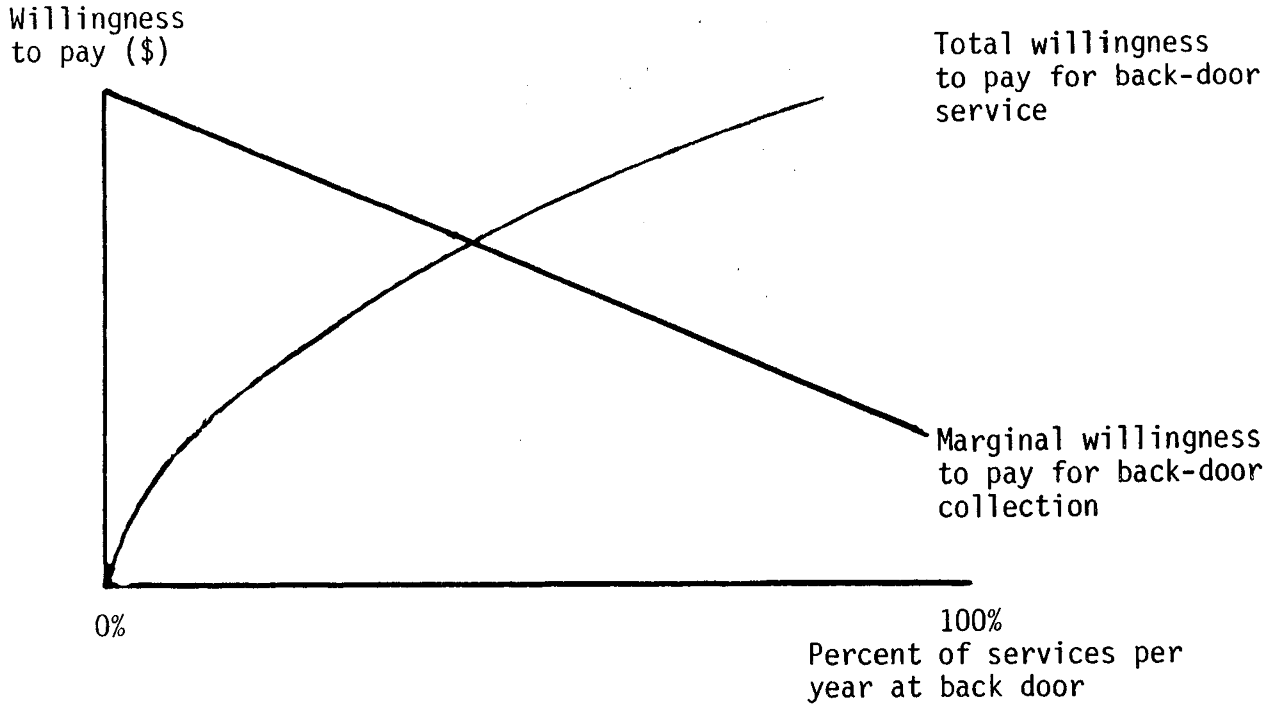
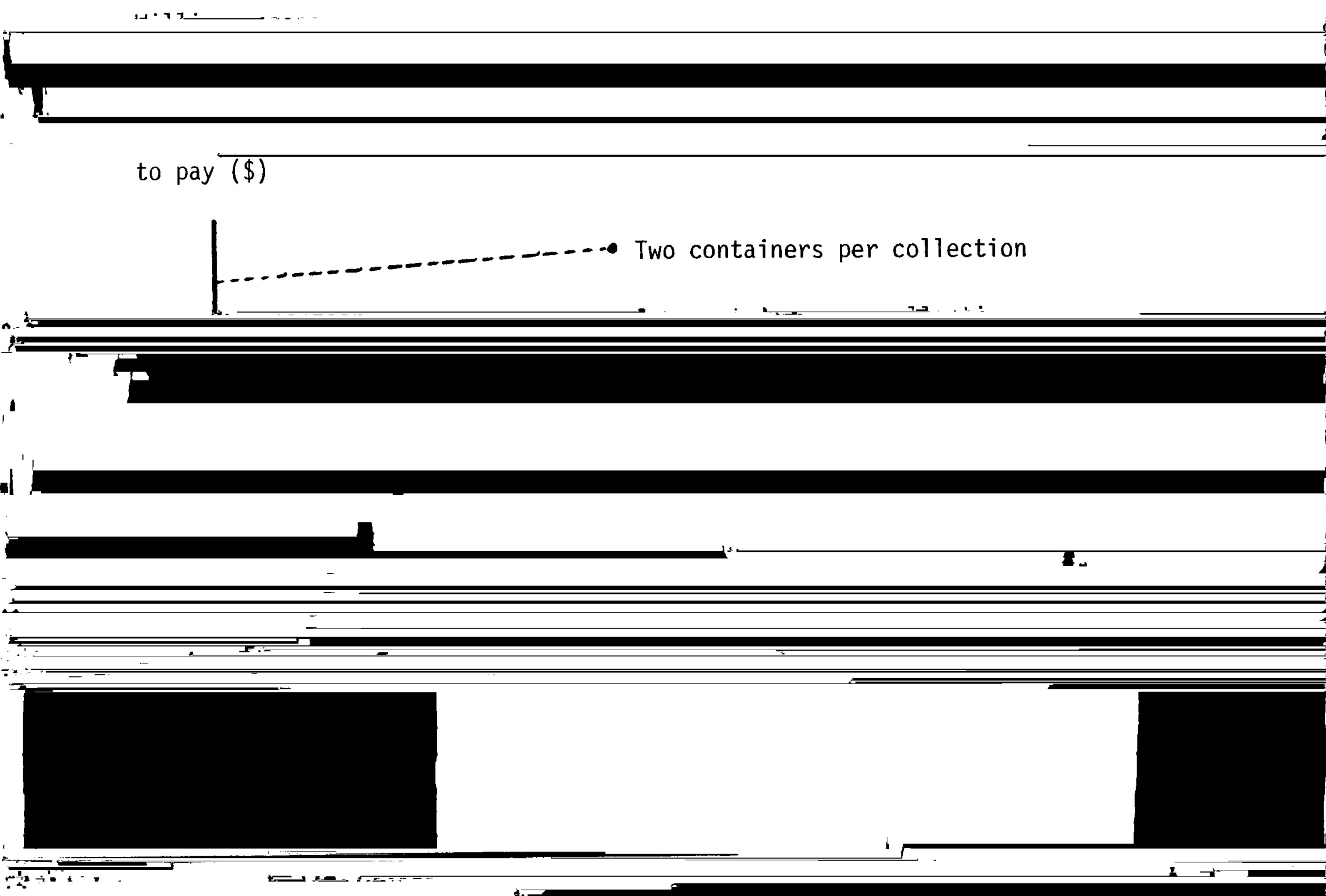
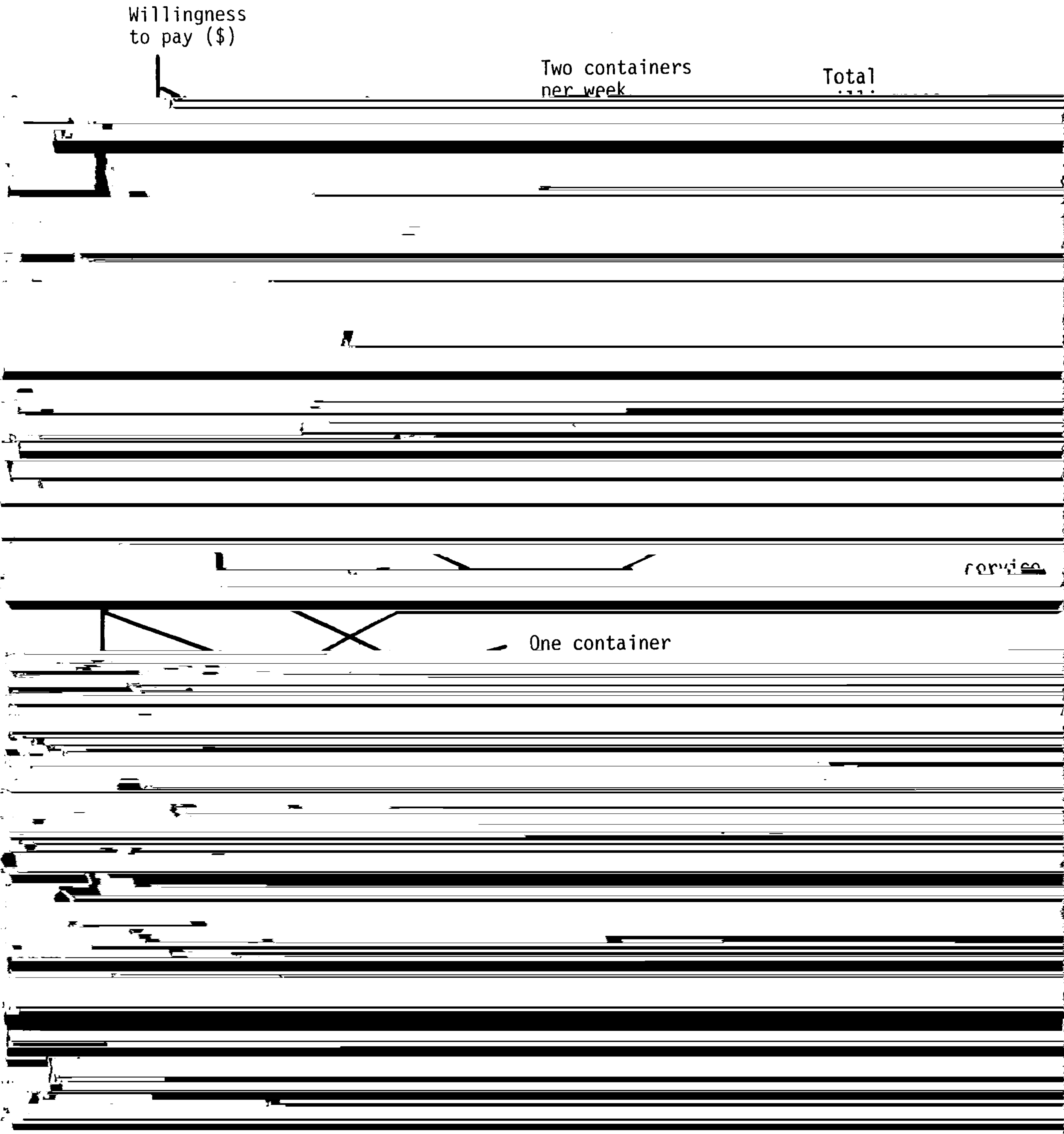


Figure 4a. Willingness to pay for back-door services on a pay-as-you-go basis.



door. This is portrayed in this way mainly to make the relationship compara-
ble to the cost function portrayed in Figure 1a. The cost relationship i

assumption since it is time that is involved in cost, which is directly pro-
portional to distance. However, for willingness to pay, there is probabl


Willingness
to pay ($)
Two containers
per week
One container

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

(with the $-\frac{1}{2}$ 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

Then

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

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

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, Wednes-

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

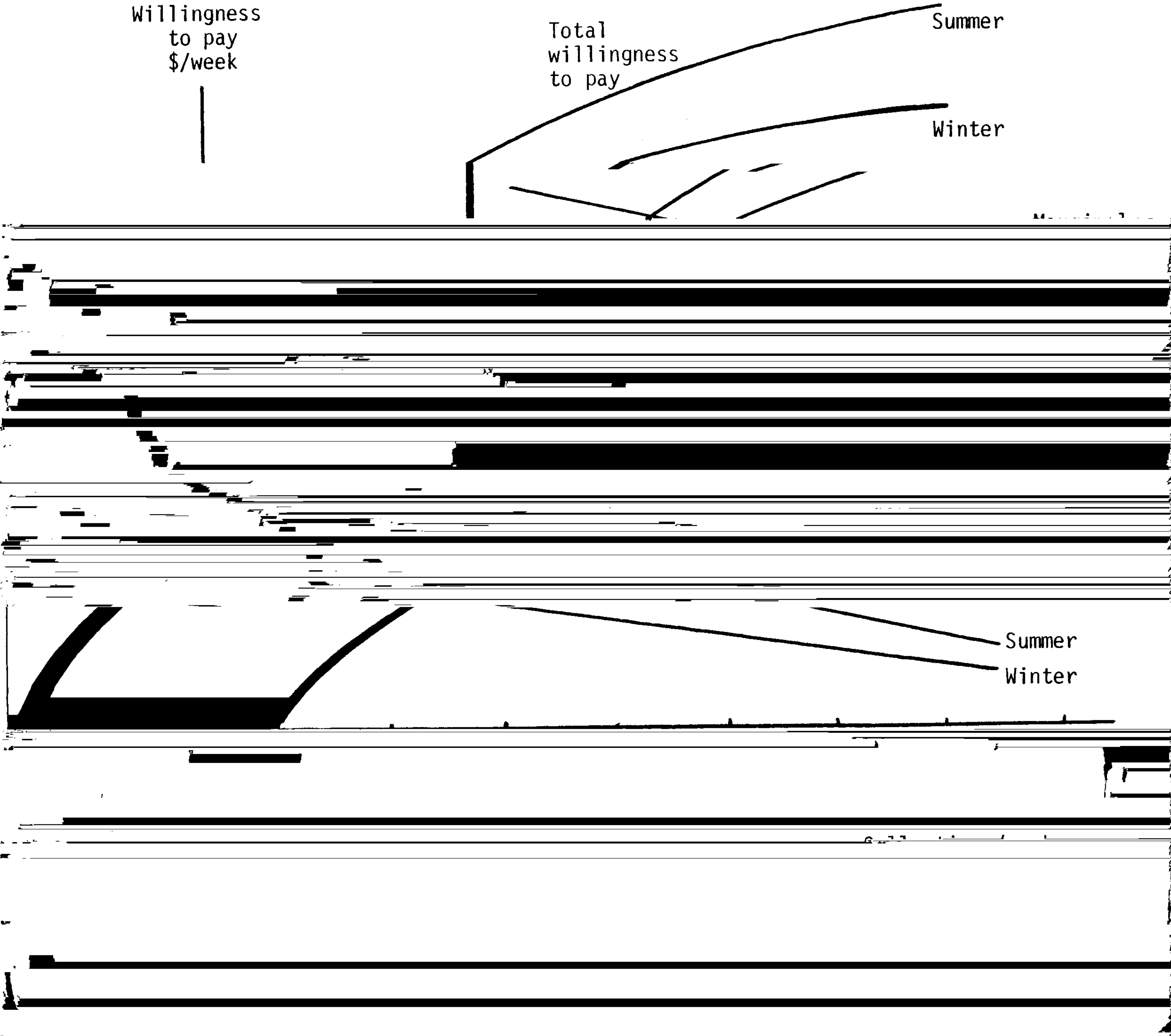
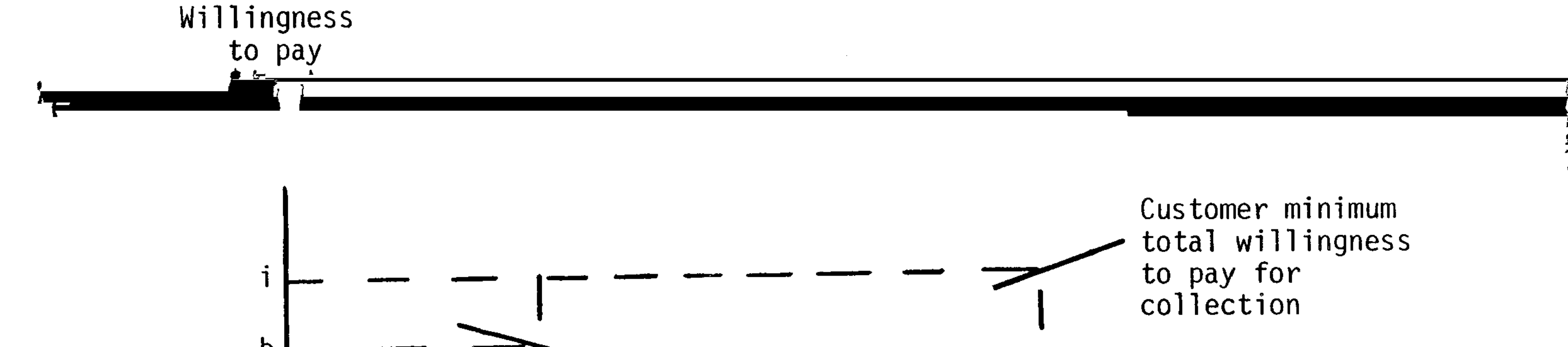


Figure 6a. Willingness to pay for frequency of collections showing summer winter difference.



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, [illegible]

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 collec- [illegible]

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 [illegible] waste generation." Obviously, Ernst's thinking was for some reason [illegible] 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/

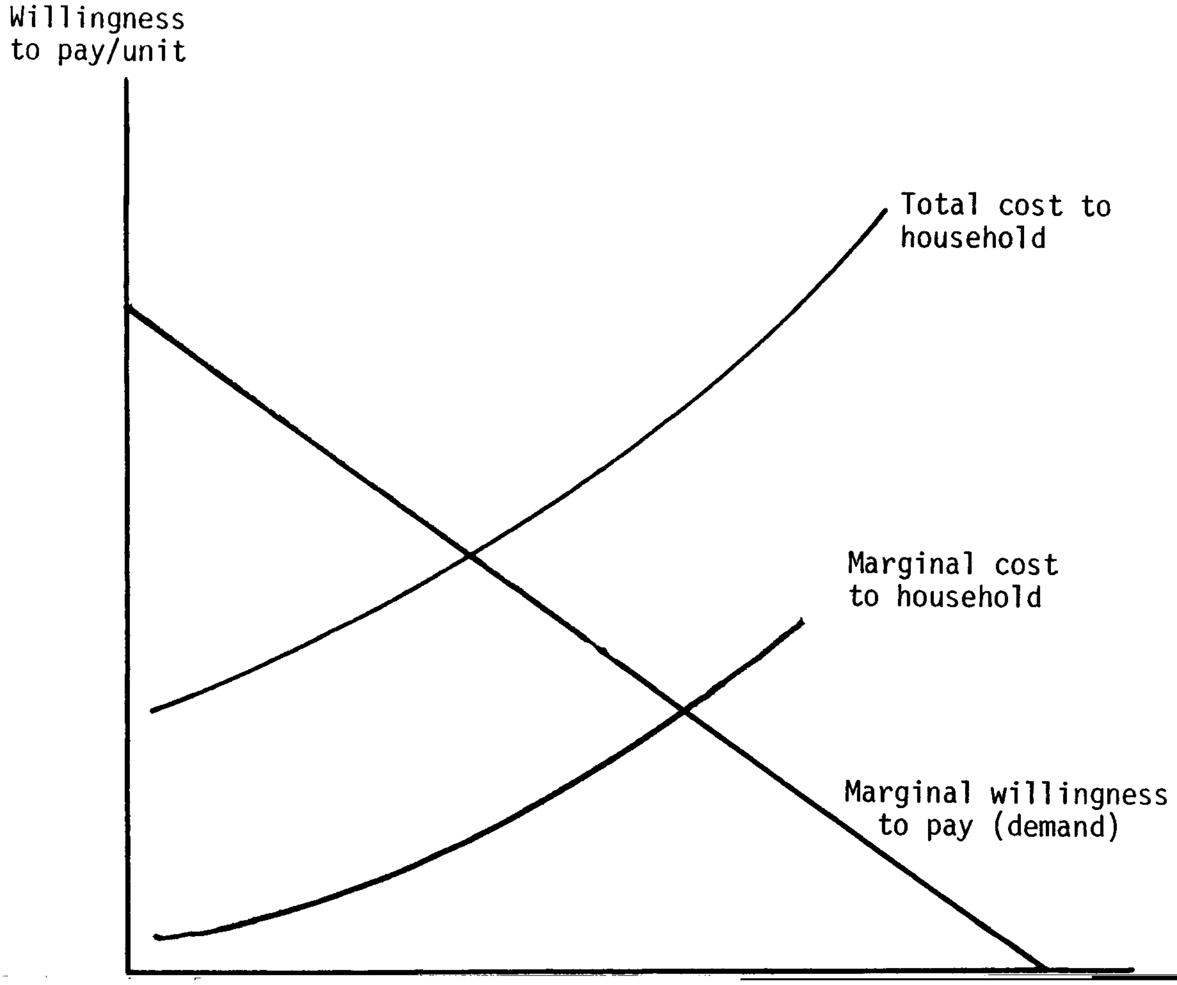


Figure 7. Supply and demand functions for cleanliness/spaciousness

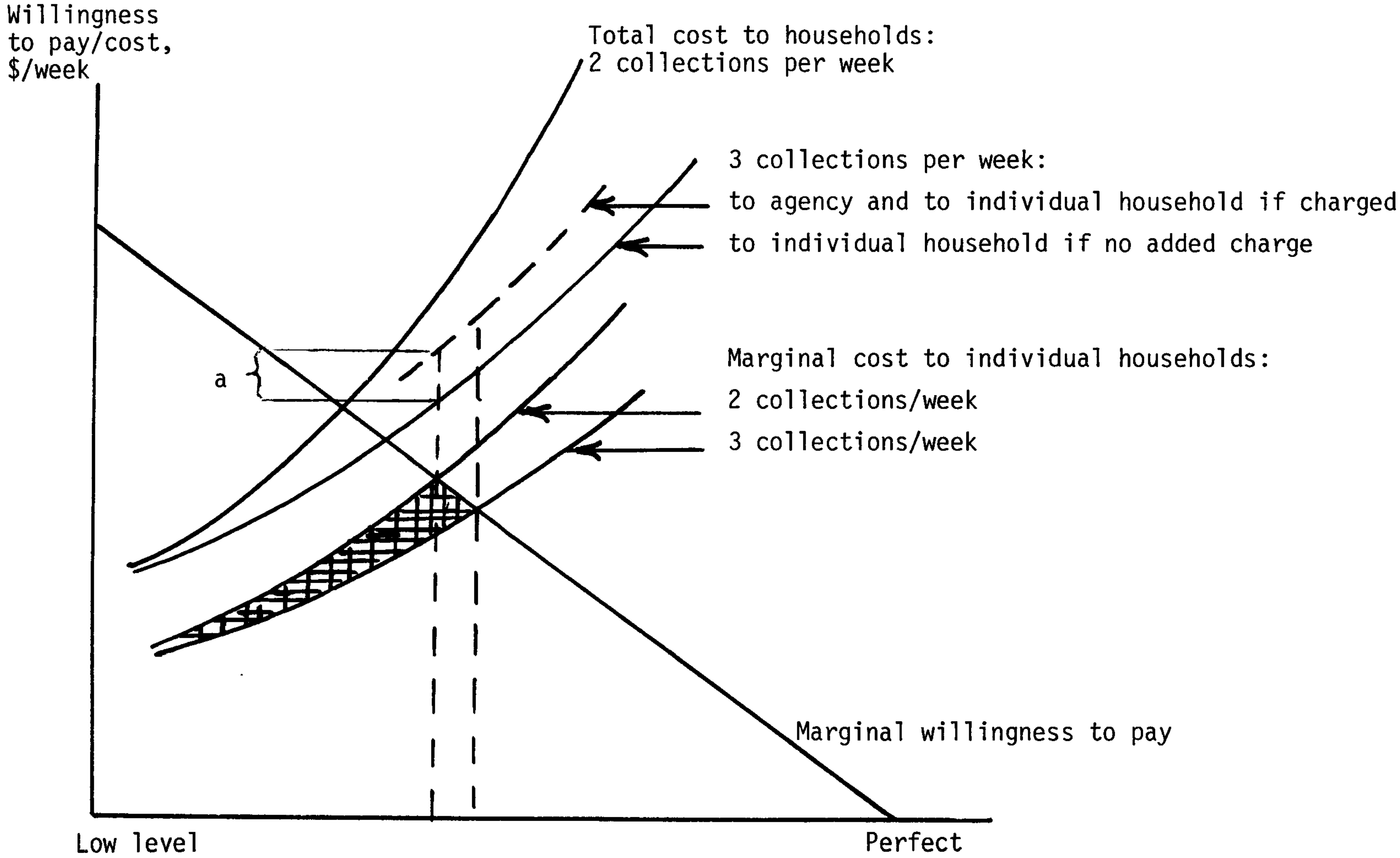
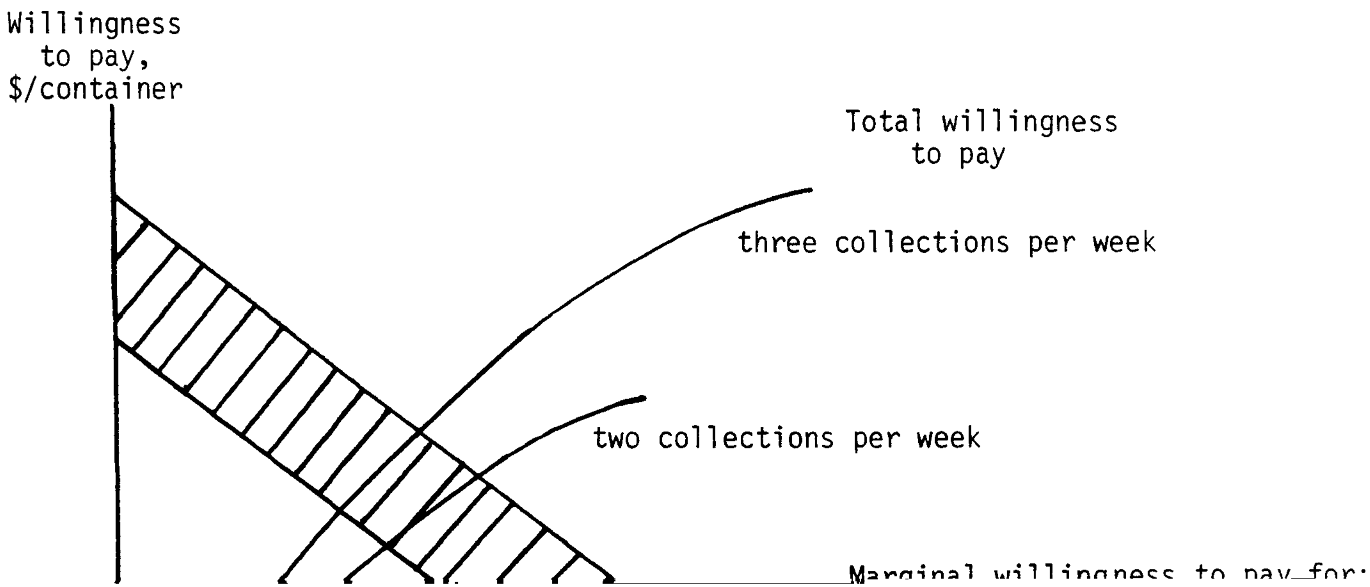


Figure 8. Shift in cleanliness/spaciousness supply function with change in collection frequency.


Willingness
to pay,
$/container
Total willingness
to pay
three collections per week
two collections per week
Marginal willingness to pay for:

container the consumer surplus is the [illegible]

[illegible]

ceptual 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 [illegible]

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

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 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 change. Thus, the same proportions of added income, compared to base income, 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).

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

3. While costs probably do tend to rise (for example, it requires

b. On the side of discouraging alternatives, one cost may be the conscience cost--knowledge that in littering and

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 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 improvement in management, for example, improved record keeping through [redacted]

[redacted] consciousness, improved technology, etc. These effects need [redacted]

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 [redacted]

For Portland, the charge was $1.75 for 1, $3.00 for 2, and $4.00 for 3 30-

[redacted]

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

[redacted]

can over 30 gallons). Redmond had no limit on the number of cans. It 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./ [illegible]

[illegible]

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 [illegible] 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

SECTION III

FACTORS AFFECTING RESIDENTIAL SOLID WASTES IN CHICAGO

PURPOSE

The purpose of this section is to update the findings of the Sheaffer-

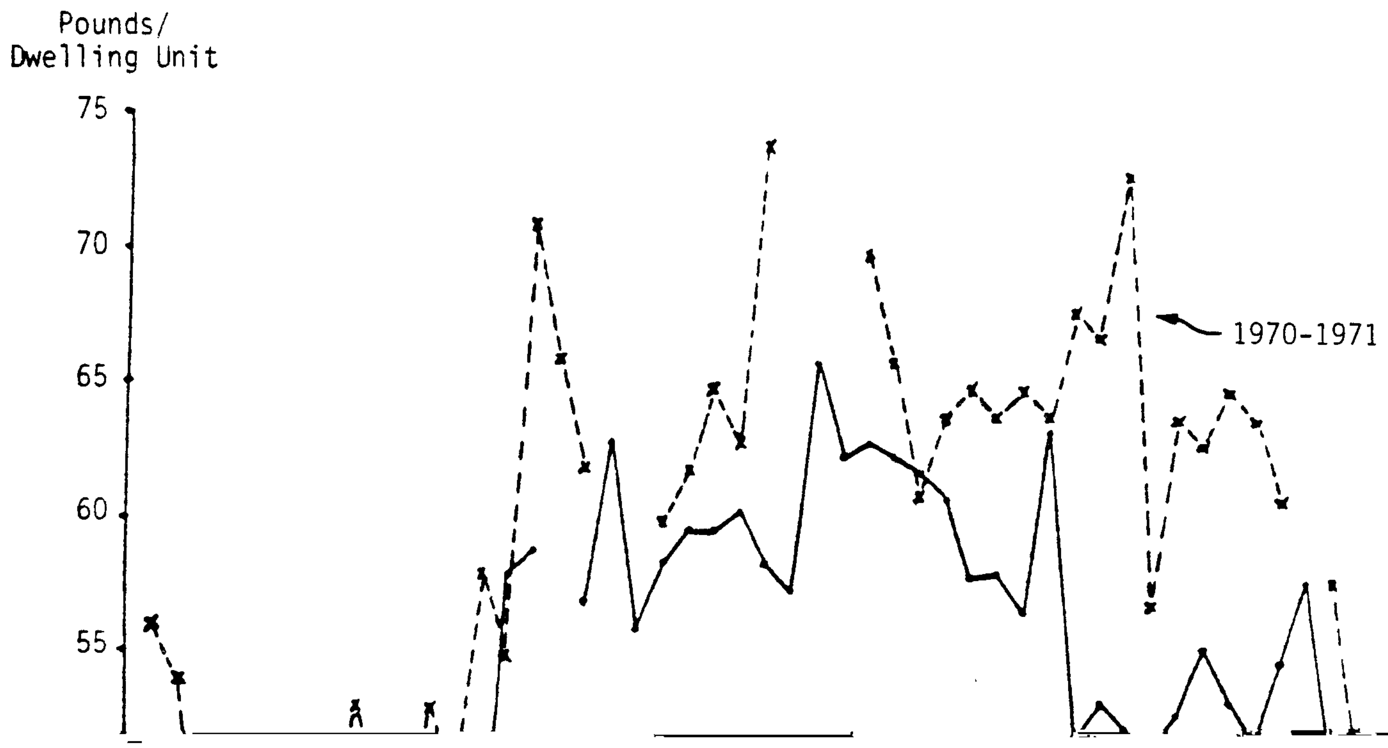

Pounds/
Dwelling Unit
75
70
65
60
55
1970-1971

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

[illegible]	Week 7 [illegible]	Week 21 [illegible]	Week 32 [illegible]	Week 50 [illegible]
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	[illegible]	[illegible]	[illegible]	[illegible]
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	[illegible]	[illegible]	[illegible]	[illegible]
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	49.3	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
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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

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

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
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

averaging the median 1970 family income of all census tracts that fall [redacted]

shown in Table 4. (No estimates of income by season were made.)

[redacted]

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

[redacted]

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
[redacted]	[redacted]	[redacted]	[redacted]
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

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	[illegible]	[illegible]
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

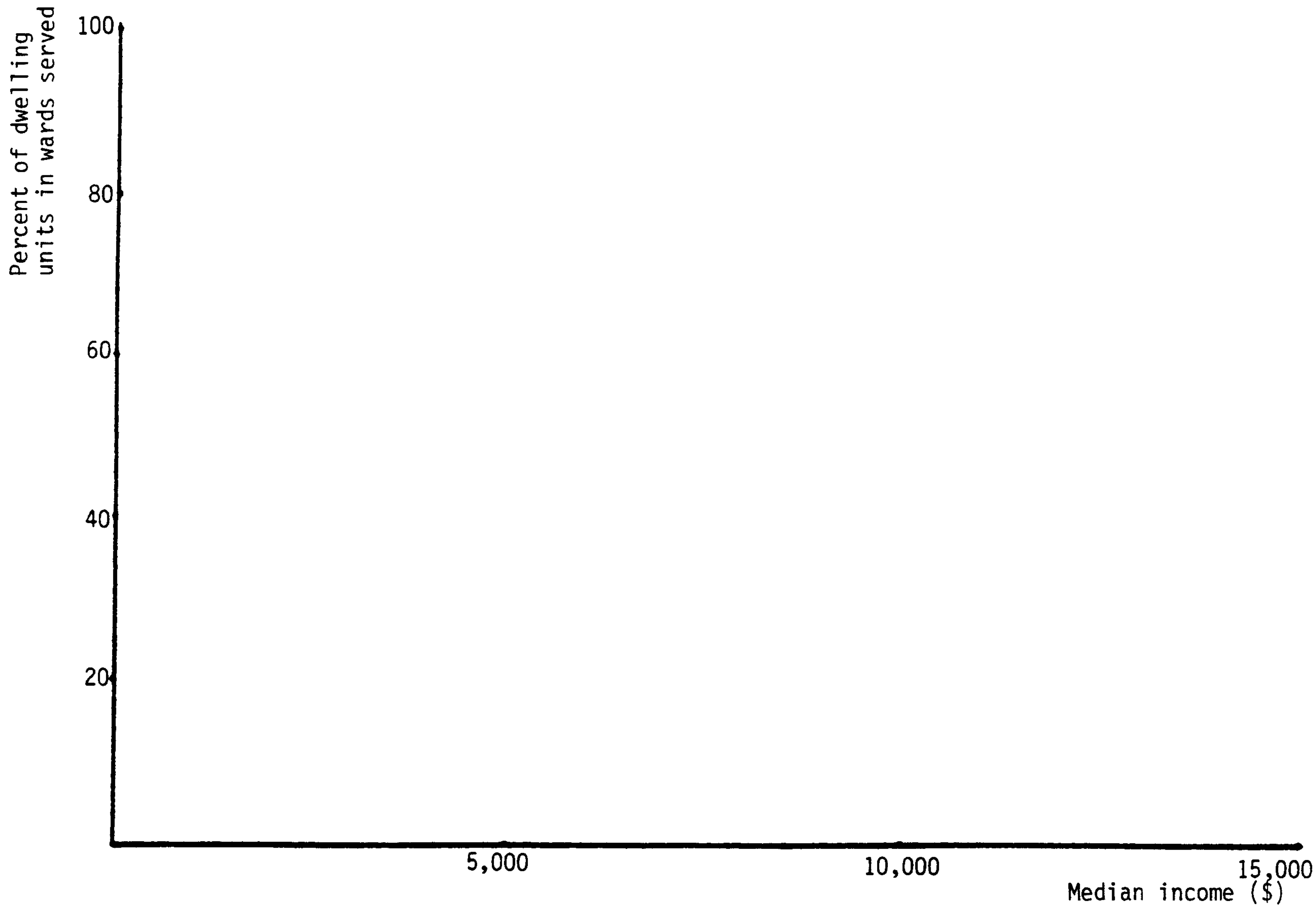


Figure 12. Relationship between ward median family income and percentage of dwelling units served by municipal waste collection.

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

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

$\bar{\mu}$ and σ were determined by graphical means. This method was shown in the [illegible]

TABLE 6. FAMILY INCOME [illegible]

	Estimates from	Estimates Derived from		Estimates from	Estimates Derived from
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 7.   WARD POPULATIONS, 1970

Ward	Population	Ward	Population
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

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
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 [illegible]

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

The income elasticity is thus equal to β and is constant as income increases

[redacted]

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

[redacted]

[redacted]

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	-0.000730	Y_i	0.0082	0.399
		(12.05)	(0.0012)			
F_i	D_i	54.278	0.001102	Y_i	0.0434	2.18
		(6.08)	(0.000746)			
$(F_i)^2$	D_i	56.404	0.00103	Y_i	0.0503	2.54

Weights Used	Dependent Variable	$\hat{\alpha}$	$\hat{\beta}$	Explanatory Variable	R^2	F
--	D_i	130.20	-7.342	log Y_i	0.0089	0.430
		(103.17)	(11.20)			
F_i	D_i	[illegible]	[illegible]	log Y_i	[illegible]	[illegible]

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

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	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 12 SOLID WASTE - INCOME RELATIONSHIP 1970-1971

Week	Dependent Variable	$\hat{\alpha}$	$\hat{\beta}$	Explanatory Variable	R^2	F
	log C_i	-2.05 (0.363)	0.5056 (0.428)	log Y_i	0.7439	139.43
	D_i	41.34 (3.15)	0.000345 (0.00045)	Y_i	0.0120	0.584
19	log D_i	2.98 (0.369)	0.1296 (0.043)	log Y_i	0.1558	8.86
	log C_i	-1.82 (0.386)	0.5180 (0.045)	log Y_i	0.7294	129.37
	D_i	55.90 (4.34)	0.000851 (0.00062)	Y_i	0.0375	1.87
21	log D_i	2.50 (0.340)	0.1922 (0.040)	log Y_i	0.3231	22.91
	log C_i	-2.30 (0.355)	0.5806 (0.042)	log Y_i	0.7999	191.88
	D_i	52.12 (4.12)	0.00202 (0.00059)	Y_i	0.1966	11.75
26	log D_i	2.76 (0.374)	0.1675 (0.044)	log Y_i	0.2301	14.35
	C_i	-37.99 (4.45)	6.386 (0.526)	log Y_i	0.7544	147.46
	D_i	58.49 (4.76)	0.00153 (0.00068)	Y_i	0.0956	5.07
32	log D	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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
10	D_i	[illegible]	[illegible]	Y_i	[illegible]
	$\log C_i$	-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
	[illegible]	[illegible]	[illegible]	Y_i	[illegible]

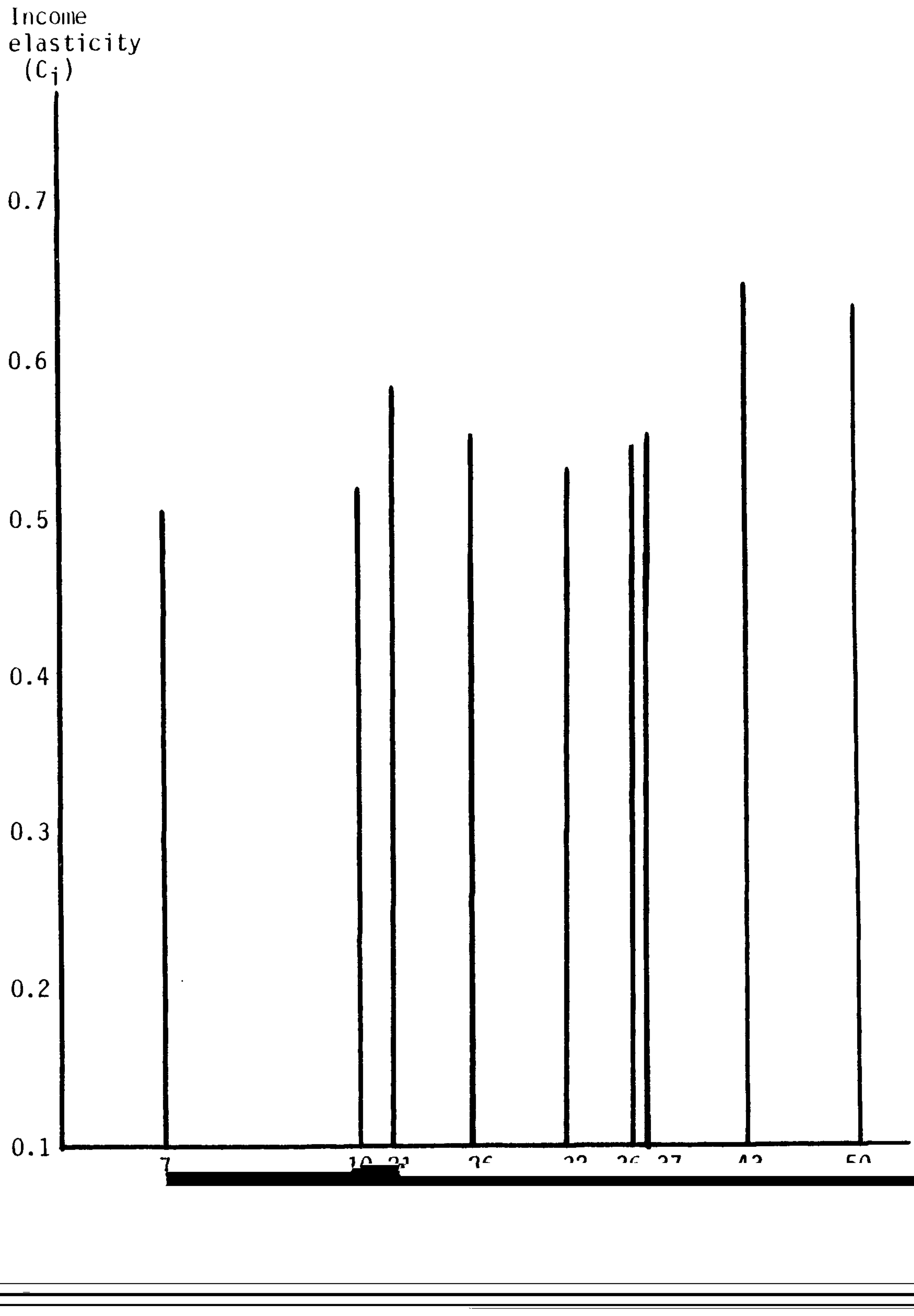


Figure 1[illegible] Income elasticity of the demand for solid waste elasticities were about average in the summer months when the volume of solid wastes collected was relatively high (Figure 11), was highest in the

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

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

Week	Dependent Variable	$\hat{\alpha}$	$\hat{\beta}$	Explanatory Variable	R^2	F
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	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	0.2305	log V_i	0.2582	16.71

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	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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. [illegible]

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

Week	Dependent Variable	$\hat{\alpha}$	$\hat{\beta}$	Explanatory Variable	R^2	F
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	0.1972	$\log S_i$	0.2850	19.21

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

Week	Dependent Variable	$\hat{\alpha}$	$\hat{\beta}$ Explanatory Variables: Log Y	$\hat{\beta}$ Explanatory Variables: 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
[redacted]						
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

[illegible]

tied to the number of persons. [illegible]

[illegible]

portance 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.

<u>Race</u>

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 [illegible]

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 [redacted]

was 0.79, compared to 0.31 on a dwelling unit basis. The income variable [redacted]

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

Week	Dependent Variable	$\hat{\alpha}$	$\hat{\beta}$ Explanatory Variables Log B_i	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
14	log D_i	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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

Week	Linear (L), Semi-log (SL) or Double-Log (DL)	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	0.0056	17.98	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	0.00563	14.47	0.4392	18.41

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

$\hat{\beta}$

Explanatory Variables

7	log C_i	-0.7321 (0.611)	0.3877 (0.061)	0.00134 (0.014)	0.2462 (0.085)	0.7949	59.41
10	log C_i	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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.

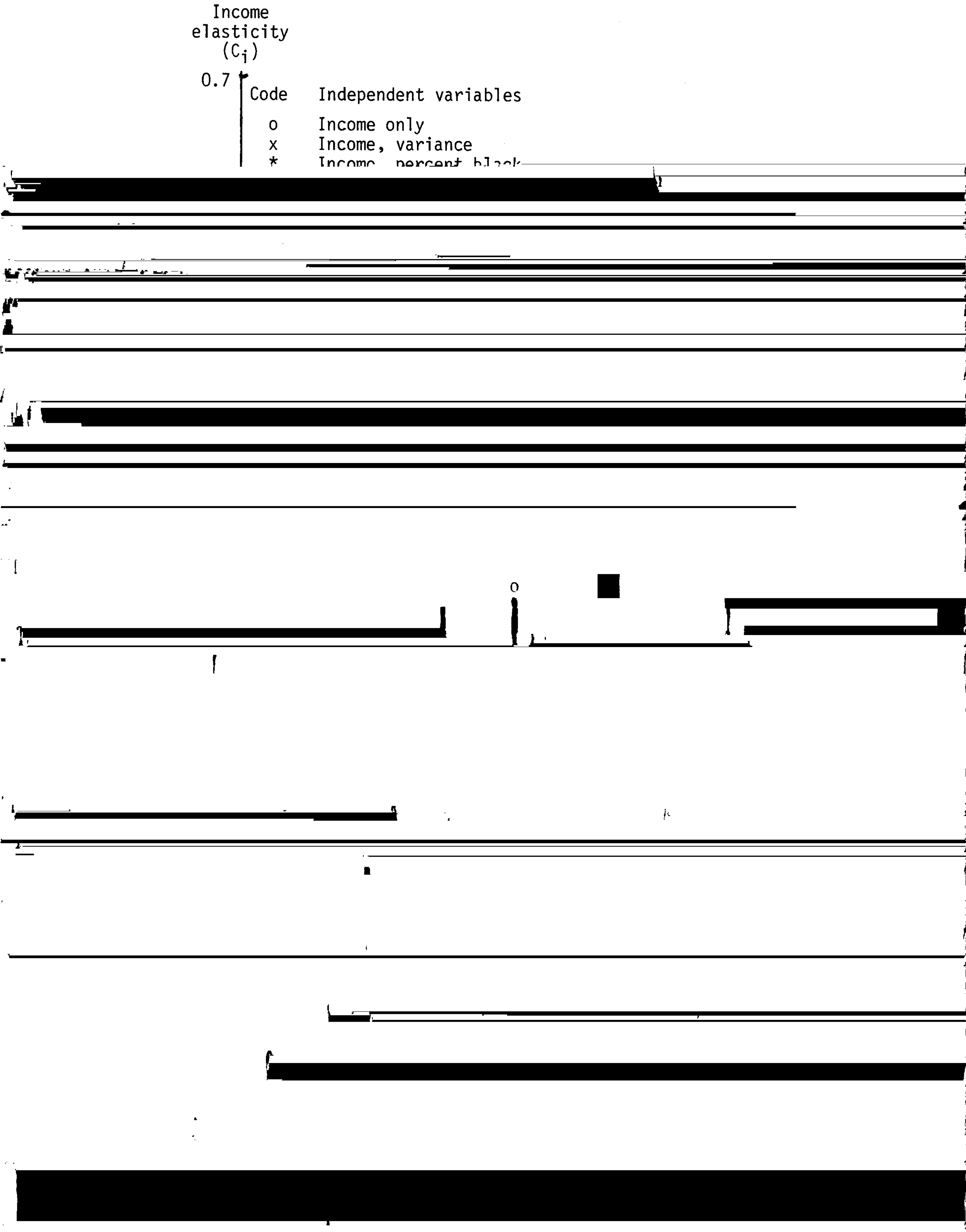
SUMMARY OF RESULTS, COMPARISON WITH 1971 STUDY AND WITH OTHER RESULTS IN THE LITERATURE, AND CONCLUSIONS

In this section the results of this study are first summarized

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
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]



Income elasticity (C_i)
0.7
Code Independent variables
o Income only
x Income, variance

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,

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.

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

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	
	β(log V)	R^2	β(log V)	R^2	β(log V)	R^2
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

TABLE 23

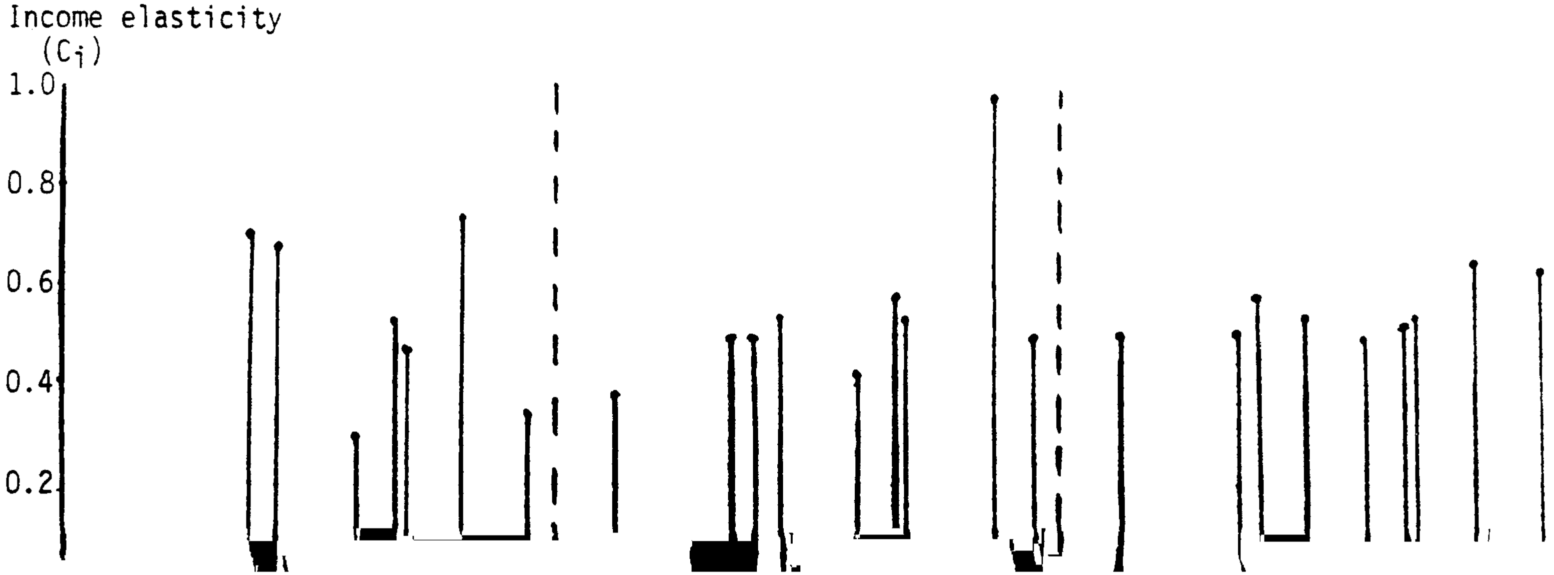
PER CAPITA WASTE VOLUME ELASTICITIES
WITH RESPECT TO PERCENT BLACK, β(log B),
FROM MULTIPLE REGRESSIONS FOR 9 WEEKS

	Percent Black		Percent Black, Income	
	Income		Variance	
	β(log B)	R^2	β(log B)	R^2
7	0.0208	0.7561	0.00134	0.7949
[illegible]	0.0204	0.7528	0.0120	0.7831
21	0.0231	0.8122	0.00933	0.8282
26	0.0316	0.7705	0.0155	0.7926
[illegible]	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
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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


Income elasticity
(Ci)
1.0
0.8
0.6
0.4
0.2


1.0
0.8
0.6

that of the close-in 1970 Census, for the analysis using 1970-1971 waste [redacted]

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 and race sensitivity of weekly waste output. The income and race patterns

positive race effects in the rest of the year. These race effect patterns, 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 con- [illegible]

sidered. There is an alternative way of looking at essentially the same explanation. The current study showed that percent black and income variance [illegible]

in the current study picked up what appeared as a percent black effect in the [illegible]

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, 0.270, 0.272, and 0.30 compared to a median of a little over 0.5 in the [illegible]

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.

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 rising input costs, particularly labor, the real cost of which continues to 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 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 [illegible]

(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? [illegible]

(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 [illegible]

(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? [illegible]

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

(i) What are the added (or reduced) costs of

RECOMMENDATIONS FOR RESEARCH PROCEDURES AND METHODOLOGY

There are three basic research approaches that can be used in economic

...ation/tire service analysis. It is ...

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