

ELECTRICITY PRICE STRUCTURES:  
EFFICIENCY, EQUITY, AND THE  
COMPOSITION OF DEMAND

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Revised  
August 1975

## ABSTRACT

### Electricity Price Structures: Efficiency, Equity, and the Composition of Demand

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A framework is developed which facilitates comparisons of alternative pricing schemes: declining block, high tailed, and rate inversion. A given aggregate demand is assumed to be composed of six different combinations of three individual demand curves. Each individual curve is a fraction of the constant elasticity aggregate demand. The combinations have different standard deviations and varying degrees of skewness. We examine the impact of the pricing schemes on total quantity demanded, consumers surplus, and total revenue; the relative contributions from and benefits to each of the components of the aggregate demand are also explored.

Although relatively few cases are examined (with three different demand elasticities), the framework illustrates the need to go behind aggregate demand schedules and the average price in order to better understand the differential impacts of alternative pricing schedules on "rate spread." The work suggests that microdata sets ought to be developed and analyzed in the study of appropriate electric utility pricing policies.

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The purpose of this paper is to examine the declining block (DB) structure which characterizes many electric utilities, and to explore the impact of alternative pricing structures, including life-line rates (rate inversion). In the case of life-line rates, households with low consumption face lower rates than under DB; if rates for heavy users increase to offset the resulting revenue loss, there may be a rate inversion. It will be seen that the effects of changes in the block structure depend on the composition of demand, including the pattern of price elasticities and demand intensities. Impacts to be investigated include adequacy of total revenue, the distribution of consumer expenditures, and the pattern of consumer benefits.

This work may be viewed as an extension of the two-part tariff literature [Oi (10), Lapinski (9), and Feldstein (4)]. To facilitate comparisons, a third block is introduced; but most important, we focus upon the components of aggregate demand. Six special cases are presented to illustrate how skewness and variance in the composition of demand affect the pattern of burdens and benefits. For example, if each customer had identical demands (zero variance and skewness), rate inversion will have uniform effects (gains and losses) across customers. When components of demand differ, rate restructuring yields differential impacts. The elasticity of demand is shown to be another determinant of the relative benefits received by consumers under alternative pricing schemes.

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\*Assistant Professor of Economics, University of Florida, and Research Associate, Public Utility Research Center, respectively. The research was supported by grants from the Division of Sponsored Research and the Public Utilities Research Center, University of Florida. Preliminary research results were reported in a paper presented at the Atlantic Economic Society meetings, September 1974. Rafael Lusky, Milton Kafoglis, and referees provided helpful suggestions on earlier versions of the material presented here.

The analytical comparisons presented here suggest that microdata in the form of customer billings and income levels (by census tracts) is essential for analysis of rate restructuring. For example, in some situations a rate inversion will encourage aggregate consumption rather than discourage it. In addition, an analysis of consumer's surplus can identify what customer class (by level of usage) gains and what class loses from an alteration in the block schedule. But first we examine the extent to which revenues sufficient to cover incurred costs might be realized under the alternative pricing schemes.

### 1. Impact of Alternative Block Pricing Schemes on Quantity Demanded and Revenues

To compare various block pricing schedules, we will consider a case in which an electric utility knows the aggregate (constant elasticity) demand function it faces:  $Q = \alpha P^\eta$  where  $Q$  represents quantity demanded,  $P$  represents the single, uniform price of electricity,  $\alpha$  is a scale (or intensity of demand) factor, and  $\eta$  is the price elasticity. For simplicity, we assume that there are three customers. Since total quantity demanded by the three customers combined will depend on the nature of their separate demand functions, we will consider six of the possible combinations of constant elasticity individual demands which are consistent with the aggregate demand. As a simple analytic tool, each individual demand (i) may be characterized by its scale coefficient,  $\alpha_i$ . The six composites of individual demands considered are shown in Figure 1. Elasticities of  $-0.7$ ,  $-1.0$ , and  $-1.3$  are used to illustrate the effect of different responsiveness of aggregate demand. The three aggregates intersect at 2,250 kwh; which would be the amount demanded for each of the composites (at each of the elasticities) if a single price of 2.5¢ per kwh were charged. The three rate structures are depicted in Figure 2: declining block, inverted block, and high tail schedule.

For computational simplicity we have assumed a zero income effect, since in the absence of this assumption, rate inversion would increase the amount demanded

FIGURE 1

## CONSTANT ELASTICITY DEMAND COMPONENTS:

Composite	Elasticity ( $\eta$ )	(Aggregate Demand, $Q = \alpha P^\eta$ )			Relative <sup>a/</sup> Standard Deviation	Relative <sup>b/</sup> Skewness
		Constant Terms ( $\alpha$ )				
		-0.7	-1.0	-1.3		
	1/6	28.35	9.375	3.1		
A	1/6	28.35	9.375	3.1	1.2247	.75
	2/3	113.4	37.5	12.4		
	1/12	14.175	4.6875	1.55		
B	1/4	42.525	14.0625	4.65	1.2747	.5938
	2/3	113.4	37.5	12.4		
	1/3	56.7	18.75	6.2		
C	1/3	56.7	18.75	6.2	0	0
	1/3	56.7	18.75	6.2		
	1/4	42.525	14.0625	4.65		
D	1/3	56.7	18.75	6.2	.3535	0
	5/12	70.875	23.4375	7.75		
	1/6	28.35	9.375	3.1		
E	1/3	56.7	18.75	6.2	.7071	0
	1/2	85.05	28.125	9.3		
	1/12	14.175	4.6875	1.55		
F	1/3	56.7	18.75	6.2	1.0612	0
	7/12	99.225	32.8125	10.85		

<sup>a/</sup> This number is the standard deviation of  $\alpha$ 's from a composite, divided by its mean, i.e.  $\sigma/\mu$ .

<sup>b/</sup> This number is a weighted measure of skewness, i.e.  $\Sigma(x_i - \mu)^3/\mu^3$ .

FIGURE 2

Price Per kwh under Alternative Price Structures

	Declining Block Schedule	Inverted Block Schedule	High Tail Schedule
0 - 250 kwh	7.5	2.5	7.5
250 - 500 kwh	5.0	5.0	5.0
500 kwh and above	2.5	7.5	5.0

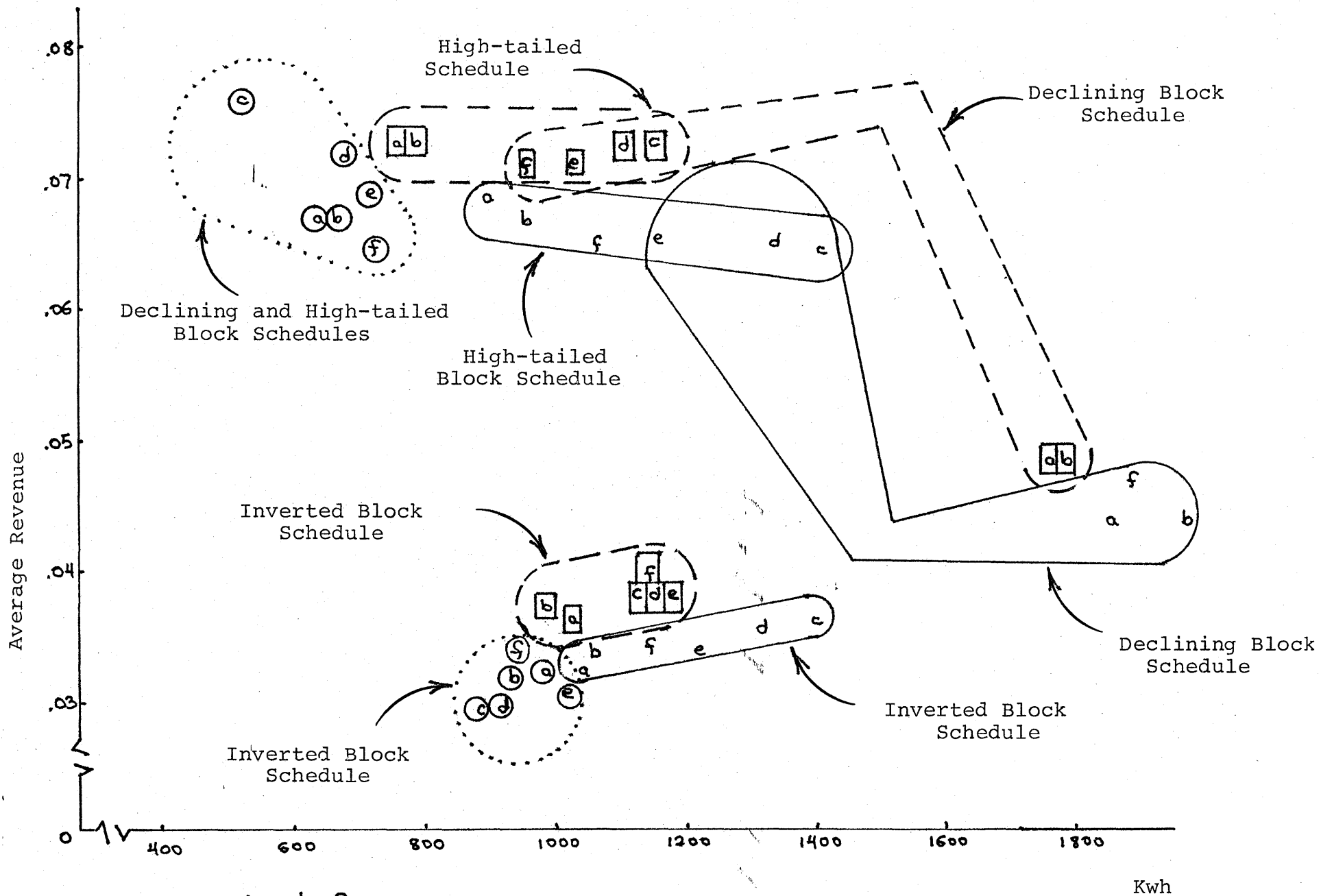
kwh (kilowatt-hour) is an energy measurement of electricity

at each marginal price. Taylor has surveyed and extended work in this area by Buchanan, Davidson, and Gabor, but the income effect so complicates the analysis that it is not considered here. Taylor brings into question the concept of "the" price elasticity as a measure of the responsiveness of consumption. The same percentage change in average price can have very different effects on individual and aggregate consumption, depending on the particular change in the price structure, (which blocks are affected). But even in the absence of income effects, discontinuities in the budget line result in discrete consumption jumps when the maximizing consumer shifts from one block to another (see Berg<sup>(2)</sup> for further discussion of this problem in the context of estimating consumer responsiveness to changes in block pricing structures).

Given a zero income effect, we determine the total quantity demanded by all three individuals combined in each case by calculating the total quantity demanded by each individual, and summing over the three customers. Since an individual, when facing a block pricing schedule, will consume up to the point at which his consumer's surplus is maximized, we can calculate the appropriate amount demanded (here a simple computer program facilitated our work). In some cases, an increase in the marginal price results in the costs outweighing the benefits of continuing to consume in that block, causing consumption cutbacks that are greater than might be estimated merely from the price elasticity. Figure 3 (for demand elasticities of  $-.7$ ,  $-1.0$ , and  $-1.3$ ) shows the total quantity demanded and average revenue (expenditure) at that quantity for each of the composite demands, under three alternative price schedules.

## 2. Inelastic Demand

From Figure 3, we can see how aggregate (composite) consumption is affected by the three rate schedules. When demand elasticity is  $-.7$ , the declining block structure does result in high total consumption for those composites with a high relative standard deviation, A, B, and F. With inelastic components, the greater



$\eta = -0.7 : a b c d e f$

$\eta = -1.0 : \boxed{a} \boxed{b} \boxed{c} \boxed{d} \boxed{e} \boxed{f}$

$\eta = -1.3 : \textcircled{a} \textcircled{b} \textcircled{c} \textcircled{d} \textcircled{e} \textcircled{f}$

FIGURE 3  
Average Revenue and Quantities Demanded



the disparity among the weights ( $\alpha_i$ ) given to each component of the aggregate, the greater is the aggregate consumption. For A and B (the composites with high relative skewness), one of the components comprises two-thirds of aggregate demand, so the aggregate quantity demanded (about 1900 kwh) is near the 2,250 kwh that would obtain if a single price of 2.5¢ per kwh were charged. The higher marginal prices at low levels of consumption only cuts back a little of the potential (uniform price) amount demanded.

The relevance of this observation for public utility pricing is clear. When there would be substantial differences in electricity consumption per household if a uniform price were charged, the declining block structure will tend to induce high capacity requirements (irrespective of peak-load considerations and demand diversity in that dimension). In the past, such diversity (especially skewness) may have generated its own reward, since the declining block structure in that situation facilitated the achievement of scale economies. In our simple example, if average cost were about 5.0¢ in the 1,900 kwh range, (and marginal cost were 2.5¢) declining block structure yields near optimal output (compared with 2,250) and results in sufficient revenues. In the presence of aggregate demands with lower relative standard deviation, that same declining block schedule results in lower aggregate consumption but higher average revenue (which may or may not meet total costs).

One implication of this tendency is that across states or by jurisdiction, observed differences in average price paid by electricity consumers may partly reflect inequalities in the mix of consumers. For example, assuming that components are price inelastic and that the level of income essentially determines the scale factor ( $\alpha_i$ ), income inequality will result in different levels of aggregate (and average) consumption -- even in the presence of the same price schedule and average incomes.

Furthermore, the use of average prices yields an aggregation problem:

$$Q_1 = \alpha_1 P_1^\eta$$

$$Q_2 = \alpha_2 P_2^\eta$$

but  $Q_1 + Q_2 = (\alpha_1 + \alpha_2)P^\eta$  only if  $P_1 = P_2$ , and with declining block rates individuals 1 and 2 may face different marginal prices. So assuming the same price elasticity across individual customers, the use of average price will yield biased estimates of  $\eta$ . See Berg, Griffin, and Taylor for further discussion of related problems.

Turning to other price structures, the high tailed block schedule only affects the consumption of large consumers--dropping A, B, and F (which have such components) back to about 1,000 kwh. Note that inverting the rate schedule does hit A, B, and F (relative to the declining block structure) and substantially reduces average revenue for the firm. The quantities demanded under the three relatively "balanced" composites, C, D, and E (low relative standard deviation, and zero relative skewness) are not affected by rate inversion. This observation suggests that for some aggregate demands, the technique is an ideal way to rid the firm of revenue--without encouraging consumption. For example, if marginal cost is above average cost and marginal cost pricing results in a firm earning excess profits--rate inversion might dissipate those profits, without causing significant changes in the level of output (assuming zero income effect). In Figure 3, if average cost is about 3.5¢ per kwh, and marginal cost is 7.5¢ per kwh (in the 1200 kwh range), rate inversion would be an alternative to taxing away those excess profits. The distributional consequences of such a move are discussed in Section 4 of this paper

### 3. Unitary and Elastic Demand

Similar results for a demand elasticity of -1.0 are also depicted in Figure 3. Here, the declining block structure only encourages substantial consumption (1800 kwh) for composites A and B (those with the largest relative standard deviations of  $\alpha$ 's). This suggests that as aggregate and individual demands become less inelastic, that greater diversity among components is necessary for high aggregate (and average) consumption to characterize declining block schedules. Composites A and B also have

the largest standard deviations of quantities actually consumed by the three customers--given the rate structure. Diversity among the actual consumption levels serves as an observable proxy for relative standard deviation among the  $\alpha$ 's. Again, the high tailed schedule cuts back these large aggregate demands (to 750 kwh), while inverted rates slightly encourage consumption for the other composites.

When individual and aggregate demands are relatively elastic (-1.3), the declining block structure results in aggregate consumption in the 700 kwh range (for the particular functions used here). Because the incremental expenditures would outweigh the benefits, none of the individual components consume in the third block under declining block rates, so the high tail price structure does not reduce aggregate amount demanded for any of the composites. However, rate inversion greatly expands consumption (to the 950 kwh range). Thus, when the small consumers have relatively elastic demands, their consumption under rate inversion can swamp the cutbacks by larger components. The implication for social programs like "life-line" rates should be clear.

These results for rate inversion are reinforced if there is a positive income effect. In such cases, if electricity occupies a large portion of a consumer's budget, the price he pays for units in the first block of the schedule will have a large impact on the quantity purchased in succeeding blocks. Even without an income effect, high relative standard deviation characterizes the composites whose total consumption is most affected by rate inversion. For example, aggregate consumption by F, A, and B increases for  $\eta = -.7$ , while it increases for D and E, as well as F, A, and B, for  $\eta = -1.0$ . For relatively elastic demand, all the composites (even C, the most balanced) experience higher consumption. As elasticity increases, less diversity (as measured by relative standard deviation) is required for rate inversion to increase consumption.

#### 4. Impact of Alternative Price Structures on Consumer Surplus

Now we turn to the impact on welfare. Assuming no income effects, the area under individual and composite demands serves as a measure of consumer benefits.

Figure 4 shows the aggregate quantity consumed and aggregate consumer surplus for each of the six composites and each of the three elasticities under the alternative pricing schemes. The surplus is calculated beginning at a quantity of 10 kwh to avoid comparisons at unrealistically low consumption and high incremental consumer surplus (for inelastic demand in particular).

Because of our assumption that all three aggregate demand curves contain the point (2,250 kwh, 2.5¢), as elasticity increases, consumer surplus falls. What is important is the impact of alternative price structures on the distribution of consumer surplus among composites. For the demand elasticity of  $-.7$ , consumption by composites A and B drops substantially, while aggregate consumers surplus falls only about five percent (\$20) when the high-tail price structure is substituted for the declining block. Composite F, which has a lower relative standard deviation for its components than A and B, experiences a smaller consumption cutback and only a \$10 drop in consumer surplus. So if new cost conditions warrant a sharp rise in the tail block--aggregate consumption will be most greatly affected if there is substantial diversity among the three components. Yet, the price increase does not "hurt" consumers proportionally as much.

For the unitary elasticity case, there is again a significant consumption cutback when shifting from declining block to high-tailed, but only for A and B; and in those cases, consumers surplus only falls by about \$5, or 2 percent. For each of the composites and elasticities, consumers surplus often increases under rate inversion--as the low 2.5¢ per kwh price is applied to the first 250 kwh; thus consumers surplus can rise even though aggregate consumption falls.

Not shown here is the distribution of benefits among components; in particular, rate inversion affects consumers surplus within the composites. For example, under unitary elasticity for the least intensive component (one-twelfth of the composites B and F,  $\alpha_1 = 14.17$ ) consumers surplus increases by 36 percent under rate inversion relative to declining block structure. For the most intensive component, (two-thirds

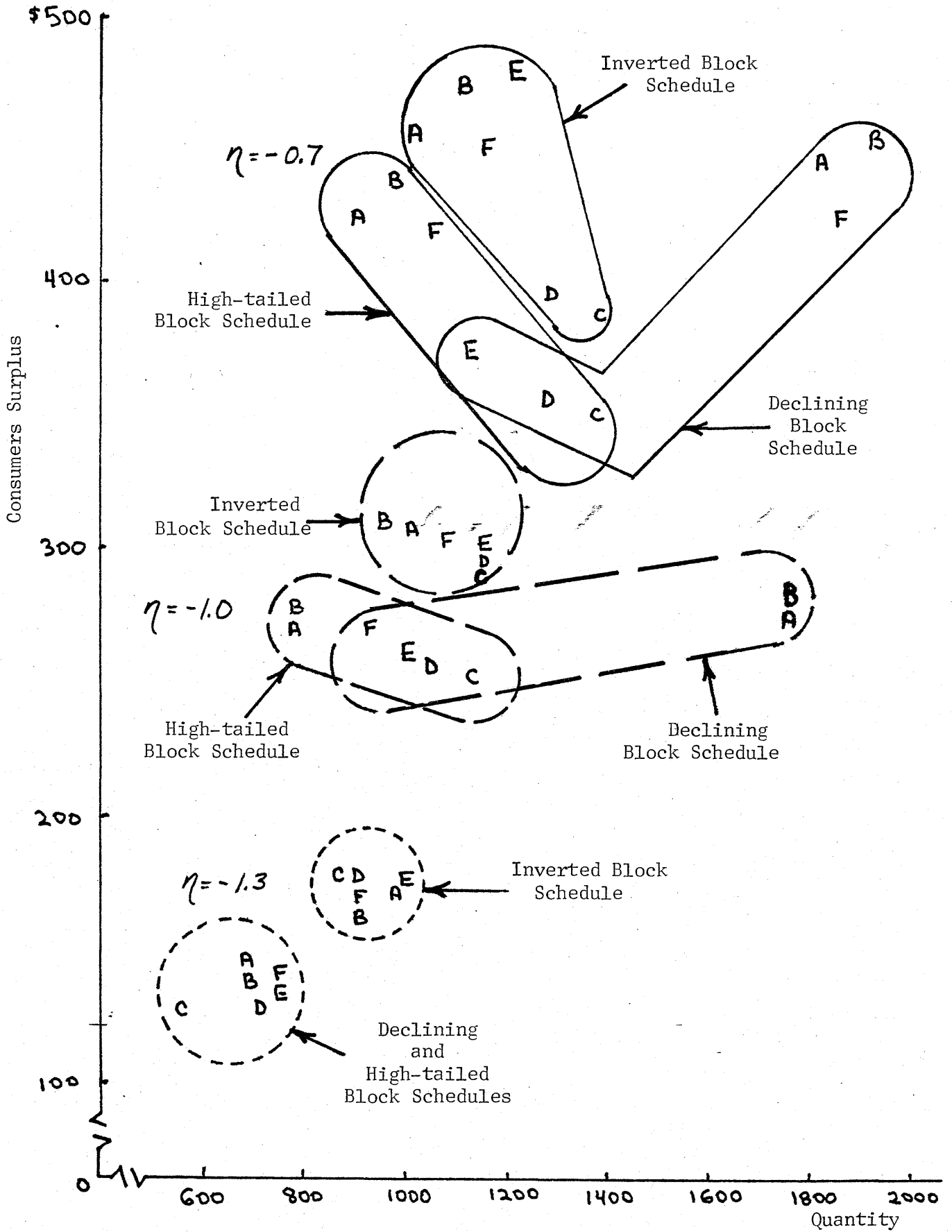


Figure 4

Aggregate Consumers Surplus and Quantity Demanded  
 (Three Price Schedules and Three Elasticities)

of composites A and B,  $\alpha_i = 113.4$ ) consumers surplus increases by only 4.3 percent. Thus, changes in rate structure have very different distributional effects, depending on the composition of demand.

## 5. Conclusions

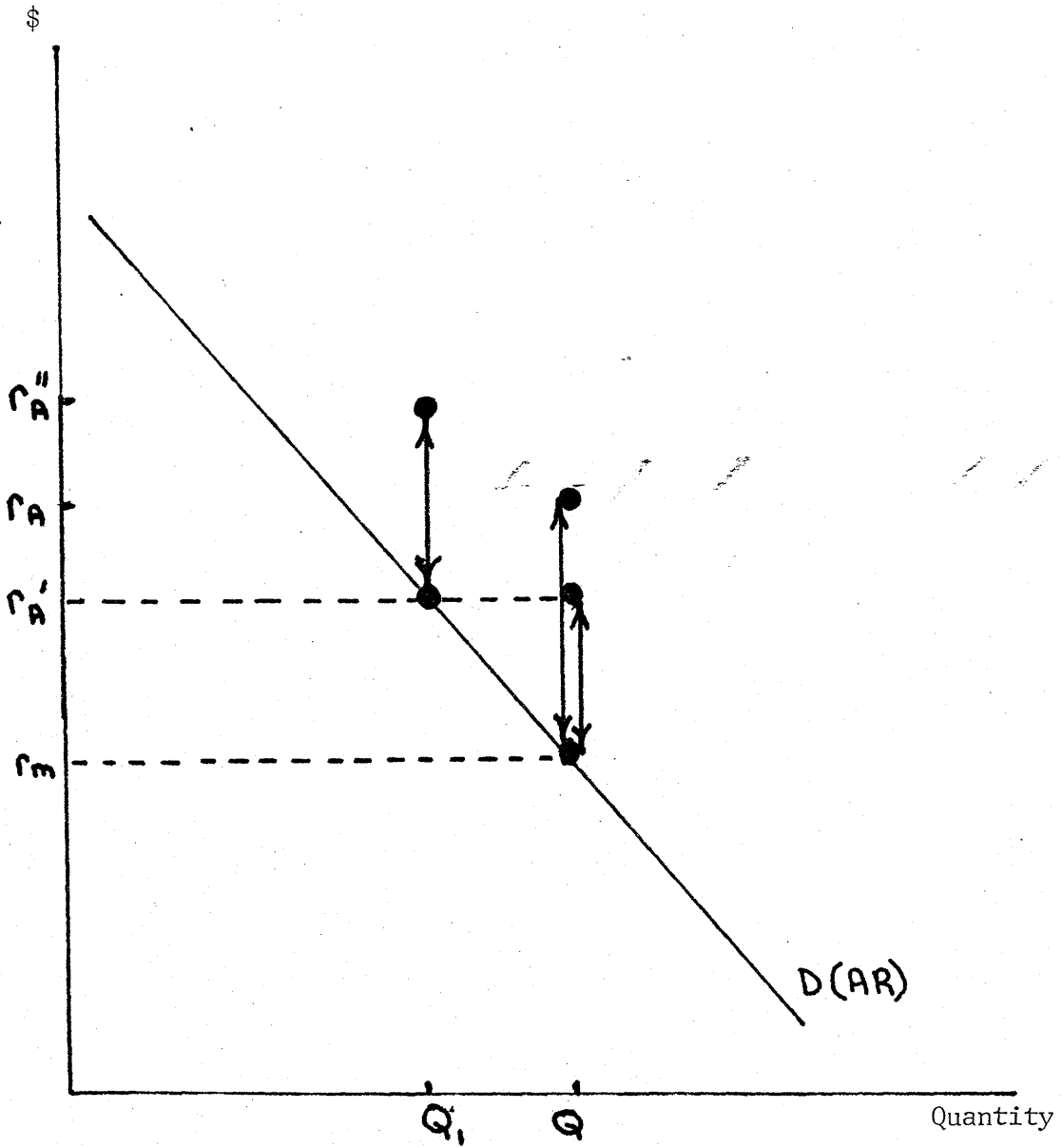
Although the absolute level of consumer surplus cannot be directly related to particular elasticities (because of the different positions of the aggregate demand functions), it is clear that rate structures affect both the level and pattern of benefits. Such a notion has been implicit in previous research, and the simulation results presented here illustrate the role of demand diversity in determining a firm's output level--given the price structure. In addition, the relative contributions of the three components to coverage of total cost depend on the elasticity and composition of demand, as well as the price structure.

The framework presented here suggests that within a customer class, the relative contributions of customers of various sizes (say, due to income differences) depends on the rate structure and the elasticity of demand.\* Following a paper by Kafoglis and Needy (7), we define "rate spread" as the absolute difference between marginal and average price. As depicted in Figure 5, the aggregate demand is  $D(ar)$ , and a declining block structure yields an average revenue of  $r_A$ , although the marginal price is  $r_M$ . The distance  $r_M r_A$  is a theoretical measure of rate of spread. If the front block is reduced (as from 7.5¢ to 5¢), average revenue falls and (if consumption does not increase) rate spread declines to  $r_M r_A'$ . Rate spread may also be reduced by increasing the tail block. If that block is increased to  $r_A'$ , consumption falls to  $Q_1$ , and rate spread falls to  $r_A' r_A''$ . So, by reducing the initial blocks, small users are helped--as is reflected in the reduction in rate spread. And as price at high consumption levels is raised, heavy users are hit, and again rate spread falls.

\* Different demand elasticities for large and small components could be incorporated into the framework, but complexity increases exponentially.

Figure 5

Rate Spread Due to Size of Use



Note, however, that the above analysis ignores the composition of demand. For a given composite, it is correct to conclude that rate spread reductions reflect more equal sharing of the cost burden, (although cost conditions might warrant declining block pricing). However, when comparing two rate spreads from different utilities, the different composition of aggregate demands will result in the calculation of different rate spreads, even if they have the same rate schedules. Alternatively, the same rate spread can obtain when the utilities have different rate schedules, but also different demand compositions which compensate for the price differences.

The conclusion is that welfare is not easily judged from measures of rate spread nor from an alternative measure like Gini coefficients (see Kafoglis and Needy, 8). Similarly, the supporters of "life-line" rates should examine more carefully the distributional and allocative effects such charges. Furthermore when forecasting future demand, aggregate consumption depends on the composition of demand. More detailed analyses of individual consumers or groups within the residential aggregate) will be necessary to assess the distributional and allocative effects of changes in price structures. Such studies are necessary to ascertain the differential effects of both fuel adjustments and rate restructuring based on incremental cost pricing.



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