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WORKING PAPER 84-86

THE EVALUATION OF COMPLEX URBAN POLICIES:
SIMULATING THE WILLINGNESS TO
PAY FOR THE BENEFITS OF SUBSIDY PROGRAMS

BY

JOHN M. QUIGLEY

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THE EVALUATION OF COMPLEX URBAN POLICIES: SIMULATING THE WILLINGNESS TO PAY FOR THE BENEFITS OF SUBSIDY PROGRAMS*

by

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Working Paper 84-86

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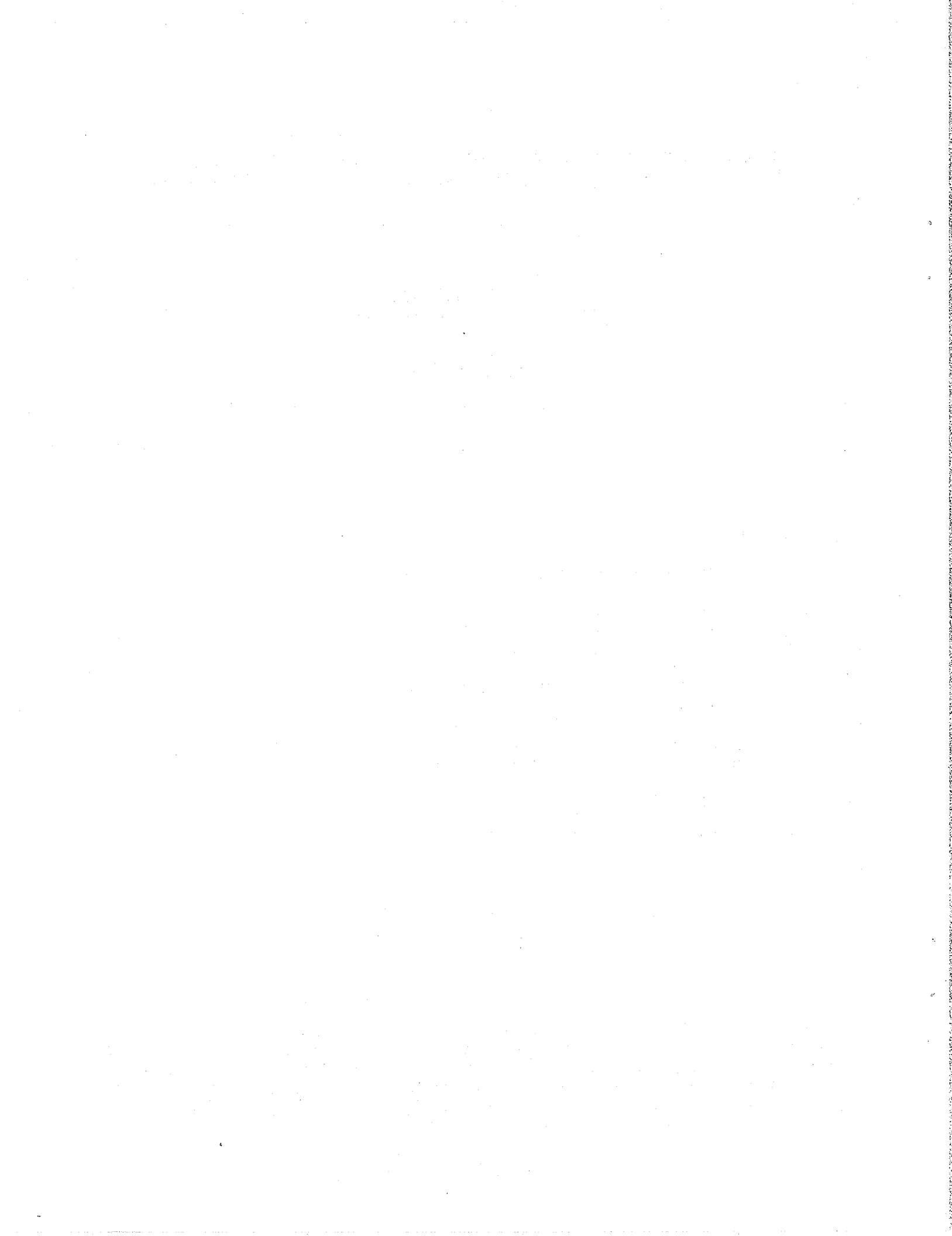
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I. INTRODUCTION

To an economist, the justification for publicly provided urban shelter or urban renewal projects is much stronger if they are socially "profitable" than if they are merely politically acceptable forms of redistribution towards deserving groups. Indeed, if such programs pass the cost-benefit criterion of social profitability, then efficiency can be improved with no sacrifice of distributional goals. Urban shelter or urban renewal projects can be justified as socially profitable, in turn, if either suppliers or demanders face inefficient price signals -- for example, if some prisoners' dilemma prevents atomistic suppliers from maximizing collective profits or if some non-marketed external benefit incidental to housing consumption prevents demanders from maximizing utility.

To justify some urban shelter program on the basis of consumption externalities, it would be necessary to demonstrate that an urban housing investment program provided increased public health, safety or labor market benefits which were not reflected in consumers' willingness to pay for increased amenities. Although there is no lack of assertions about the importance of these externalities, there is little or no serious evidence to support their existence.¹

In contrast, to justify an urban shelter or urban renewal project due to failures in individual profit signals, it would be necessary to demonstrate that the aggregate willingness to pay for improved conditions exceeds the supply cost of provision. This criterion is quite demanding. Nevertheless, casual empiricism suggests that many proposed projects might satisfy it. Neighborhood exter-

¹ See Burns and Grebler [1976], for example, for a critique of such evidence from developing countries where, it has been asserted, the magnitude of such external consumption benefits is large.

nalities and the propinquity of parcels, buildings, and land uses all seem to indicate that the level of private and public investment in urban amenities could deviate substantially from the level that would maximize individual well-being and collective profits.

This paper considers the evaluation of urban renewal and other urban investment policies and the application of this aggregate willingness to pay criterion to investment decisions. In the following section, we discuss two rigorous approaches to the measurement of program benefits, each deduced from general theoretical notions advanced a decade ago. In section three, we compare the two methods by relying upon a series of simulations. The preliminary results are presented in section IV.

II. WILLINGNESS TO PAY FOR URBAN SHELTER PROGRAMS

Consider the following general problem. A household of income y is observed to consume a vector of housing and urban amenities at some market price (e.g., monthly rent). Without loss of generality, assume the vector of amenities is h at market price $p(h)$ leaving y minus $p(h)$ for the consumption of other goods. As a result of some public investment policy, the household is offered the opportunity to consume H at some price $P(H)$. What is the household's willingness to pay for the public program?

Let $U(.,.)$ be the utility function for the household. The amount of money $_$ which could be given to the household in lieu of the proposed public investment program is the solution to:

$$(1) \quad U(h, y - p[h] + _) = U(H, y - p[H])$$

The amount of money, δ , which could be taxed from the household benefiting from the public program to leave it as well off as it was initially is the solution to:

$$(2) \quad U(H, y - p[H] - \delta) = U(h, y - p[h])$$

These measures, the so-called Hicksian equivalent variation and compensating variation, represent the cash value of the public program in terms of its effects upon the household. In the absence of general equilibrium effects, the aggregate willingness to pay for the investment program is merely the sum of δ over the relevant population.

The estimation of these magnitudes requires some theoretically defensible procedure for inferring the "shape" of the ordinal utility function or for deducing the compensated demand curve for the vector of amenities. Extensions of Rosen's work on hedonic prices and McFadden's work on discrete choice models, both published in 1974, provide alternative methods for using market information to estimate utility contours rigorously and for measuring the benefits of public investment programs rigorously according to equation (1) or (2). In the remainder of this section, we indicate how these models can be applied to estimate program benefits.

A. A Continuous Model: Hedonic Pricing

Two of the distinguishing features of the housing market are that a large fraction of the housing services consumed in a given period are produced from the standing stock and that the stock is itself expensive to modify. Thus, to a first approximation, housing prices are demand determined as existing dwellings

are "auctioned" for occupancy by the highest bidder in any period. In addition the resulting housing prices are generally non-linear functions of quantity, due to high transformation costs (or "repackaging" costs, in Rosen's terminology).

Utility maximization implies that each household chooses h to:

$$(3) \quad \max U(h, y - p[h])$$

with a given exogeneous price function. The price function itself is determined endogeneously from the competitive behavior of households solving the above maximization problem. This hedonic price function is given by the solution to:

$$(4) \quad \frac{\partial U(h, y - P[h]) / \partial h}{\partial U(h, y - P[h]) / \partial y} = \frac{dP}{dh}$$

The left hand side of (4) is the marginal rate of substitution of housing for income, the income compensated demand for housing, or the household's marginal bid for an additional unit of housing. In equilibrium, the marginal bid just equals the marginal price of housing dictated by the market, the right hand side of equation (4).

Given an exact functional form for the utility function, and given some mapping of housing to income, $y = f(h)$, the market wide hedonic price relationship can be computed.

For example, if the utility function is Cobb-Douglas with parameters α and β ,

$$(5) \quad U = Ah^\alpha (y - P[h])^\beta = Ah^\alpha (F[h] - P[h])^\beta,$$

then integration of (4), with initial condition $P(1) = 0$, yields

$$(6) \quad P(h) = (\alpha/\beta) h^{-\alpha/\beta} \int_1^h F(u)/u^{1+\alpha/\beta} du$$

If the mapping is known exactly, say the linear and continuous function

$$(7) \quad y = f(h) = h - 1$$

then the hedonic function can be derived explicitly,

$$(8) \quad P(h) = \{\alpha/(\alpha+\beta)\}h + \{\beta/(\alpha+\beta)\}h^{-\alpha/\beta} - 1$$

For different assumptions about the form of the utility function and for different mappings relating the distribution of housing to income, equation (4) can be solved for the market-wide hedonic price relation. Of course, for plausible utility functions it may not be possible to solve (4) in closed form. The hedonic relationship between $P(h)$ and h may, however, be approximated quite easily using numerical methods. In a demand determined world, the exact locus of the hedonic function can be inferred from knowledge of the utility function and the housing-income frequency distribution.

Of course the essence of the welfare economics problem is that the parameters of the utility function are not known. They must be inferred from limited information about market behavior. In contrast, the hedonic price relationship can be "observed" directly in a market, at least by statistical means. In particular, a body of observations on dwellings and their prices permits the computation of some regression approximation to the "exact" hedonic function. This, in turn, permits statistical estimation of the parameters of an assumed functional form for the utility function. For example, if the form of the utility function is GCES

$$(9) \quad U = [\alpha h^\beta + (y-p)^\varepsilon]^\phi ,$$

then substitution into (4) yields

$$(10) \quad \frac{\alpha\beta h^{\beta-1}}{\varepsilon (y-p)^{\varepsilon-1}} = \frac{dp}{dh} ,$$

or

$$(11) \quad \log (\alpha\beta/\varepsilon) + (\beta-1) \log h + (1-\varepsilon) \log (y-p) = \log (dP/dh)$$

The parameters of the utility function, α , β , ε can be estimated consistently from the three coefficients of the regression estimate of equation (11). The dependent variable is the logarithm of the derivative of the hedonic price function and the independent variables include the logarithms of the consumption of housing and other goods. If the utility function is CES, $\theta = \alpha = \beta = \varepsilon = 1/\phi$, then (11) can be simplified to

$$(11') \quad \log \theta + (\theta-1) \log (h/[y-P]) = \log (dP/dh) .$$

B. A Discrete Model: Quantal Choice

Another distinguishing feature of the housing market is the discrete nature of consumer choice. Although the housing bundle is composed of a large number of diverse components, housing choice consists of the selection of one unit out of a potentially large number of discrete alternatives. In this market, a household chooses a specific and discrete dwelling to solve the maximization problem in (3). In particular, as McFadden [1974] has shown, if the individual

utility function includes an additive stochastic component, and if the stochastic component is independently and identically Weibully distributed across households, then the probability, Π , that a household will choose a particular dwelling, h^* , is:

$$(12) \quad \Pi(h=h^*) = \frac{\exp \{U(h^*, y-p[h^*])\}}{\sum_h \exp \{U(h, y-p[h])\}}$$

If the preference function is linear in parameters, then these parameters may be uniquely estimated, up to a factor of proportionality, by maximizing a log likelihood function of the form:

$$(13) \quad \log L \propto - \sum_k \frac{\log e^{U(h^*, y-p[h^*])}}{\sum_h \log e^{U(h, y-p[h])}}$$

for a sample of k observations on choices h^* and available alternatives h . Clearly the set of alternative dwellings in a metropolitan area is so large as to make an iterative solution of (13) computationally infeasible. However, as McFadden [1978] has shown, it is possible to estimate the choice model in a consistent manner by selecting a sample d of rejected alternatives for each household according to the sampling rule, θ ,

$$(14) \quad \text{if } \theta(d|h^*) > 0, \text{ then } \theta(d|h^*) = \theta(d|h)$$

This sampling rule possesses the so-called "uniform conditioning property." For each individual, the sample includes the chosen alternative, and each alterna-

tive in the set d is equally likely to be the chosen alternative. Under these conditions, the summation in the denominator Σ_h can be replaced by Σ_d and the parameters of the model can be estimated by maximum likelihood using a sample of metropolitan housing alternatives.

C. Housing Market Applications

During the past few years, there have been an increasing number of applications of these techniques to the housing market. Empirical analyses exploiting the non-linearity of housing prices to estimate the benefits of urban amenities have been reported by Harrison and Rubinfeld [1978], Kaufman and Quigley [1984], Quigley [1982], Witte, *et al* [1979], among others.

Empirical applications of the quantal choice model to the housing market include papers by Anas [1984], Ellickson [1981], Kain and Apgar [1977], Lerman [1977], Quigley [1983, 1985] and Williams [1979].

In applying these very different techniques to estimating demands for amenity, researchers have utilized the same kinds of data -- a sample of households, their incomes and demographic characteristics on the one hand, and the characteristics of the dwellings these households occupy, including exogenous housing prices, on the other hand.

III. A STYLIZED COMPARISON OF WILLINGNESS TO PAY

Although they rely upon substantially the same data to answer similar questions about the slopes of consumers' utility functions, the hedonic and discrete choice approaches employ very different assumptions and statistical techniques.

One objective of the analysis described in this section is to compare the implications of the two models using the same underlying data. In particular, a major objective of the comparison was to characterize the circumstances under which one or the other analysis is likely to provide more accurate estimates of the welfare benefits of programs. Currently, a more elaborate Monte Carlo comparison is underway to investigate how sensitive estimates of welfare effects are to changes in parameter values or to stochastic factors.

The second objective of the analysis is to consider explicitly the endogeneity of prices in the housing market and the effects of this endogeneity upon estimated welfare effects. As noted above, previous applications of these hedonic or discrete choice techniques to the housing market have assumed that housing prices are given exogeneously. The comparative analysis in this section is based upon the market equilibrium prices determined by the choices of actors in the housing market.

A. The Structure of The Simulations

We conduct the simulations by choosing the form of the utility function for households in the market and the parameters of that function. Thus the compensated demand curves for housing and the shapes of the utility contours are known.

We next choose a continuous mapping from housing to income, $y = f(h)$, in the market. This is equivalent to selecting the joint frequency of income and available housing units. We assume throughout that housing is a normal good, that is, that the mapping is a monotonically increasing function.

The form of the utility function and the relative frequency distribution are

sufficient to define the market clearing price relationship in the market, at least if housing is auctioned to the highest bidder. We assume that the market consists of 100 households of varying incomes and more than 100 dwellings. The structure of these prices is computed by numerical integration of (4) using the Runge-Kutta method. The price structure will have the following properties: all dwellings below those 100 which provide the highest levels of service (h) will be vacant. That dwelling numbering 100 from the highest in terms of h will be occupied at a price of zero, and the remaining 99 dwellings will be occupied at positive prices. The equilibrium price structure clears the market and assigns each household to its preferred dwelling. The endogeneous price relationship represents the equilibrium pattern of housing prices in the market.

At this point a "data set" has been created. The data set consists of 100 observations on households: their incomes y , their housing consumption h , their expenditures on housing, $p(h)$, and on other goods, $y-p(h)$. This data set is then analyzed using the two techniques described above: the so-called hedonic and quantal choice approaches. For each technique we estimate the parameters of the utility function, the slope of the contours, and we compare the estimates with the characteristics of the known function.

B. Estimating the Hedonic Model

We use the 100 observations on h and $P(h)$ to estimate the hedonic price function in the market by a power series approximation, i.e., we estimate the regression

$$(15) \quad P(h) = \omega_0 + \omega_1 h + \omega_2 h^2 + \omega_3 h^3 + \omega_4 h^4 + \omega_5 h^5 = g(h)$$

We then differentiate this function, take logarithms, and estimate the re-

gression:

$$(16) \quad \log (dg/dh) = \eta_0 + \eta_1 \log h + \eta_2 \log (y-p)$$

using the sample of 100 observations. The parameters of this regression are transformed to provide estimates of the GCES approximation to the unknown utility function.

$$(17) \quad U = \alpha h^\beta + (y-p)^\varepsilon$$

where

$$\alpha = [(1 - \eta_2)/(1 + \eta_1)]e^{\eta_0}$$

$$\beta = 1 + \eta_1$$

$$\varepsilon = 1 - \eta_2$$

C. Estimating the Quantal Choice Model

For each of the 100 observations on the housing chosen by a household of income y at price p , we select a sample, d , of four dwellings not chosen by the household according to the sampling rule

$$(18) \quad \theta(d|h) = 4/99 \quad ,$$

that is for each household in the sample, we randomly select four dwellings which have been rejected according to a rule with the uniform conditioning property. We estimate the parameters of a linear approximation to the unknown util-

ity function.

$$(19) \quad U = \alpha_1 h + \alpha_2 (y-p) + \alpha_3 h(y-p)$$

from the observations on the chosen alternative and a sample of four rejected alternatives for each of 100 households. The estimation is undertaken by maximizing the likelihood function in (13) according to the procedure suggested by McFadden [1978].

IV. SOME PRELIMINARY RESULTS

This section presents a comparison of these methods of estimating the preferences of housing consumers using the same body of information. This information is, in turn, generated by a known structure of household preferences and some specified relative distribution of income and housing. The following example may provide a concrete illustration of the comparison.

Assume the structure of preferences is GCES with $\alpha = \beta = \epsilon = 0.250$ and there are 100 households with incomes, y , ranging from 1 to 11 in units of 0.1. Assume further that the market consists of 100 units whose quality level, h , is normally distributed with mean 5 and standard deviation 2. Housing is a normal good; the rectangular income distribution and the normal housing distribution yield a monotonic relationship,

$$(20) \quad y = (1/\sqrt{2\pi}) \exp[-(h-5)^2/2],$$

between h and y in the market. Together these assumptions yield an equilibrium structure of prices (by integrating equation 4) throughout the market.

Consider the hedonic approach. The equilibrium price structure is approximated by the continuous function in equation (15), estimated by ordinary least squares. The derivatives of this function at the prices computed for each dwelling are then used to estimate the parameters of equation (16) by ordinary least squares.

This procedure yields estimates of $\alpha = 0.227$, $\beta = 0.264$, and $\varepsilon = 0.244$ for the three parameters, estimates which differ from the true values by 2 to 9 percent. Although the estimates differ from the true parameters, the values of the utility functions are highly correlated (at 0.99) within the range of the data. The marginal willingness to pay for housing computed from the regression procedure is also highly correlated with the true willingness to pay ($r = .99$), and the mean value of the estimated willingness to pay is very close to the true value (the ratio is 0.99), at least for the 100 observations in the sample.

Now consider the quantal choice approach applied to the same data. For each of 100 households of differing income, the quantity of housing chosen and its price are both known. For each household, we randomly select four rejected dwellings and estimate the parameters of equation (19) by maximum likelihood. Again, the average value of the estimated utility function is highly correlated with the known true value ($r = .96$). The correlation of the computed with the actual marginal willingness to pay is somewhat lower ($r = .90$), but the average values are close (the ratio is 0.99).

Tables 1 and 2 provide a summary comparison of the two methods of estimating willingness to pay. These measures are estimated for a single uniform income distribution (with y varying from 1 to 11 in units of 0.1), for four different housing distributions with mean 5, but with standard deviation of 2, 2.5, 4, and

8, and for one housing distribution with mean 11 and standard deviation 5. A "housing market" is defined by drawing one hundred values of h from the distribution. Since the income distribution is the same for each housing market, those with relatively less variation in h are those where, *ceteris paribus*, the slope of the hedonic function is greater. In each case, the parameters of the utility function, the houses, and the income of occupants are sufficient to determine the equilibrium structure of housing prices. Willingness to pay is estimated from the set of 100 observations on income, housing, and housing prices.

Table 1

Comparison of Welfare Measures for GCES Utility Functions
 Estimated by Hedonic and Quantal Choice Methods

Mapping: $y = F(\mu, \sigma)$, where F is the cumulative normal density function, and

μ	5	5	5	5	11
σ	2	2.5	4	8	5

A. Correlations of true marginal willingness to pay with estimated values

Hedonic Method/Quantal Choice Method

α	β	ϵ					
.25	.25	.25	.99/.90	.99/.59	.99/.06	.99/.99	.99/.91
.25	.25	.75	.99/.93	.99/.90	.99/.76	.99/.07	.99/.46
.25	.75	.25	.99/-.02	.99/.18	.99/.89	.99/.99	.99/.75
.25	.75	.75	.97/.07	.99/.79	.99/.98	.99/.98	.97/.05
.75	.25	.25	.99/.04	.99/.64	.99/.95	.99/.99	.99/.83
.75	.25	.75	.99/.01	.99/.07	.99/.96	.99/.99	.72/.36
.75	.75	.25	.99/.15	.99/.64	.97/.69	.99/.93	--

B. Mean values of estimated marginal willingness to pay relative to true mean

Hedonic Method/Quantal Choice Method

α	β	ϵ					
.25	.25	.25	1.00/1.00	1.00/1.01	1.00/1.23	1.00/1.00	1.00/1.01
.25	.25	.75	1.00/1.01	1.00/0.97	1.00/0.87	1.00/0.60	1.00/0.39
.25	.75	.25	0.99/0.49	0.99/1.33	1.00/0.98	1.01/0.99	1.00/1.06
.25	.75	.75	0.99/0.38	1.00/1.03	1.00/1.00	1.00/1.02	1.00/1.10
.75	.25	.25	0.99/1.65	1.00/1.04	1.00/1.00	1.01/1.00	1.01/1.07
.75	.25	.75	1.00/1.16	1.00/1.02	1.00/1.02	1.00/1.00	1.01/1.14
.75	.75	.25	0.95/2.87	0.98/1.34	1.02/1.04	0.97/1.05	--

Table 1 summarizes the estimates when the true utility function is GCES for a number of values of the underlying preference parameters. Panel A presents the correlations between the true marginal willingness to pay, $(\partial u/\partial h)/(\partial u/\partial y)$, and that estimated by the hedonic and quantal choice procedures. For 30 of 34 estimations by the hedonic method, the correlations of willingness to pay are almost exact ($r = .99$). For three replications the correlations are close ($r = .97$) and in one instance the correlation is far off ($r = .72$). In contrast, the correlations of the marginal willingness to pay estimated from the quantal choice model with the true values are often bizarre. For 13 of the 34 comparisons, the correlations are above .9, but for 10 of the comparisons it is below .1; in one case it is actually negative. Panel B compares the average values of the marginal willingness to pay the different samples and estimating techniques. In all cases the mean value estimated by the hedonic technique is quite close to the true mean. It is never off by more than five percent. Again, the results for the quantal choice method are much more varied. In 21 of 34 cases, the estimated mean is within 10 percent of the true mean. In other cases, the mean is quite far off indeed. In one case, the estimated value is only 38 percent of the true value; in one case it is 287 percent. There is no pattern of deviation.

Table 2 provides a similar comparison of estimates when the underlying utility function is linear in parameters. Results are presented for eight values of the underlying taste parameters for the same five mappings. Again comparisons are presented of the correlation of estimated and true marginal willingness to pay in each sample, and the relationships between the true mean willingness to pay and the estimated value. Despite the fact that the form of the utility function is linear, the estimates obtained by the hedonic method (which assumes they are GCES) are quite close. In 37 of the 40 replications, the correlations are .94 or better, and in two of the other cases the correlations are reasonable

(i.e., $r = .80$, $r = .89$). In one case, the correlation is very low, $r = .44$. In contrast, the estimates obtained from the quantal choice function are again unexpected. In 18 of the 40 comparisons, the quantal choice method produces marginal willingness to pay estimates that are correlated at .9 or higher with the true values. In another three or four cases the correlations are reasonable, but in 10 cases the simple correlations are below .15. In four cases, the correlations are actually negative.

Similarly, comparisons of the mean values of the marginal willingness to pay, in Panel B, reveal that the hedonic method provides estimates reasonably close to the true average. In fact, in 40 comparisons only one is off by as much as 2 percent. In 27 cases the linear method results in an average willingness to pay within 10 percent of the true average. But in other cases it is quite far off--141 percent, 243 percent, as much as 313 percent of the true mean.

Table 2

Comparison of Welfare Measures for Linear Utility Functions
 Estimated by Hedonic and Quantal Choice Methods

Mapping: $y = F(\mu, \sigma)$, where F is the cumulative normal density function, and

μ	5	5	5	5	11
σ	2	2.5	4	8	5

A. Correlation of true marginal willingness to pay with estimated values

Hedonic Method/Quantal Choice Method

α_1	β_2	ϵ_3					
2.00	2.00	-0.25	.99/.97	.98/.79	.99/.89	.99/.99	.99/.96
2.00	2.00	-0.75	.99/.05	.96/.32	.44/-.13	.97/.92	.90/.15
2.00	4.00	-0.25	.99/.85	.99/.45	.99/.69	.99/.05	.99/.92
2.00	4.00	-0.75	.99/.90	.99/.60	.99/.06	.99/.99	.99/.95
4.00	2.00	-0.25	.99/-.07	.98/-.07	.99/.95	.99/.99	.99/.12
4.00	2.00	-0.75	.99/.11	.94/-.44	.80/.69	.99/.94	.89/.54
4.00	4.00	-0.25	.99/.93	.99/.61	.99/.05	.99/.99	.99/.99
4.00	4.00	-0.75	.99/.99	.98/.97	.99/.98	.99/.99	.99/.96

B. Mean values of estimated marginal willingness to pay relative to true mean

Hedonic Method/Quantal Choice Method

α_1	β_2	ϵ_3					
2.00	4.00	-0.25	0.99/0.94	1.00/0.97	1.00/0.95	1.00/0.95	1.00/0.99
2.00	2.00	-0.75	0.99/0.01	1.00/1.14	1.01/0.92	1.01/0.87	1.01/1.35
2.00	4.00	-0.25	1.00/1.02	1.00/1.01	1.00/0.85	1.00/1.04	1.00/1.00
2.00	4.00	-0.75	1.00/0.97	1.00/0.98	1.00/0.87	1.00/0.91	1.00/0.95
4.00	2.00	-0.25	0.99/2.43	0.99/3.13	1.00/0.99	1.01/0.96	1.00/1.06
4.00	2.00	-0.75	0.98/0.31	0.99/1.41	1.01/0.97	1.01/0.92	1.01/1.39
4.00	4.00	-0.25	0.99/0.98	1.00/0.99	1.00/0.84	1.01/0.99	1.00/0.99
4.00	4.00	-0.75	0.99/1.05	1.00/0.99	1.00/0.94	1.00/0.92	1.00/0.94

V. CONCLUSION

It is obviously premature to draw firm conclusions from the few simulations presented in this paper. The numerical results so far, however, do not provide strong support for the robustness of the quantal choice technique when used to make welfare judgments about urban policies. In part, these results may have arisen because of the particular parameters or mapping used. The number of replications is rather small, especially by the standards of large Monte Carlo techniques. In part, however, these results may merely indicate the fact well-known by macroeconomists: is "hard", statistically speaking to estimate a function and to have any confidence in its rate of change.

In any case, the results suggest extreme caution in using these analytic techniques in making serious welfare comparisons.

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