Gross Rents and Market Values: Testing the Implications of Tiebout's Hypothesis

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In this paper, we propose a new empirical test of the implications of the Tiebout hypothesis. The test we advance uses gross rent rather than market value as the dependent variable in the estimating equation; we argue that this improves upon the previous studies in several respects. We then explore the determinants of gross rent using a large sample of single-family dwellings in San Mateo County, California.

1. INTRODUCTION

More than 20 years have passed since Tiebout [25] suggested that households shop around the many jurisdictions in a metropolitan area for one that provides each household with its preferred mix of local public services. Eight years ago Oates [16] provided the first empirical "test" of a corollary of Tiebout's hypothesis—that the price of a house reflects not only its structural characteristics and those of the neighborhood surrounding it, but also the quality and cost of the public services provided by the community in which it is located. Since the publication of Oates's paper, the number of similar studies has grown dramatically.

Almost all previous studies attempt to determine the impact of public services and taxes on the market value of houses. But, as we shall see, even if households act in a manner perfectly consistent with the Tiebout hypothesis, property taxes and the quality of public services may have

1 This work was made possible by a grant to Resources for the Future from the Edna McConnell Clark Foundation. We thank A. M. Freeman and especially V. Kerry Smith for their comments on an earlier draft of this paper.

2 There now exist two review articles and a bibliography on the subject. See Ball [1], Smith [22], who concentrates on the effects of air pollution on property values, and Denne [4].
no effect on market values. Thus, tests of Oates's corollary of the Tiebout hypothesis that attempt to explain market value are flawed.

In this paper, we propose a reinterpretation and alternative test of that corollary of the Tiebout hypothesis, one based on the concept of gross rent. This test, we claim, does not fall prey to the shortcomings plaguing tests using market values. In Section 2, we review the theory that underlies property value studies, point out the respects in which existing studies are deficient, and present our view of the way such studies ought to proceed. In Section 3 we present the results from such an approach and discuss the implicit prices for housing and public service attributes that may be derived from our estimates of the determinants of gross rents. Section 4 contains a brief summary and conclusion.

2. THE THEORY AND PREVIOUS APPLICATIONS

2.1 Hedonic Prices

Studies attempting to identify and measure the determinants of residential property values are applications of the theory of differentiated products. This theory is suited to the analysis of house prices because a house may be viewed as a bundle of structural and neighborhood characteristics. Furthermore, houses in different communities provide their occupants with different public service menus. If Tiebout was correct, public services should also be included in the bundle of characteristics that describes a house.

From all the dwellings in a metropolitan area, a household selects one that maximizes its utility subject to its income and the gross rent of each dwelling. By the gross rent of a dwelling, we mean the total per-period cost that a household incurs by occupying that dwelling. Thus, gross rent includes mortgage interest payments, the opportunity cost of equity, property taxes, depreciation and maintenance expenses. It is, in effect, the "user cost" of the dwelling. When all households occupy their preferred dwelling, identical ones—those with the same structural, neighborhood, and public service characteristics—must command the same gross rent. In other words, when all households are in residential equilibrium, there is a function $P(X, Y)$ that links the structural and neighborhood characteristics of a dwelling, which we represent by the vector $X$, and the public service characteristics supplied by the community in which it is located, the vector $Y$, to its gross rent, $P$.

If a household occupies its preferred dwelling given $P(X, Y)$, the increase in gross rent required for an increment of any one attribute—another bedroom or better police protection, for example—must be at

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*See Grilliches [10] and Rosen [20].*
least as great as the marginal benefit the household will derive from that increment. Thus, for any characteristic that households enjoy, and therefore consider in their location decisions, the marginal gross rent of that characteristic (its implicit price) must be positive. In particular, if Tiebout was correct in his hypothesis that households consider public services in their location decisions, then \( \frac{\partial P}{\partial y_i} \) must be positive for those public services. Thus, we interpret the Tiebout hypothesis to imply (i) that there is a single hedonic gross rent function that spans a range of communities in a metropolitan area and (ii) that the implicit prices calculated from that function are positive for local public services that households consider in their location decisions.

We can arrive at the more common interpretation of the Tiebout hypothesis using the relationship between market value and gross rent. If we ignore maintenance expenses, this relationship may be written

\[
P = tV + dV + rV,
\]

where \( P \) is the gross rent of a dwelling, \( V \) is its market value, and \( t, d, \) and \( r \) are the effective property tax, depreciation, and interest rates, respectively. It is clear from (1) that since the gross rent of a dwelling is related to local public service quality, so too is its market value.

Our interpretation of Oates's corollary of the Tiebout hypothesis yields another implication that has received considerable attention in previous tests. Consider two dwellings physically identical and located in different communities providing identical public services. The gross rents of these two dwellings must be the same. Suppose, however, that the property tax rate is lower in one community because that community has a larger proportion of expensive houses. Note that from (1), this difference in tax rates must be offset by a difference in the market values of the two houses. Thus, an area-wide gross rent function implies that interjurisdictional differentials in property tax rates should be fully offset by differences in market values. This is sometimes expressed as the condition that interjurisdictional differences in tax rates are completely capitalized into market values.4

2.2 Previous Studies

Previous tests of the Tiebout hypothesis have set out to determine whether the market value of a dwelling is positively related to its structural, neighborhood, and public service characteristics but is also diminished by its property taxes.

The estimating equations have been of the form

\[
V_i = \alpha X_i + \beta Y_i + \gamma t_i + \epsilon_i,
\]

*If sales or income tax rates differed between communities, these differences also might be reflected in market values.
where \( V_i \) is the market value or sales price of dwelling \( i \), \( X_i \) is a vector describing its structural and neighborhood characteristics, \( Y_i \) is a vector of the public services provided by the community in which it is located, \( t_i \) is the effective property tax rate in the jurisdiction, and \( \alpha, \beta, \gamma \) are coefficients to be estimated. Environmental amenities like clean air or the absence of airport noise often have been included in \( Y \) along with a measure of accessibility to employment centers.

Tests of the Tiebout hypothesis using estimating equations like (2) are deficient in several respects. First, estimates from (2) imply that a difference in property tax rates between two communities has the same effect on the value of expensive homes in those communities as it has on inexpensive homes. But, as King [12] has pointed out, and as the previous section demonstrates, tax rate differences will have a larger impact on the value of expensive homes than on those of inexpensive homes. In fact, it is the difference in property tax payments that should be capitalized, not the difference in property tax rates.\(^5\)

Even if King's objection to the conventional specification of the property tax term is met, the relationship between market value and local public services as expressed in (2) may still fail to turn up. As Pauly [17] has demonstrated, it is possible to have households in equilibrium with respect to current gross rents and levels of public services and yet have no net capitalization of public service benefits or property tax differentials. Furthermore, Hamilton [11] and Edel and Sclar [6] have suggested that communities tend to approach that "no-capitalization" equilibrium. There the positive effect on gross rent exerted by public service quality is exactly offset by property taxes needed to finance those services. Consequently, net rents (gross rents minus property taxes), and thus house values, will not reflect differences between communities in either public services or property taxes. A regression like (2) will therefore fail to turn up the hypothesized relationship even though households are behaving in a manner completely consistent with the Tiebout hypothesis.

2.3 An Alternative Test

To surmount these difficulties, we propose an alternative test based on the concept of gross rent. A large sample of houses drawn from a number of communities in a major metropolitan area forms the basis of this test. First, we regress the gross rent of these houses on their

\(^5\) This misspecification can be partly mitigated by the use of a semi-log estimating equation, but that form also imposes relationships on other independent variables that may not be warranted. In general, it would be preferable to test the tax capitalization hypothesis without having to impose a particular functional form \textit{a priori}. 
structural, lot, and neighborhood attributes as well as the public services provided by the community in which they are located. One implication of the Tiebout hypothesis is that the coefficients of public services in that regression ought to be positive and significant. This will be true even if these communities are in a no-capitalization equilibrium. Thus, our test does not fall victim to the criticism of earlier studies offered by Pauly [17], Hamilton [11], and Edel and Sclar [6].

This estimated relationship between gross rents and the many attributes of a dwelling is our candidate for a hedonic gross rent function spanning all the communities in our sample area. We test this second implication of the Tiebout hypothesis using the procedure developed by Chow [2]. Note that ours is also a test of Oates's tax capitalization hypothesis because that hypothesis is implied by the existence of a single gross rent function spanning all communities. Furthermore, since the null hypothesis of our test implicitly assumes that differences in property tax payments, not rates, are capitalized, our test meets King's criticism of earlier studies. Thus, tests of the implications of the Tiebout model that use gross rent as the dependent variable are, we feel, superior to those using market value on the left hand side.

3. THE DETERMINANTS OF GROSS RENT

3.1 The Sample

Our unit of observation is the individual dwelling. Data on sales price and the structural, lot, and neighborhood characteristics of 1453 single-family homes sold in San Mateo County, California, between June 1, 1969 and June 1, 1970 were provided by the County Assessor. San Mateo County occupies the peninsula bordered by the city of San Francisco on the north and by Santa Clara County on the south. Almost all dwellings in our sample are located in the heavily suburbanized area between the Bayshore and Junipero Serra freeways. We assigned each to a "political unit," a term we use to connote the intersection of a municipality and an elementary school district.

Among the physical descriptors of each house are its age, size, number and types of rooms, the presence of a swimming pool, and quality of construction. The lot characteristics include size, location on a cul-de-sac, presence of an alley, and possible nearness to a nuisance. Also included is an evaluation of the way its surrounding neighborhood is planned. There was substantial variation within the sample with respect to most of the structural, neighborhood, and lot characteristics.

We matched each house in our sample with an extensive menu of public services provided by the political unit in which it is located. For example, we measured police protection by the FBI Uniform Crime total
per capita, fire protection by the rating assigned to specific residential areas by the Insurance Services Office of California, local streets and recreation departments by expenditures per capita, and accessibility to employment by distance from downtown San Francisco. We tested for the effects of environmental disamenities by including a measure of exposure to air pollution. While our intention was to include measures of still other public services (e.g., libraries), data were not available for all political units.

Finally, we employed two measures of the quality of education because it is widely recognized to be the most important local public service. We included elementary expenditures per pupil because we felt parents might value large expenditures apart from the effect they might have on learning. That is, new classrooms, books, and equipment might be valued in and of themselves. We also included a measure of average reading improvement shown by pupils in the school district to measure the effectiveness of the district in educating students.

3.2 Constructing the Dependent Variable

The assessor provided us with the sales price rather than the gross rent of each dwelling. Therefore, we used Eq. (1) to construct the gross rent using sales price and the rates of property tax, depreciation, and interest.

The effective property tax rate of the jurisdiction in which each dwelling was located gave us the appropriate value for $t$. For the opportunity cost of capital, $r$, we used 9%—the rate on conventional home mortgages during the 1-year period in which all the dwellings were sold. The depreciation rate, $d$, which turned out to be negative, was calculated from data on housing price trends reported in the Northern California Real Estate Report. These figures are based on appraisers' estimates of the value of each of 21 representative houses in San Mateo County. Each has been appraised semi-annually beginning, in some cases, in 1960. The rate at which these typical dwellings appreciated in the 2 years prior to the end of our estimation period was approximately 4%. We used this rate for $d$.

Of course, not all houses appreciate at the same rate. An urban renewal program in one area might lead property owners there to expect above-average rates of appreciation. Fortunately, our data allowed us to identify such cases because the neighborhood characteristics of each house include a judgment as to whether the trend in property values in the neighborhood is below or above average. We excluded those houses, 80 in number, with abnormal appreciation rates. In the assessor's view, therefore, all houses remaining in our sample are appreciating at the average rate for the County.
As an example of our procedure, consider a house selling for $50,000 located in a jurisdiction with an effective property tax rate of 2%. The calculated annual gross rent for this dwelling would be \((0.09 + 0.02 - 0.04)\times 50,000 = 3500\) and this is the dependent variable for that observation.

In addition to houses dropped from the sample because of abnormal appreciation rates, 49 others were dropped because their characteristics did not adequately reflect their market values. For instance, the description of each house included an evaluation of whether its lot was being put to its "highest and best use." We excluded all dwellings on lots not being put to their highest and best use since the sale price of such dwellings was likely to represent the value of the lot in some other, perhaps nonresidential, use.

Furthermore, some judgment can be made as to whether the house itself is deteriorating at an abnormal rate. If a house is aging faster than its contemporaries because of poor care, for instance, the assessor may adjust its "effective year of construction" downward to reflect its premature aging. Similarly, remodeling or extensive repairs may cause the assessor to adjust the effective year to reflect its abnormally good condition for a house of its age. In these cases, the physical characteristics of the house did not appear to adequately describe its condition. Therefore, we excluded all houses for which the effective year of construction was not the same as the actual year of construction.

### 3.3 The Regression Equation

First, we estimated a hedonic gross rent function spanning the 25 political units in our sample. We made some a priori judgments in specifying the form of this equation. We felt, for instance, that the number of rooms and the square feet of living space could not both be logically included in the regression equation. Holding square feet constant, an increase in the number of rooms should increase gross rent only to a point, beyond which an increase in the number of rooms could not be considered an improvement in quality. Certainly, however, an increase in living space holding the number of rooms constant should increase gross rent. To capture this effect and avoid the problems inherent in including both number of rooms and living area, we used both average room size (house size divided by number of rooms) and number of rooms in our equation.

We also felt that there might be some interaction between the number of rooms in a house and the implicit price of public education. Some houses are not well suited for families with children. One bedroom houses are obvious examples, but even two bedroom homes may be inhabited primarily by households without children. We would expect that such
households would be unwilling to pay more than a minimal amount for the opportunity to live in a community with good public schools. In equilibrium, therefore, the implicit price of public education must be lower for houses inhabited primarily by childless households than for other houses. We tested for this effect by including a cross term, defined as number of rooms multiplied by educational expenditures, in our regression.

Our measure of accessibility to employment opportunities is distance to San Francisco's central business district. One would expect gross rents to vary inversely with that distance. There is, however, a second major source of employment for residents of San Mateo County—the electronics and other industries in southern San Mateo County and northern Santa Clara County. In fact, the 1970 Census reveals that more workers in the southern part of San Mateo County commute to destinations outside the San Francisco SMSA (presumably, Santa Clara County) than to San Francisco. One would expect, therefore, that gross rents might begin to rise in approaching the southern end of San Mateo County. We tested for this possible U-shaped rent gradient by including both the distance from San Francisco and its square in the estimating equation.

The variable indicating the quality of construction of each house took on 14 different values in our sample. We divided this range into three classes and represented presence or absence in each class by a dummy variable.

The complete list of independent variables is presented in Table 1.

Two general functional forms have been used in estimating hedonic price indices for housing: the linear and the semi-log. The former embodies the assumption that the implicit price of an attribute is independent of the quality of other attributes. Thus, a swimming pool would add as much to the gross rent of an inexpensive house as to that of an expensive house. The semi-log form implies that the implicit price of an attribute is directly related to the quality of other attributes. Thus, the implicit price of a swimming pool would be twice as high for a house with a gross rent of $4000 as it will be for one with a gross rent of $2000.

The semi-log form is implicitly defined by expressing the log of the dependent variable as a linear function of the independent variables. In reality, there is a whole range of functional forms between the linear and the semi-log which, like the semi-log, are implicitly defined through a transformation of the dependent variable. This transformation, called the Box-Cox transformation, takes the following form:

\[ P_{\lambda} = \frac{P^\lambda - 1}{\lambda}. \]  

This transformation is discussed in Zarembka [27].
TABLE 1
List of Independent Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROOMS</td>
<td>The number of rooms in the dwelling, excluding bathrooms</td>
</tr>
<tr>
<td>BATH</td>
<td>The number of bathrooms</td>
</tr>
<tr>
<td>QUAL 1</td>
<td>Dummy variable indicating average quality of construction</td>
</tr>
<tr>
<td>QUAL 2</td>
<td>Dummy variable indicating good quality of construction</td>
</tr>
<tr>
<td>POOL</td>
<td>Dummy variable indicating presence of a swimming pool</td>
</tr>
<tr>
<td>RMSIZE</td>
<td>Average room size in square feet</td>
</tr>
<tr>
<td>AGE</td>
<td>The age of the house</td>
</tr>
<tr>
<td>LOT</td>
<td>The size of the lot in square feet</td>
</tr>
<tr>
<td>CULSC</td>
<td>Dummy variable indicating location on cul-de-sac or dead-end street</td>
</tr>
<tr>
<td>ALLEY</td>
<td>Dummy variable indicating alley behind house</td>
</tr>
<tr>
<td>NUIS</td>
<td>Dummy variable indicating presence of a nuisance near property (this may be a bus stop, parking lot, church overflow parking, etc.)</td>
</tr>
<tr>
<td>PLAN</td>
<td>Dummy variable indicating well-planned neighborhood (1 if good, 0 otherwise)</td>
</tr>
<tr>
<td>FIRE</td>
<td>Insurance Services Office of California rating of the quality of local fire protection, based on local department, adequacy of water supply, etc. (low rating indicates better protection)</td>
</tr>
<tr>
<td>CRIME</td>
<td>FBI Uniform Crime total per 100 residents</td>
</tr>
<tr>
<td>REC</td>
<td>Recreational expenditures per capita</td>
</tr>
<tr>
<td>ROAD</td>
<td>Expenditures per capita on streets and highways</td>
</tr>
<tr>
<td>DIST</td>
<td>Linear distance to downtown San Francisco</td>
</tr>
<tr>
<td>DIST 2</td>
<td>The square of DIST</td>
</tr>
<tr>
<td>AIR</td>
<td>Number of days per year with at least 0.10 ppm high hour oxidant concentration</td>
</tr>
<tr>
<td>READ</td>
<td>Improvement in reading level between first and third grades (measured in months)</td>
</tr>
<tr>
<td>EXADA</td>
<td>Expenditures on elementary education per pupil in average daily attendance</td>
</tr>
<tr>
<td>(ROOMS) \times (EXADA)</td>
<td></td>
</tr>
</tbody>
</table>

For $\lambda = 1$, this is simply a linear transformation. As $\lambda$ approaches zero, this transformation approaches the log of $P$. For values between 0 and 1, the transformed dependent variable is a non-linear function of the independent variables but this function is less extreme than the semi-log form. That is, the implicit price of an attribute increases less than in direct proportion to gross rent.

In the long run, the implicit price of many structural attributes ought to be approximately equal to the annualized replacement cost of those attributes. This argues for the linear form since the replacement cost of a swimming pool, for instance, would be the same for an inexpensive.
house as for an expensive house. Of course, this assumes that the typical swimming pool for an inexpensive house is the same as that for an expensive house. If the attributes of an expensive house tend to be larger and more elaborate (and if our data do not adequately reflect these differences), the replacement cost argument would tend to support a value of $\lambda$ less than one. It seems to us, therefore, that there are no strong arguments for selecting a particular value of $\lambda$ a priori. Consequently, we estimated $\lambda$ as one of the parameters of our regression equation.

That equation takes the form

$$P_i^{[\lambda]} = \alpha X_i + \beta Y_i + e_i,$$  \hspace{1cm} (4)

where $P_i$ is the annual gross rent of house $i$, $X_i$ is a vector of its structural, lot, and neighborhood characteristics, $Y_i$ is a vector of the public services provided by the community in which the house is located (including air quality and accessibility to employment opportunities), $e_i$ is an error term, and $\alpha$ and $\beta$ are the parameters to be estimated. These parameters are estimated by the maximum likelihood method which, in this case, consists of finding least squares estimates of $\alpha$ and $\beta$ conditional on $\lambda$ and then picking that $\lambda$ that maximizes the likelihood function.\(^7\)

We suspected that the variance of the error term might differ among the political units in our sample. While heteroscedasticity of this sort will not bias parameter estimates, Toyoda [26] has demonstrated that it may affect the significance level of the Chow test. Since this test is a vital part of our procedure, we corrected our sample for heteroscedasticity using a two-step procedure outlined in Theil [24]. We first estimated $\lambda$, $\alpha$, and $\beta$ in an unweighted regression. Residuals were then calculated for each observation, and the sum of squared residuals within each political unit divided by the number of observations in that unit was used as an estimate of the variance of the error term within that unit. This provides consistent estimates of the true variances within each jurisdiction. These estimates were then used to weight observations in each jurisdiction, and the regression equation was re-estimated.

### 3.4 Coefficients and Implicit Prices

Our results are summarized in Table 2. Note first that the maximum likelihood estimate of the Box-Cox parameter is 0.6. This indicates a functional form almost midway between the linear and semilog form. The $R^2$ indicates that 79% of the variance of the transformed dependent variable, $P_i^{[0.6]}$, is explained. All the structural characteristics are of

\(^7\) See Zarembka [27].
The implicit prices for additional rooms and increased educational expenditures reflect both their individual coefficients and the cross product terms.

When ROOMS and (ROOMS x EXADA) are considered jointly, the net coefficient of ROOMS is positive. This is also true of the net coefficient of EXADA. This explains the positive implicit prices of both variables.

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**Table 2**

Results of Weighted Regression

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Implicit price ($)</th>
<th>t-ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>67.0733</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROOMS</td>
<td>-3.3699</td>
<td>173.32e</td>
<td>1.47</td>
</tr>
<tr>
<td>BATH</td>
<td>3.8218</td>
<td>89.93</td>
<td>3.86</td>
</tr>
<tr>
<td>QUAL 1</td>
<td>7.0862</td>
<td>155.61</td>
<td>6.00</td>
</tr>
<tr>
<td>QUAL 2</td>
<td>32.1307</td>
<td>705.59</td>
<td>6.11</td>
</tr>
<tr>
<td>POOL</td>
<td>13.8539</td>
<td>304.23</td>
<td>5.39</td>
</tr>
<tr>
<td>RMSIZE</td>
<td>0.2221</td>
<td>4.88</td>
<td>17.21</td>
</tr>
<tr>
<td>AGE</td>
<td>-0.4276</td>
<td>-9.39</td>
<td>8.01</td>
</tr>
<tr>
<td>LOT</td>
<td>0.0015</td>
<td>0.03</td>
<td>11.22</td>
</tr>
<tr>
<td>CULSC</td>
<td>4.9364</td>
<td>108.40</td>
<td>2.99</td>
</tr>
<tr>
<td>ALLEY</td>
<td>-4.0885</td>
<td>-89.78</td>
<td>1.55</td>
</tr>
<tr>
<td>NUIS</td>
<td>-3.2206</td>
<td>-70.72</td>
<td>0.43</td>
</tr>
<tr>
<td>PLAN</td>
<td>-0.4220</td>
<td>-9.27</td>
<td>0.24</td>
</tr>
<tr>
<td>FIRE</td>
<td>-2.5200</td>
<td>-55.34</td>
<td>2.55</td>
</tr>
<tr>
<td>CRIME</td>
<td>-264.4180</td>
<td>-58.07</td>
<td>2.24</td>
</tr>
<tr>
<td>REC</td>
<td>-0.9638</td>
<td>-21.17</td>
<td>4.94</td>
</tr>
<tr>
<td>ROAD</td>
<td>1.5606</td>
<td>34.27</td>
<td>3.13</td>
</tr>
<tr>
<td>DIST</td>
<td>-0.5339</td>
<td>-11.72</td>
<td>0.66</td>
</tr>
<tr>
<td>DIST2</td>
<td>0.0407</td>
<td>0.89</td>
<td>1.31</td>
</tr>
<tr>
<td>AIR</td>
<td>-0.6457</td>
<td>-14.18</td>
<td>1.97</td>
</tr>
<tr>
<td>READ</td>
<td>2.3655</td>
<td>51.95</td>
<td>6.88</td>
</tr>
<tr>
<td>EXADA</td>
<td>-0.0407</td>
<td>0.93e</td>
<td>2.38</td>
</tr>
<tr>
<td>(ROOMS) x (EXADA)</td>
<td>0.0145</td>
<td></td>
<td>4.98</td>
</tr>
</tbody>
</table>

\[ \lambda = 0.6 \]

\[ R^2 = 0.79 \]
regression equation. By implicit price, we mean the addition to gross rent necessary to purchase an additional increment of an attribute. The implicit price of some attribute $i$ in our regression is given by the following expression

$$\frac{dP}{dX_i} = a_i P^{1-\lambda},$$

where $P$ is gross rent, $X_i$ is the $i$th attribute, $a_i$ is the coefficient of the $i$th attribute in our regression equation, and $\lambda$ is the Box-Cox parameter, estimated to be 0.6. Thus, according to our estimated regression, the implicit price of an attribute increases in less than direct proportion to its gross rent. The implicit prices for the attributes of the median house in our sample, one with an annual gross rent of $2260, are presented in Table 2.

The size of these prices is quite plausible. For example, a swimming pool adds $304 to the annual gross rent of the sample house; nearness to a nuisance, on the other hand, reduces annual gross rent by $70, as does the presence of an alley behind the house, by $108, although neither are significant. An extra bathroom adds $83 and an extra room $173. Increasing the average size of the rooms by one square foot increases annual gross rent by slightly less than $5.00. An increase in the quality of construction from the lowest class to the middle class increases annual gross rent by more than $150, while an increase to the highest class increases it by over $700.

It is interesting to note that the implicit price of the planning measure, while negative, is quite low. Indeed, the coefficient was not significantly different from zero in the regression equation. This conflicts with the findings of Stull [23] that zoning significantly influences property values.

Our primary concern is with the effect on annual gross rent of public services. The implicit prices of these services measure the increase in gross rents that would result from an improvement in the level of a particular service, the levels of all others remaining constant. This will be so as long as the homes in the community or school district making the change comprise a very small fraction of the total housing stock in

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9 If our regression can be interpreted as an equilibrium gross rent function, the implicit prices derived from that regression can be regarded as marginal willingness-to-pay (MWP). Furthermore, for estimating MWP's, a regression using gross rent as the dependent variable is to be preferred to similar regressions where market value is the dependent variable. This is because the former do not run afoul of the problems pointed out by Niskanen and Hanke [15]. In reality, a further adjustment to these implicit prices is required before they can be interpreted as MWP's. This is because gross rent is excluded from a household's taxable income, and thus, the real cost of a $1.00 increment in gross rent is $(1 - T)$ where $T$ is the household's marginal income tax rate.
the metropolitan area. That is, the communities or school districts must be analogous to "price takers" in the purely competitive model.10

Consider first the public safety measures, police and fire protection. A one-unit increase in crime per hundred residents decreases gross rent by $58 annually. We also find that an increase of one point in the fire rating assigned a community, which signals a lower level of fire protection in the eyes of the Insurance Services Office, reduces annual gross rent by $55.

Expenditures on streets have an implausibly high implicit price. An increase in per-capita spending of $1 increases the annual gross rent of the median dwelling by $34. Recreation, on the other hand, exerts a negative effect on annual gross rent; each dollar increase in per capita spending results in a $21 reduction in the annual gross rent of the sample house. The reasons for the high implicit price of street expenditures and the negative implicit price of recreational expenditures are difficult to determine.

Air pollution has a negative effect on the gross rents of the dwellings in our sample. For the sample house, an additional day per year on which the high-hour oxidant concentration exceeds 0.10 parts-per-million decreases annual gross rents by more than $15. It is difficult to compare this effect with estimates from other studies because of measurement differences—other studies have used average particulate concentrations to measure pollution. However, studies by Zerbe [28] and Nelson [14] report significant impacts of air pollution on property values, findings that are consistent with ours.

Public education has the significant effect on gross rent that other studies have led us to expect. The annual gross rent of our median house is increased by about $52 for each additional month of average reading improvement achieved by students in the elementary school district. Each additional dollar of per-pupil expenditures on elementary education increases the annual gross rent of the median house by more than 90 cents. Note that the coefficient of the cross-term is positive. This indicates that the gross rents of larger houses are increased by more than those of smaller houses when educational expenditures are increased. For example, a dollar of increased per-pupil elementary spending increases the gross rent of an eight-room house by more than $1.50, about 50% more than the increase received by a house with the average number of rooms.

10 If individual communities are large enough to affect the gross rent function, the coefficients will not provide accurate estimates of the effects on property values of changes in public service levels. This point has been discussed at length in the debate over the effects of air pollution on property values. See Freeman [8] and Polinsky and Shavell [18]. Coen and Powell [3] discuss a similar but broader question concerning the conclusions about capitalization that one can draw from cross-section data.
Thus, our hypothesis that marginal prices of educational spending should vary directly with house size is confirmed.

3.5 The Chow Test

A second implication of the Tiebout hypothesis is that one hedonic gross rent function spans all 25 political units. To test this, we estimated a separate gross rent regression for each political unit in our sample. The regression for any one of these units must fit the observations within that unit at least as well as the single, county-wide regression. In general, the individual regression will fit them better—that is, the sum of squared residuals for the observations within a political unit will be lower if those residuals are calculated from the regression specific to the unit than if they are calculated from the county-wide regression.

If one gross rent function spans all political units, however, the county-wide regression will fit the observations within any one unit almost as well as the regression specific to that unit. That is, the difference in the sum of squared residuals calculated from these two regressions will be small. A large difference would lead one to reject the hypothesis that there is one hedonic gross rent function spanning all jurisdictions.

The Chow test can be used to indicate the significance of this difference.\(^{11}\) Actually, the null hypothesis of the Chow test implies more than the existence of a single gross rent function spanning all jurisdictions. Suppose, for instance, that such a function exists but that it has some non-linearities that are not adequately reflected in our specification of the regression equation. The regression equation must be considered a first-order approximation to the true gross rent function. In estimating the county-wide regression or a particular individual regression, we are essentially picking the best approximation given the set of observations for that regression.

Now if the set of observations is different in two different regressions, the best approximation can also be different. This is particularly true if the two different sets of observations are taken from different regions of attribute space. For example, the best approximation to the true gross rent function for a community of predominantly small houses will differ from that for a community of predominantly large houses. But, this is precisely the comparison we make in the Chow test—we are testing whether the first-order approximation appropriate for one sample is the same as that for another. Quite obviously, we may reject the hypothesis that the approximating functions are the same even though one gross rent function spans all jurisdictions.

Even if the regression is an approximation, however, we should not

\[^{11}\text{See Chow [2] and Fisher [7].}\]
expect large differences in these estimating equations as long as there exists a single gross rent function for the metropolitan area. Hence, our use of the Chow test to test the Tiebout hypothesis. The results of the test must be interpreted somewhat cautiously, however, since rejection of the null hypothesis does not necessarily imply rejection of the Tiebout hypothesis.

The conventional form of the Chow test must be altered to account for two peculiarities of our data. One is that certain independent variables in the overall regression do not vary within every political unit. By definition, all public service variables fall into this category; in addition, some dummy variables are constant within certain political units. Therefore, they cannot be included in the regression equation for those individual units because they would be exactly collinear with the constant term. Consequently, we included only those variables that did vary within a unit in calculating the degrees of freedom for the regression within that unit.

Also, the number of observations did not exceed the number of independent variables in eight of our political units so that individual regressions could not be estimated for these units. Following Chow, we assigned a value of zero to both the sum of squared residuals and the degrees of freedom for regressions within units that have an inadequate number of observations.

The sum of squared residuals divided by the degrees of freedom was 20% higher when the overall regression was used to calculate the residuals than when the individual regressions were used. While fairly modest, this difference was enough to force us to reject the null hypothesis—the $F$ statistic is 3.03 while the critical value of $F$ at the 1% significance level is 1.38.

We considered the possibility that racial segmentation of the housing market could account for rejection of the null hypothesis, but were forced to disregard this explanation a priori. Only 2 of the 102 census tracts that constitute our sample area are more than 20% black. We have remarked on the presence of employment centers at both ends of the county, though, the importance of which is verified by the U-shaped rent gradient we obtained. We therefore divided our sample into northern and southern subsamples to test for possible geographic stratification. The $F$ ratios led us to reject this possibility.

The Chow test on the overall sample does not lend statistical support to the hypothesis that a single gross rent function spans the San Mateo County housing market. However, we were unable to find any evidence of segmentation in that market. Also, the non-linearities that may exist in the true gross rent function force us to be cautious in interpreting the Chow test. As a consequence, we cannot conclusively rule out the exist-
ence of an area-wide gross rent function. A plausible explanation of our results is that such a function exists but that our regression is only an approximation to it.

4. CONCLUSION

This paper has recast the standard empirical test of a corollary of the Tiebout hypothesis using gross rent rather than market value as the dependent variable. Our motivation for so doing is our observation that this standard test using market values may fail to turn up the hypothesized relationship even when households are behaving in a manner perfectly consistent with that hypothesis. A test of the implications of the Tiebout hypothesis using gross rents does not fall prey to the same objection.

We have used this alternative test on a sample of houses from San Mateo County, California. As the Tiebout hypothesis would lead us to suspect, gross rents were found to be positively related to the quality of local public services, including elementary education, street expenditures, police and fire protection, and ambient air quality. On the other hand, we were forced to reject another implication of the Tiebout hypothesis, namely, that one gross rent function spans the entire county.

REFERENCES