THE VALUE OF TRAVEL SAVINGS,
AS REFLECTED IN HOUSING PRICES:

A Study of Alameda County Homes

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INTRODUCTION:

Urban geographers, land economists, and transportation planners have long asserted that a household's location decision depends, to a large degree, on access to opportunity sites. Subject to budget, time, and other constraints, it is a common assumption that households maximize their "utility" by locating in as desirable a home as possible — as near to necessary and desired activities (such as work, shopping, and recreation) as possible.[1] The utility maximization is profoundly complex, dependent on far more environmental attributes than those that can be observed and quantified; for example, people often care about subtle neighborhood qualities (Krumm 1980), public services (Tiebout 1964, Sonstelie & Portney 1980), proximity to relatives, and other "goods" a location and its environment offer. Rather than attempt to elucidate all determinants of location choice and home valuation, this paper limits its focus to the variation of travel costs across an urban area and how these are reflected in housing prices.

If access is a critical determinant of land prices by allowing people to reduce travel expenses, then one may reasonably expect that reductions in travel expenses will be reflected in higher bids for homes. For example, John Holtzclaw (1994) has argued that reduced automobile use (as evidenced through odometer tabulations) for more population-dense environments should translate to more income available for home purchases (and loan guarantees). Holtzclaw estimates that an "efficient location" like Nob Hill (in San Francisco) allows a household to save $6,000 a year in transportation expenses relative to a similar household in a city such as San Ramon. The American Automobile Association (1993) estimates that the daily *fixed* cost of -- owning the average automobile is roughly ten dollars, representing over $3,500 a year — or a present value of over $40,000 on a 30-year eight-percent loan (assuming one did not then need to spend the money on some other mode of transportation). However, in a study of so-called "wasteful" commuting, Giuliano and Small (1992) conclude that factors other than location vis-a-vis opportunity sites affect household location choice to a much greater extent. And Wheaton (1977) argues that the evidence for location choice with respect to transportation amenities is not a major factor in location decisions. The results of the research pursued here aim to test some of these conclusions.

It is well accepted that people value time and generally prefer to minimize delays in accessing opportunities, *ceteris paribus*.[2] A great number of studies have been undertaken to estimate travellers' value of time (for examples, see: Waters 1992, Small 1992, and/or Kraft & Kraft 1974); these rely almost exclusively on discrete-choice random-utility models where the ratio of coefficients estimated on time and fare variables is expected to provide a value of time. Applying this methodology, a varied assortment of value-of-time estimates have emerged, with values ranging from six percent (Morrison & Winston 1985) to 86% of wage (Thomas & Thompson 1979, as referenced in Waters 1992) for inter-city car travellers and from 20% (Bruzelius 1979) to 180% (Train 1980) for auto commute trips. The variation in these estimates is one indication that the relationship is a highly complex one, not yet well modeled. However, the dependence of time valuation on income is widely accepted, given that one's opportunity cost in many cases may be based on income-producing pursuits.

This research's methodology takes a very different tack in approaching travel-time valuation, relying instead on home prices as a function of travel costs, with time representing an important dimension of travel expenses. The general hypothesis tested here — that home prices fall with travel costs — is premised on the underlying theories of location-choice models developed by economists such as Alonso (1964) and Anas (1982): *i.e.*, that there is a trade-off between housing cost and travel expenses. The data used and their analysis, along with results and conclusions, follow here.

DATA ANALYZED AND METHODS USED:

The Data:

Three distinct datasets have been merged here in order to look at the trade-off between housing costs and travel expenses; they are: TRW home-sales data for 1132 Alameda houses in the second quarter of 1990; 1990 Census data; and 1990 Bay Area Travel Survey (BATS) data. The home-sales data provide detailed information on house and lot characteristics (*e.g.*, the number of bathrooms, age of structure, and lot size), but do not given information regarding the purchasing household. The Census data provide information on a variety of variables used at some point in the analysis, but only variables regarding a neighborhood's ethnic composition were used as regressors in the final models (after being orthogonalized with respect to income per capita in order to avoid a *de facto* income term as a regressor) [3]. The BATS data provide very detailed trip-making information for a random sample of households; these were used to estimate average travel times, average automobile ownership, and average vehicle miles traveled (VMT) per person (over five years of age) in each census tract. To avoid variance over these variables in tracts with minimal sampling, only those which had at least five persons (over the age of five) in trip-making households were used; this limitation reduced the sample size to 882 homes. (Note: BATS surveyed the trip-making of persons only five years old or older. Thus, all averages and estimates discussed here are with respect to this household size.)

In order to estimate travel times, auto ownership, and VMT per purchasing household, household size was estimated from the number of bedrooms and tract income per capita (since crowding is associated with poorer families). The formula for this regression was based initially on a census dataset of persons per owner-occupied dwelling unit [4], average number of bedrooms per owner-occupied dwelling unit, and average income per capita (which contributed substantially to the regression's coefficient of determination) across Alameda County's 289 populated census tracts. Then, this estimate was transformed to expected number of household members over five years of age by using a regression based on the BATS dataset. (These equations are shown in the Appendix.) Finally, these estimates of household size were multiplied by average car ownership, VMT, and travel time rates (which were estimated per person from the BATS dataset) to arrive at estimates of household car ownership, weekday VMT, and weekday travel time, which are used as explanatory variables in the regression models.

Additionally, a MINUTP network algorithm was used to estimate inter-traffic analysis zone (TAZ) travel times and these times were coupled with census-based job data by TAZ to derive measures of accessibility to jobs; these TAZ accessibility measures were then linked, almost one-to-one, to census tracts.[5] Initially, it was expected that inclusion of this accessibility variable could substantially diminish the contributions of travel costs in the regression (due to an expectation of positive collinearity), but its inclusion did add substantially to the coefficient of determination while avoiding a possible correlation between the travel-cost regressors and the error term.[6]

Since the data set lacks information on the households purchasing the specific homes, one must estimate travel time, auto ownership, and vehicle operation savings for a given location and housing type (as discussed above) — irrespective of income. Additionally, since income enters housing price through a constraint on affordability — and not intrinsic home worth — any sort of income term as a regressor is suspect. For this reason, only the residuals of the ethnicity variables were used (after regressing them on income per capita) and income was not included (in contrast to what Landis *et al.* [1995] and many other researchers tend to do) as a descriptor of neighborhood quality.[7] Additional reasons for initial model selection can be found in the attached paper titled "Housing Price as a Function of Accessibility: A Hedonic Model for Alameda County Homes."

The Hedonic Model:

Despite the land market's complexities and model limitations, many researchers have attempted to estimate residential land values, often with respect to transportation provision (*e.g.*, Anas 1979, Boyce & Allen 1973, Mohring 1961, Voith 1991). One of the functionally simplest methods of evaluating transportation's impact on land valuation may be the hedonic price model, in which sales price is modelled as a function of a good's multiple attributes. (See Griliches [1971] for a discussion of this method.) This is the method used here, but one should note that the coefficient estimates on individual attributes cannot be directly interpreted as the marginal values of these attributes except under highly restrictive assumptions (*e.g.*, all households are identical in preferences and in income). Under substantially less restrictive assumptions, McMillan *et al.* (1980) demonstrate that, for households which do not vary too greatly in their tastes, the biases implied using these coefficients as estimates of marginal value may be very minor. In any case, our interest here lies more in the general magnitude, rather than the exact value, of transport costs as they are incorporated into housing prices.

RESULTS OF ANALYSIS:

Several stages of analysis were necessary for full model development. Early models relied on ordinary least squares (OLS) for estimation and tested a variety of explanatory variables; many of these are discussed in the attached paper, and the results of the models tested here can be found in the Appendix. Since the observations are independent, there is no concern of cross-observation correlation of error terms; however, many housing attributes can be reasonably expected to give rise to heteroskedasticity, or a non-scalar covariance matrix for the error terms. For example, depending on how well a home is maintained and/or how flat its parcel is, housing price can be expected to fluctuate more across older homes and those on larger lots. For these reasons, heteroskedasticity was hypothesized. The null hypothesis of the ensuing tests for homoskedasticity was soundly rejected, so the method of feasible generalized least squares (FGLS) was used to obtain asymptotically efficient estimates and correct the error estimates of the OLS regression. The detailed results of these stages of statistical analysis are more fully described below.

Early Models:

Starting with information garnered from the data analysis discussed in the attached paper ("Housing Price as a Function of Accessibility") and with the paper's resulting "preferred model" form, the earliest models explored in *this* research added estimated income (per capita for each census tract) through an interaction term with car and time regressors (because it is believed, *a priori*, that higher income persons purchase more expensive vehicles and value travel time more). However, these early models resulted in such strongly positive coefficient estimates for the car-times-income and time-times-income variables (which are supposed to represent *negative* qualities) that it was assumed that the large differences in income levels were overwhelming the time and car differences, allowing for a *de facto* introduction of the budget constraint (and income effect) into the regression, a constraint which has little if anything to do with the intrinsic valuation of the home. For these reasons, income in any form was left out of the set of regressors and no estimates could be made for value of time or cost of car ownership *with respect to* income. This is not thought to be a major weakness of the methodology given that an "average" value of time is what policy-makers often require, rather than the value of time by type of specific traveler [8]; and people are free to own whatever quality of car they desire — regardless of where they purchase a home, so home type does not imply car value (although they are correlated).

Somewhat surprisingly, the variables of distance to a highway interchange and to a BART station (via the road network), airline distance to a highway structure, and an index of job accessibility were generally highly statistically significant in these regressions, while clearly contributing to the coefficient of determination. *A priori*, it was expected that travel times, VMT, and auto ownership would be strongly correlated with accessibility and the three distance variables and that these "new" variables would do a far better job of explaining travel considerations in home valuation than would variables such as freeway and BART access. However, one could argue that there is still value to our index of accessibility, regardless of the travelling that one actually does. In other words, just the *option* to visit many opportunity sites relatively quickly is of benefit — even if one does not expect to need them. Plots of auto ownership, VMT, and travel time per person versus accessibility (as shown in Figures 1, 2, and 3) indicate relatively little relationship between these variables (correlations between these are -0.19, -0.16, and -0.04, respectively). BART access is another case of an "option" or opportunity that may add value, regardless of actual system use. For these reasons and thanks to their general levels of statistical significance, the accessibility and distance variables were left in final model estimations.

Investigation of Heteroskedasticity and Estimation Using Feasible Generalized Least Squares:

The presence of heteroskedasticity can be ascertained from OLS output, assuming that the model's residuals are consistent estimates of the underlying error terms. By regressing the square of these residuals on a set of variables expected to affect error-term variance (such as home age and lot size), one can test for the significance of such a regression (or the presence of *homo*skedasticity). The regression of the squared residuals on the primary (hedonic) model's set of variables ("X") produced an R^2 of 0.177 and a p-value for insignificance (or homoskedasticity) of 0.0000, allowing us to reject the null hypothesis of homoskedasticity.[9] This regression's results were compared with those for two other forms of heteroskedasticity: an exponential (where $\sigma_i^2=\exp(z_i\beta)$), and a squared form (where $\sigma_i^2=(z_i\beta)^2$) — both of which ensure positivity of variance estimates. The squared form performed substantially better than the other two (registering an R^2 of 0.244), so this was the form assumed for the FGLS solution.

TABLE 1.

Primary Model [y=Xβ]:	**OLS Coefficient (SE) & p-value**			**FGLS Coefficient (SE) & p-value**		
Dependent Variable: Home Price (1990$)	R^2= **0.733**			R^2=**0.646**		
Independent Variables:						
Constant	-3.726e+5	(6.621e+4)	.0000	+3.953e+4	(3.347e+4)	.2379
#Bedrooms	-1.352e+3	(4.213e+3)	.7539	-8.993e+2	(2.317e+3)	.6980
#Bathrooms	+1.059e+4	(4.386e+3)	.0158	+1.718e+4	(2.755e+3)	.0000
#Half Bathrooms	+1.500e+4	(8.036e+3)	.0626	+2.782e+4	(5.445e+3)	.0000
Log(Age+2)	-2.210e+4	(4.168e+3)	.0000	-7.411e+3	(1.834e+3)	.0001
Square Feet of Floorspace	+1.166e+2	(7.202)	.0000	+9.090e+1	(4.216)	.0000
Asian % Residuals	-1.025e+5	(2.576e+4)	.0001	-8.598e+4	(2.120e+4)	.0001
Black % Residuals	-8.656e+4	(1.510e+4)	.0000	-5.529e+4	(1.584e+4)	.0005
Hispanic % Residuals	-5.744e+4	(2.760e+4)	.0374	-8.861e+4	(1.900e+4)	.0000
Dist.Highway Interchange (m)	+9.796	(2.114)	.0000	-2.952e-1	(1.480)	.8420
Dist. BART Station (m)	+9.983e-1	(3.942e-1)	.0113	-1.059	(3.120e-1)	.0007
Dist.Highway Structure (m)	+1.392e+1	(3.143)	.0001	+3.284e+1	(1.616)	.0000
Log(Lot Size [sf])	+3.798e+4	(6.751e+3)	.0000	-1.459e+3	(3.047e+3)	.6322
Estimated Travel Time (min)	-4.684	(2.868e+1)	.8703	+8.856e+1	(2.380e+1)	.0002
Estimated # Cars + Trucks	-6.979e+3	(3.141e+3)	.0263	-4.228e+3	(2.693e+3)	.1168
Estimated VMT	-1.223e+2	(1.634e+2)	.4542	-1.716e+2	(1.376e+2)	.2127
Accessibility (to all jobs, 30 min.)	+1.205	(1.402e-1)	.0000	+3.217e-1	(1.090e-1)	.0033
Variance Model [abs(σ_i)=z_iβ]:						
Constant	+7.896			-8.542e+4	(2.819e+4)	.0025
# Half Bathrooms	n/a			+1.017e+4	(3.334e+3)	.0024
Log (Age+2)	n/a			+3.744e+3	(1.751e+3)	.0327
Square Feet of Floorspace	n/a			+1.838e+1	(2.709)	.0000
Asian % Residuals	n/a			-2.768e+4	(1.588e+4)	.0816
Black % Residuals	n/a			+2.238e+4	(7.572e+3)	.0032
Dist.Highway Interchange (m)	n/a			+5..388	(9.667e-1)	.0000
Log(Lot Size [sf])	n/a			+4.289e+3	(3.132e+3)	.1712
Estimated # Cars + Trucks	n/a			-3.803e+3	(1.653e+3)	.0217
Accessibility (to all jobs, 30 min.)	n/a			+3.323e-1	(4.774e-2)	.0000

Fortunately, feasible generalized least squares is as asymptotically efficient in estimation as is the method of maximum likelihood — assuming that one has initially consistent estimates of residuals and that the information matrix (*i.e.*, the negative of the expected value of the matrix of second derivatives of the log-likelihood function for the data) is block-diagonal (in other words, that there exists no relation between the primary model's coefficients and those in the model of variance [Oberhofer & Kmenta, 1974]). Moreover, FGLS does not require any assumptions as to the error terms' distribution (*e.g.*, normal versus something else). This method uses the inverse of the fitted values (or estimates) of the variance model to weight the least-squares regression of the primary model. The results of this method are shown in Table 1.

Since heteroskedasticity appears to be present, the standard error results of the earlier OLS regression must be revised; OLS error estimates are biased down under the presence of heteroskedasticity. White's robust estimate of the coefficient estimates' covariance matrix (1980) can be computed independent of the underlying form of heteroskedasticity and relies on a summation of variance estimates (*i.e.*, the squared OLS residuals) times the outer product of observation vectors.[10] These results of this estimation are shown in Table 1 for OLS estimates.

One of the most striking results of the models is the fact that travel time, while estimated as having a negative — but statistically *in*significant — coefficient under OLS, finds itself with a highly significant *positive* coefficient under FGLS. This is in contrast to *a priori* expectations, but this result may be deciphered in several ways. First of all, travel time may be in fact enjoyable — especially where one can switch to a slower but (sometimes) preferred mode of transport, such as walking. In fact, the correlation across Bay Area tracts between almost any index of accessibility and travel time per person is essentially non-existent (although negative). For example, a correlation coefficient between the exponential form of jobs accessibility throughout the region and travel time per household member is -0.036. A plot of the accessibility measure used in these regressions versus travel time per person is shown in Figure 2; it indicates essentially no relationship. Only a plot versus a measure of highly local accessibility (all jobs within 10 minutes by walking) offers any semblance of a downward trend (Figure 3).

Another reason for this unexpected coefficient may arise from the fact that travel time is strongly and positively correlated with VMT (+0.713) and car ownership (+0.464), so the coefficients on these three variables are very dependent on model setup. For example, if one weights the FGLS regressions by the inverse of the squared OLS residuals (rather than their fitted values from the variance model), the coefficient on time is negative and highly statistically significant (along with those on automobiles and VMT). And if one uses *all* primary-model regressors in the variance model, the resultant FGLS estimate for time falls roughly 40% along with that for autos, while that for VMT rises by 66%. Finally, one should recall that there are trips foregone and more trips likely to be linked in less accessible environments, which entail disutility but which are not evidenced in higher VMT or travel times, so these variables are probably not measuring the disutility of inaccessibility as well as was initially hoped. Moreover, these models lack variables of transit-trip cost expectations (and the number of walk trips expected). Yet, overall, the lack of statistical and economic significance of travel time in many of the models examined suggests that nearness to opportunities, rather than minimum travel time, may be what households seek. Figures 2 and 3 also send this message, since travel times appear to change minimally with "accessibility" (at least the way accessibility is measured here). This finding would tend to support Zahavi's (1974) and others' claims of fixed travel-time budgets, at least in cross section. Moreover, this indication is in contrast to some very fundamental expectations of urban-land market modelers, such as Alonso (1964), since it suggests that travel time and housing costs may not be traded off; yet other areas of travel costs (such as VMT and auto ownership) may still be very relevant and traded off with housing costs.

Also of note is the fact that the coefficient for the log of lot size appears as statistically insignificant in the FGLS model, although not in the OLS model. This variable contributes substantially to variance, so large parcels are weighted less in the FGLS model and thus can exert less of a "pull" on the regression line. And since the logarithm of lot size is being used, lot size's variation is being diminished even more. But if all primary-model variables had been used in the model of variance, this coefficient estimate would have appeared to be statistically significant (and positive). Thus, one should probably not rule out the usefulness of this variable.

While auto ownership and VMT are not very statistically significant in the FGLS model, they appeared to be so in most other models explored — and their coefficients indicate that they should be somewhat economically significant. Figure 4 is a graphic interpretation of the FGLS results for these two variables. Computations indicate that in a home with all the "median home" attributes, the savings associated with being "able" to own just one car instead of three and travel 100 vehicle-miles less each day are about ten percent of median home value, or $20,000. To balance this figure (and keep home value constant) requires a 50% increase in median accessibility levels. But, as discussed previously and as evidenced by Figure 1, accessibility and VMT and auto ownership needs are not highly interchangeable.

Computation of Per-Minute, Per-Mile, and Per-Car Values:
Of great interest is the value that a household places on *each* minute of travel time, each mile of travel, and each car it expects to save by locating in a more accessible neighborhood. This requires that one translate an entire home-life's worth of one location's savings in these attributes (as evidenced in the model coefficient estimates) to a daily value per unit. To do this, one must estimate the personal discount rate that households attach to time, as well as money, savings. Since most investors can expect to earn, on average, about ten percent in *real* interest on stocks, one could argue that this is a likely discount rate for non-inflated monetary savings experienced by a household. Thus, the daily fixed costs associated with owning another car (over the life of the location) may be approximated as $4,228 (the coefficient estimate) times the annual payment factor (to convert a present value to annual payments) divided by 365 (days in a year). Over an infinite life, the ten percent implies in a $0.10 annual payment on every dollar of present value, so the daily-cost estimate is just $1.16 — far less than what one would expect, given that the depreciated daily value of a $20,000 car on a six year life at ten percent is $12.60. A couple things could be happening here: first of all, people may not fully appreciate auto costs; secondly, people may have a far higher discount rate and/or shorter discount period (given the uncertainties of their lives and the desire for short-term fulfillment); thirdly, auto ownership, as estimated using the dataset, may be far more a function of wealth than of location needs so that this variable's coefficient is imperfectly estimated (at least for our interpretation).

To discount the $4,228 car coefficient to a daily value of $10 (or a yearly value of $3,650) requires a discount rate over almost any multi-year period of over 86%! This is extremely high and implies that actual *future* car-ownership expenses are not considered hardly at all in purchasing a home. Applying *this* discount rate to the VMT coefficient yields a single-mile value of over 40 cents per mile, far in excess of actually operating costs of ~9¢/mile (AAA 1993). To discount the $171.60 coefficient to 9¢/mile over 10 years would imply a discount rate of 14 percent (or 19% discounted over 30 years), which seems much more reasonable. Applying this discount rate over a 10 year period to the *positive* value associated with travel times yields a value of time of negative $2.78/hour of present travel time. If this were a positive value of time, it would conform rather well with expectations given that most studies place adult travelers' value of time near 40% of after-tax wage (*e.g.*, Small 1992, Waters 1992) and given that many children and retired or unemployed persons (with relatively low values of travel time) are adding substantially to the household travel time in our sample's data. However, the fact that this value is positive calls the entire model into question, although some of the contrast to expectations may be explained by lack of robust estimates under different model assumptions, the reduction of trips made in inaccessible areas, and the positive values possibly associated with some slow modes like walking.

Model Limitations:
Given the FGLS model's rather unexpected results, as discussed in the above section, one may want to scrutinize the model and acknowledge its limitations as well as weaknesses. Many of these are discussed here. They are:

- Travel benefits need to be incorporated into the price of land by better linking travel variables with lot size. This is a difficult task, because, given dwelling unit size and the durability of housing, additional land essentially will not affect a buyer's travel expenses; so buyers tend to appreciate land as just added space [11], although land price is substantially determined by accessibility.
- A "true" equilibrium in the housing market is essentially impossible to achieve for the following reasons: housing is a highly durable good, the costs of acquiring information on homes for sale and the costs of moving are substantial, and local entities impose zoning and other constraints on home construction. For this reason there may be excess demand and/or supply for different housing attributes (including location) which will then impact the hedonic "prices" (*i.e.*, coefficient estimates).
- The BATS trip data are limited to *weekday* travel, when work travel is relatively dominant; thus, only proxies of estimated travel savings have been constructed here. Moreover, sampling rates vary across tracts, so the variance of estimates such as average travel time per household member is itself variable by location (even though some variation has been avoided by confining the data used to tracts where at least five persons over five years of age live in surveyed households).
- Non-automobile trip costs should be accounted for. In other words the number of estimated transit trips and walk (or cycling) trips should be incorporated as regressors since these add to travel costs (via transit fares, physical exertion, and bike ownership, for example).
- The travel characteristics (or lack thereof) of BATS households that made no trips should be included in the dataset so that the averages are not biased toward households that travel a great deal.
- Much travel takes place completely away from the home location: for example, round- trips based at one's job site and/or travel for one's job (such as a salesperson may be expected to do). Thus, home location is not the only determinant of travel costs incurred by a household.
- Foregone trips are not recorded. So mileage, car ownership, and travel time do not rise as quickly as one may expect, since households are likely to minimize costly travel. There is a value to these foregone trips, which comes out of housing price but is unrecorded in travel changes. Additionally, households will link trips into several-stage itineraries, probably incurring some disutility, in order to minimize travel costs — particularly if their home locations are relatively inaccessible (*e.g.*, see Ewing *et al.* [1994]). Such disutility is expected be reflected in lower housing costs, but not in added observable travel costs.
- Household tastes vary in unobservable ways which can dampen expected changes in home valuation. For example, those whose value of travel time is less (because, for example, they enjoy driving) will tend to locate in more distant areas and may bid up home prices more so than would be expected, even after controlling for income. In contrast, people who feel they need to be near plenty of activity or who dislike driving will tend to compete for more central locations.
- Average car ownership per tract (which was used to estimate the number of cars "needed" in purchased homes) depends to a significant degree on wealth ($=+0.313 across all BATS households), even after controlling for location, so that this variable's coefficient is probably

not exactly what the model is intended to estimate. As a result of this, the variable of auto ownership may be effectively introducing an income term, which, being positively correlated with home price, may be expected to reduce the coefficient on auto ownership from the actual value associated with needing additional vehicles in a given location. [12]

Moreover, travel time and VMT estimates may be poor in tracts where the sampled BATS households are in some way unusual, relative to the general population. This may occur through sorting (*e.g.*, where people who love to drive place themselves in very isolated tracts) or by interest and occupation (such as communities for the elderly or full of college students). It would be best to control for such factors in the analysis.

CONCLUSION:

The implications of this research are many, although the limitations of the model (as discussed above) are several. First, heteroskedasticity appears to play an important role in our linear model of home valuation and should not be neglected, particularly since generalized least squares results can diverge substantially from those of OLS (as evidenced here).

More importantly, once heteroskedasticity is incorporated into the model, travel costs are found to play a role in home valuation, and their monetary influence appears (in some basic ways) to be reasonable. However, the variables of estimated travel time, car ownership, and VMT do not negate the role and impact of other travel-related measures such as "accessibility" and distance to a BART station. It appears that the presence of opportunities, utilized or not, is an important consideration in household location — particularly when the disutility of foregone, linked, and minimized trips is unobservable. For example, only a 50% change in the interior square footage of a home's median size exerts more of an effect on household price (+26.4%) than does a similar change in accessibility (+8.9%); in contrast, the same relative changes in VMT and auto ownership are estimated to change home price by just -1.1% and -0.90%.

The relatively low coefficients on auto ownership and VMT and the unexpectedly positive coefficient on travel time may be illuminating several concepts. For example, households may have poor information on the travel needs of different locations or may appreciate only very short-run travel costs. It may also be that households have sorted themselves to a large degree across the region by value of time (with those of low time value opting to live happily, while still perhaps paying a premium, on the outskirts of the urban area) so that a single cross-sectional comparison is not appropriate, especially without more data on the purchasing households. Moreover, the data may be indicating that travel-time budgets are relatively constant across households, regardless of location, and that disutility of inaccessible areas is internalized in ways less observable than VMT or travel time. The possibilities for model interpretation are many and their implications complex. Yet the simple model examined here does appear to offer many insights and some hope for future models of this kind.

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APPENDIX:

ESTIMATION OF HOUSEHOLD SIZE:

Census regression (Alameda County tracts only):

(#Persons/Owner Occupied DU = 1.78 + 0.344 x Mean # Bedrooms/OODU R^2=0.164)Not Used.

#Pers/OODU = 1.482 + 0.6934 x Bedrooms/OODU - 3.866x10^{-5}xIncome/Capita R^2=0.478

BATS Regression (all surveyed households):

#Members>5yrs. = 0.2733 + 0.8192x #Persons/$OODU_{Estimate}$

R^2=0.845

Resulting Estimate:

#Member>5 Years = 0.2733 + 0.8192x(1.48+0.693x#Bedrooms-3.87$10^{-5}$xIncome/Capita)

ENDNOTES:

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[1] For a more thorough discussion of model developments, please see Anas (1982), Alonso (1964), and Muth (1969), Quigley (1976), Lerman (1978), and/or Gillen & Westin (no date) as examples.

[2] As the saying goes, "Time is money." And people with less discretionary time often find themselves contracting out services that used to be provided within the household: for example, child-care, meal preparation, laundry, home cleaning, and gardening. In this sense money is exchanged for time.

[3] Per-capita income is strongly correlated with ethnicity, producing a simple correlation coefficient of +0.604 with percentage of tract population that is white and a coefficient of -0.541 with percentage of blacks.

[4] Note the variables of concern are with respect to owner-occupied dwelling units only since the TRW home-sales dataset is based on non-rental properties.

[5] Travel times were estimated by Alexander Scabardonis using MINUTP on an unloaded road network, which is not very for congested-period trip-making and non-auto trips, but which is considered a sufficient proxy for our purposes here. Accessibility was computed using over 20 gravity-based formulae, all with the following basic form:

$$Accessibility_i = \sum_j \frac{A_j}{f(t_{ij})},$$

$$where\ A_j = \ Attractiveness\ of\ \ Zone\ \ j\ and\ t_{ij} = Travel\ Time\ \ from\ Zone\ i\ to\ \ \ j.$$

Some of the indices relied on a strictly inversive relation (*f(t)*=t), some on a simple power function suggested by Sosslau *et al.* (1978) (*f(t)*=$t^{2.2}$), and some on a variety of exponential forms suggested by Levinson & Kumar (1995) for different trip and mode types. Some used all jobs types as the measure of attractiveness; others were based solely on sales and service jobs. Some accounted for jobs located anywhere across the 9-county region, others considered only limited travel-time radii. The accessibility measure used in these analyses was selected from among all of these measures because it delivered the highest model coefficient of determination (in hedonic models that did not include travel characteristics and which were studied in the attached paper, "Housing Price as a Function of Accessibility"). This chosen measure was based on work-trip characteristics to all job types within a travel radius of 30 minutes; its form was developed by Levinson & Kumar (1995) for the Washington, D.C. metro area and is the following: *f(t)*= -1- .075*time. (A more complete discussion of the measure of accessibility can be found in the attached paper.)

[6] A lack of orthogonality between the error term (which houses unobservables, such as neighborhood crime, color of house, quality of neighbor's homes, *etc.*) and any regressor will result in inconsistent and unbiased estimates of that regressor's coefficient (and those coefficients of any correlated regressors). This hurdle is avoided by keeping accessibility *in* the regression. However, correlation among regressors adds to variance of estimates, thereby reducing the (apparent) efficiency of estimates. (Moreover, if VMT, car ownership, and travel time are outcomes of accessibility in at least a slightly linear fashion, the inclusion of accessibility here would be expected to diminish the estimated coefficients on these travel variables leading to difficulties in model interpretation.) Plots of VMT, auto ownership, and time (Figures 1, 2, and 3) versus accessibility across the Bay Area do not indicate any substantial relationship across these variables.

[7] Note: If income per capita had been used as a regressor, it would have been the second best “explainer” of housing price (\$=+0.45), second only to square feet of floor space (\$=+0.63). Its inclusion would entail such a strong correlation with unobserved variables (such as neighborhood quality) and included regressors (such as home size and square feet) that it was expected to present more of a difficulty than its exclusion (primarily because it is felt that few people pay more just to live near wealthy persons, so income’s coefficient would have been too large given its intrinsic contribution to home value).

[8] Under the current set-up, the resulting value of time may be construed as an average weighted across the population over five years of age, which, while unspecific, is still useful. One might try to argue that persons under 18 years of age and/or non-workers have a negligible value of time, yet parents often are highly concerned regarding their children's trip making and non-workers undertake many trips that one would have to pay someone to do otherwise. For example, parents may want their children to travel very short distances to school so that they will face minimal exposure to strangers and so that they (the parents) will not have to chauffeur their children around.

[9] Note that this is essentially the Breusch-Pagan Lagrange Multiplier Test (1979), where the explained sum of squares of normalized squared residuals as regressed on a set of explanatory variables is divided by two and compared with a chi-squared distribution with p-1 degress of freedom (where "p" is the number of explanatory variables).

[10] With heteroskedasticity, VC(βhat) no longer reduces to $\sigma^2(X'X)^{-1}$. Instead, one must estimate $(X'X)^{-1}(X'\Omega X)(X'X)^{-1}$, where Ω is the covariance matrix of the model's error terms. White (1980) uses SUM($e^2 x_i x_i'$) as an estimate of $X'\Omega X$ in this equation.

[11] If housing stock were easily removed and replaced, unconstrained by lot dimensions and local regulations, unit size would adapt to take better advantage of underlying land values. In this way land would be sold more in line with its underlying worth, although buyers are still not expected to appreciate an additional square foot of parcel size the way that the overall market values it.

[12] One could try orthogonalizing auto ownership with respect to income, keeping only the residuals to use in place of the auto-ownership variable. Note, however, that once one controls for accessibility levels (since wealthier households [as measured in income per household member over five years of age] tend to live in somewhat more suburban areas), auto ownership is not so strongly influenced by income; the elasticity on car ownership with respect to income (per member) is just 0.17 (evaluated at the median per-member income level of \$18,750).