Nonlinear Estimation of Household Size:
The Minnesota Housing Unit Method

TECHNICAL MEMORANDUM 79-1

Minnesota State Planning Agency
Office of State Demographer
101 Capitol Square Building
St. Paul, Minnesota 55101
November, 1979
Phone: 612/296-2557

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I. Introduction:

The demand for local, sub-county population estimates has steadily increased since 1970. Population is a factor in many federal programs, and several states distribute monies as a function of population. As a result, many agencies are now in the business of preparing subcounty population estimates.

The most widely used set of post-censal estimates is prepared by the U.S. Bureau of the Census for the Office of Revenue Sharing. The use of the revenue sharing numbers is not always desirable or feasible. First, there is a problem of timeliness. The delay between the date of the estimates and their availability can be as long as 20 months. Second, the estimates themselves are not uniformly accurate, with the possibility of substantial errors for smaller places with fewer than 2,500 persons. While these errors may not be critical to revenue sharing allocations whose formula gives less weight to population than other components, they may result in significant allocation differences when used in formulas more sensitive to population. Because of these problems several states, such as California, Florida, Oregon, Washington, and Wisconsin now distribute state revenues to local governments using subcounty estimates prepared by state officials.

In 1977 the Minnesota Legislature included current population estimates in the formula for distributing state aids to local governments. All 2,647 minor civil divisions in Minnesota were given the opportunity to provide a current estimate. The State Demographer was asked to prepare the estimates. How were these estimates to be prepared? A component method was not an option. Vital statistics are not available for places with less than 2,500 persons. The only symptomatic data available for minor civil divisions are income tax records and housing unit information. The limited development time ruled out the use of income tax records, which require time-consuming computerized methodology development and testing.[1] This left a housing unit method as the most promising methodology.

Even if time had not been a consideration, there was good reason to choose this method. A statewide survey of over 2,800 households which provided information on current household size and occupancy characteristics had just been completed. Given this survey, development of a suitable housing unit method was reduced to the problem of adapting the findings from a statewide survey to estimation of parameters (e.g., household size, occupancy rates) for individual municipalities.

This paper discusses the procedure by which we developed a ratio method to adapt survey findings for estimating local household size and occupancy factors. First, we discuss the "state-of-the-art" of the housing unit method, demonstrating the improvements in the accuracy that have resulted from use of unit type-specific methodologies. Second, we present the results of statistical analyses used to determine the most appropriate "base" areas and levels of detail for the Minnesota method. Tests demonstrating maxima and minima for household sizes for certain types of units are included. Using 1970-75 census data from California and Washington, our analysis shows that the recent rate of change in household size has been nonlinear. Third, we describe the methodology developed as a result of these tests, together with a discussion of how we actually implemented the methodology. This includes a comparison of estimate results with differing assumptions about unit-type or size of place detail.

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[1] Development work with the income tax files is now underway.

Finally, we discuss the implications of our experience for others working with the housing unit methodology.

II. The Housing Unit Method

The housing unit method is basically a censal-ratio method. An estimate of current population is obtained by multiplying a census-based ratio of population to housing units by a current estimate of housing units (Shryock and Siegel, 1975: 755). Corrections are made to allow for vacant housing units and persons not living in households. The following equation gives the basic form of the method:

$$P_{i,t} = \frac{HP_{i,o}}{HH_{i,o}} \times HH_{i,t} + GQP_{i,t} \qquad (1)$$

where: P = Population of place
HP = Household population
HH = Occupied housing units
GQP = Group quarters population

and: i = place
t = current year
o = census year

with: $$HH_{i,t} = HU_{i,t} \times OCC_{i,t} \qquad (2)$$

where: HU = Total housing units
OCC = Occupancy rate (may be current or censal rate)

A. Obtaining an Accurate Housing Unit Count:

Evaluations of the accuracy of the housing unit method uniformly underscore the importance of an accurate count of housing units. In their now well-known article concerning the accuracy of the housing unit methodology, Starsinic and

Zitter (1968) found that their population estimates for 47 places with more than 50,000 persons tend to be upwardly biased, largely due to inaccurate estimates of the number of occupied housing units. Household estimates based on building permits and demolitions reflect an almost 4.9 percent error, while those based on utility records are only slightly better, averaging a 3.7 percent error. These errors in the number of households correlate with population estimate errors, therefore, Starsinic and Zitter (p.484) conclude that "the error in the estimate of the number of households is at least as important, if not more important, than the error in the population estimate that is introduced by the assumption about average size of households."

Errors in the housing unit count can result from inaccuracies in the benchmark census data or from poor reporting of post-1970 housing stock changes (Lowe, Pittenger, and Walker, 1976). In Minnesota, for example, many 1970 seasonal units were reported as "vacant-for-occasional" use; unless these units are removed from the 1970 count of year-round stock, the unit count and vacancy rates would be severely distorted. The housing unit method requires careful checking to verify the accuracy of the reported census unit counts, as well as accurate accounting of post-censal changes in the housing stock. Rives (1976) points out that in areas where a computerized housing inventory file is maintained, accurate housing counts can be obtained at a lower cost.

Errors in the number of households also derive from inaccurate assumptions about current vacancy ratios. The Starsinic-Zitter tests used two measures of current households: 1960 stock plus new housing units times 1960 occupancy rates; or 1960 occupied units plus the post-1960 change in utility meters. The latter serves as an estimator for currently <u>occupied</u> housing units, and use of this factor reduced the average error by 1.2 percent for places without major annexations. However, utility meter data can only provide current vacancy information for places where city boundaries match those used for recording residential utility customers (Tessmer, 1976). Elsewhere, sample surveys or more abbreviated "windshield" surveys can be used to estimate changes in occupancy rates. If apartment vacancies are counted seaprately, rigorous windshield surveys can yield reasonable estimates (Lowe, Pittenger, and Walker, 1976).

B. Using Survey Data to Estimate Household Size

If we assume accuracy of the group quarters component of the housing unit estimate, the remaining estimation errors reflect inappropriate assumptions about household size. The difficulty in estimating household size lies in the fact that recent declines result from two separate forces. First, declining fertility rates are reflected in smaller families, which in turn lowers average household size, particularly the size of single-family households. Second, changing marital patterns and a larger elderly population have led to more persons living alone. In the 1970's this has increased the demand for smaller housing units, and in many places mobile homes and multiple-unit structures of all types now comprise a much larger share of the housing stock. Because multiples and mobile homes have smaller average household sizes than single family units, this change in the housing mix produces additional drops in the average household size. In Florida, for example, demographers estimate that average household size has declined by an average of 5 to 6 percent from mix changes alone, and in some localities

Table 1:

Levels of Accuracy
for Different Housing Unit Methods

Place and Date/ Methodology and Sample	Mean Absolute Error	Percent with Errors less than 5%	Number of Cases
<u>Florida, post 1972</u>.			
Average PPH			
All cities	11.08%	50%	26
All cities over 1,000 population	3.01%	71%	14
<u>California, circa 1975</u>.			
Cities over 25,000 population			
Average PPH	5.14%	66%	219
Type-Specific PPH	2.50%	76%	102
<u>Washington, post 1970</u>.			
Type-Specific PPH			
All cities	4.21%	68.6%	70
Cities of under 1,000 population	6.35%	56.5%	23
Cities with 1,000-2,500 population	3.68%	72.2%	18
Cities with more than 2,500 persons	2.85%	75.9%	29

Sources: "Comparison of BEBR Estimates and Special Census Results," Bureau of Economic and Business Research, University of Florida, June, 1979.

Prepared from tabulations provided by the Population Research Unit, Department of Finance, State of California.

"Population Trends, 1976," Washington State Information Report, Population Studies Division, Office of Program Planning and Fiscal Management, August, 1976, p. 50.

the decline due to mix change has been as high as 20 percent (Bureau of Economic and Business Research, 1978).

One solution to this dilemma is to estimate the household population by type of unit, a practice now employed by California, Washington, Oregon, and Florida. If occupancy rates also vary by type of structure, a "type-specific" methodology has the added advantage of improving the estimates of occupancy rates. Table 1 shows the levels of accuracy achieved by using type-specific methodologies.

Even if the household size estimates are calculated separately by unit type, the analyst still must supply an estimate of the current household size for each type of structure. Generally these estimates are prepared using one of several ratio estimation techniques.

The censal household/population ratio can be used with an assumption of no change. Or, the current ratio can be estimated by extrapolating from the historical intercensal pattern of change in the ratio, as demonstrated by Starsinic and Zitter (1968). Neither the censal nor the extrapolated estimates, however, would reflect known post-1970 changes in housing mix, fertility rates, and proportions of single-person households.

Sample surveys can also be used to estimate current household size and occupancy rates. Oregon's Center for Population Research and Census recently applied sample survey results to estimation of household size and occupancy rates for Portland, Oregon. The Portland survey cost a fraction of the cost of a census and yielded household size estimates with only a 2.3 percent coefficient of variation (Weiss, 1978). Yet, even the cost of surveys is high. In Washington the savings from conducting a survey instead of a census are not realized until a city has a population of 25,000 (Office of Fiscal Management, 1977:52).

Innovations in survey and household size estimating procedures may result in cost-savings. If household size at the time of the survey is highly correlated with the censal size figure (i.e., there has been no dramatic change in the types of households in the sample area), then using census data with the sample estimate of household size in a difference estimator results in lower variance, thereby allowing a smaller sample size (Palit, 1978). Palit also suggests use of a "new construction" sample if the occupancy or household size figures differ significantly for new as compared to old housing units. Rives (1976) suggests the use of a household size question as an add-on to surveys undertaken for other purposes. Also, a short survey which utilizes an existing sampling frame will be less costly because the cost of drawing the sample will be substantially reduced. Despite these suggestions, surveys providing reliable household size and occupancy data are still likely to be realistic options only for larger cities.

For smaller places an alternative to sample surveys is to borrow estimates from the census data of analogous communities, a procedure which has been adopted in the State of Washington (Lowe, Pittenger, and Walker, 1976). Estimating places are matched with censusing places that had similar household sizes and housing unit mixes in 1970, then the post-censal rate of change observed in the censusing places is applied to the estimating places' ratios.

A final method for generating post-censal household size and occupancy ratios is the ratio method. The ratio method has often been used for stepping down national or regional population projections to local levels (Pittenger, 1976), but it is also a method well-suited to calculation of post-censal local household size or occupancy rates from known rates for "base" (or "parent") areas.

The use of a ratio technique is valid only if one can assume that the relative differences in household size or occupancy between the local and base areas have not changed in the post-censal period. If this assumption can be made, the local area's household size and occupancy ratios may be estimated as the same relative difference from the base area's.[2] Clearly, the key to the ratio method is identification of base areas that actually typify the sub-areas for which they serve as estimators (Archer, 1977:243).

III. Development of a Housing Unit Methodology for Minnesota:

Given the availability of a statewide survey that provided 1977 household size and occupancy data for areas within Minnesota, a ratio method was selected for developing household size and occupancy rates for each minor civil division. The survey provided household information for two samples within the state, the Twin Cities metropolitan area and the "balance of the state."[3] Each sample could be subdivided by size of place, providing several categories of "base" areas from which to choose. Therefore, the first task was to analyze 1970 census and 1977 survey data to determine which groupings constituted relatively homogeneous areas with respect to household sizes, mixes, and 1970-77 changes.

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[2] For example, if in 1970 the average single-family household size in Place A was 82 percent that of Region X's, in 1978 we would estimate Place A's single-family household size as 82 percent of the 1978 value for Region X. Other versions of the ratio method assume that the rate of change for average household size has been the same in the local and base areas. (U.S. Bureau of Census, 1978). Mathematically the ratio method produces the same results as applying the percent change method.

[3] The Twin Cities metropolitan area includes the seven-county area of Anoka, Carver, Dakota, Hennepin, Ramsey, Scott and Washington Counties. It contains approximately half of the state's population. The balance of the state includes all eighty of Minnesota's remaining counties.

Because these categories could be influenced by the housing unit level of detail (i.e., use of average versus structure type-specific figures), decisions about appropriate base areas and structure type were made simultaneously.

A. Hypotheses to Determine Appropriate Level of Detail:

The evidence from the Washington and California experiences indicates that the accuracy of an estimate is substantially improved if a more detailed methodology is used. But using a more detailed methodology has its cost: more complicated data requirements and calculations are required. Before adopting a type-specific methodology for Minnesota, we wanted to be certain that the additional complexity would pay off with greater accuracy.

To determine whether a more detailed methodology was warranted, the following null hypotheses were tested:

1. There is no significant difference between average household sizes by type of structure.
2. There is no significant difference between average occupancy rates by type of structure.
3. The type-specific household sizes do not differ significantly by size of place.
4. The type-specific occupancy rates do not differ significantly by size of place.
5. The rate of change in household size does not vary by type of structure.
6. The rate of change in household size is linear for single-family housing units.

If these hypotheses were rejected, an appropriate level of detail would be determined by the types of differences observed. The rationale behind these hypotheses is as follows:

Hypothesis 1: The number of units in a structure governs the average number of persons living in each household. Single-family structures tend to be larger than duplexes, duplexes tend to be larger than apartments in high rises, and so on. Households with more persons seek out the larger housing units; thus, the average household size increases with the size of the housing unit.

Units per structure also indicate variations in lot size and neighborhood density. Persons seeking large lots and low density areas tend to prefer single-family structures or mobile homes, rather than apartment buildings with limited private open space. Families with children seem to prefer single-family homes or mobile homes. Young couples or small families might be found in low-rise apartments, duplexes and mobile homes, and singles, both young and old, would tend to reside in apartment buildings with many units.

Hypothesis 2: Fluctuations in the pace of construction and availability of financing relative to demand for unit types may cause fluctuations in the vacancy ratios in lower cost units, such as apartments in multi-storied buildings.

If there are significant differences in the average household sizes or occupancy ratios associated with each category of unit type, using averages which disregard these differences can result in substantial errors when estimating population for places that have experienced changes in the mix of dwelling unit types found in their communities.

Hypothesis 3: Community size may also influence the average characteristics of households or housing units. In Minnesota in 1970, places with fewer than 2,500 persons averaged 2.9 persons per household, while the average was 2.6 in larger places. Part of the difference was due to a larger proportion of single-family units in small towns and rural areas. But it also reflects the lower average household size for multiple unit structures and mobile homes in cities (U.S. Census Bureau, 1970), perhaps because there are more one-person households in the cities (Kobrin, 1976). Variations in birth rates and the propensity of larger families to live in smaller suburban or rural communities which often offer "more house" for the money could also result in slightly larger households in single-family homes in small cities or towns.

Hypothesis 4: If after controlling for unit type there are significant differences in the average occupancy rates or household sizes, household or occupancy rates for individual communities will be more accurate when based on ratios calculated separately for each distinctive community size group. (See Rosenberg, 1968, and Erickson, 1973, for discussions of improvements in accuracy resulting from stratification by size of place).

Hypothesis 5: The change in household size is likely to vary with the source of those changes. Kobrin (1976) has shown that recent declines in household size can be attributed to both declines in birth rates and increases in the number of single-person households. To the extent that changes in single family household size are linked to the trend toward smaller nuclear families, the decline in single family household size might be gradual, matching the nationwide average decline. But for multiple units, if the change in household size reflects a dramatic rise (or fall) in the number of one person households, the rate of change could be much more rapid. Thus, we expect the rate of household size change to vary with type of structure.

Hypothesis 6: Most of these differences in household size or occupancy have been documented and incorporated into housing unit methods elsewhere. We depart from prior analyses, however, with our questions about the nonlinearity in the changes of the household size.

First, we intuitively expect minimum average household sizes in certain types of structure. Florida analysts, for example, do not permit the average persons per household figure for any community to drop below 1.5, and California uses a 1.0 cutoff (Bureau of Economic and Business Research, 1978, and Rasmussen, 1975). Cost and/or maintenance requirements might dictate a minimum average size of around 2.0 for single-family households while for apartments we might expect a maximum due to size constraints.

Second, at sizes close to the maxima and minima the rate of change is likely to be nonlinear. As the average approaches a minimum level, it seems likely that the rate of decline will slow asymptotically. Further, unless an area has undergone rapid turnover, places that had a high average single-family household size in 1970 will have many "empty nesters" by 1979, which will result in the place having experienced more rapid rates of decline in single-family household size than elsewhere. If nonlinearity is present, household size estimates will need to use a nonlinear form of estimation, particularly one which uses information about expected maxima and minima.

Third, although we expect maxima or minima for each unit type, we do not expect a curvilinear rate of decline for all unit types. The theory of curvilinearity in household size decline derives from family lifecycle theory; therefore, we expect curvilinearity for "family" housing. At least until recently apartments and mobile homes have not been occupied continuously by one family throughout its entire lifecycle; rather, they were used by persons in specific lifecycle stages. This means that family lifecycle related size changes would not be expected to strongly determine the household size changes for apartments and mobile homes. With the recent upsurge in "family" mobile home subdivisions, we may need to examine curvilinearity in the rate of change for mobile homes, but presently we will restrict our analysis to single family units.

B. Testing the Hypotheses:

1. Household size and occupancy rates: Analysis of Minnesota data

For all but the last two hypotheses, tests were made using data from the 1977 Minnesota Household Survey. Because this set of population estimates would only be prepared for places outside the Twin Cities metropolitan area, we used the data for the "balance of the state" sample. The types of units included in the analysis were one-unit structures; two to six unit structures; seven or more unit structures; and mobile homes. The size of place categories included places with less than 2,500 persons; with 2,500 to 10,000 persons; with 10,000 to 50,000 persons; and with 50,000 or more persons as of 1977. The results of the tests for the first four hypotheses are as follows:

1. Household size by type of structure:	All significantly different at .01 percent significance level, t-test.
2. Occupancy rates by type of structure:	Differences significant at the 10 percent significance level for one-unit, 2+ units, and mobile home categories, Chi-square test.[4]

3. Household size by type of structure and size of place:

a. Single family units: For the "balance of the state", single family household size for places under 2,500 is significantly greater than for places over 2,500. (t-test 10% significance level). For all places over 2,500 in the entire state, single family household size in the 10-49,999 size class significantly exceeds the average for single family units in either larger or smaller classes. (t-tests, 10% significance level).

b. Duplex-to-sixplex category: No significant differences by size of place.

c. Apartments: For the entire state there are no significant differences in apartment average household size for places under 2,500 versus those over 2,500. For all places over 2,500 in the entire state, apartment household size in the 10-49,999 size class significantly exceeds the average for apartments in either larger or smaller cities. (t-test, 0.1% significance level). (The sample of apartment household size in the "balance of state" is too small to permit tests of difference between city size categories.)

d. Mobile homes: Cell size too small to test for differences by size of place.

4. Occupancy rates by type of structure and size of place:

a. Single-family category: Occupancy rates for single family units are significantly higher in places with 2,500 or more persons (10% significance level, Chi-square test).

b. Multiple units: No significant differences by size of place.

c. Mobile homes: Cell size too small.

From these results we conclude that the most appropriate level of detail for the Minnesota housing unit method is as follows:

1. Persons per household ratios for each structure type, including two multiple unit categories.

2. Occupancy rates for each structure type, with one rate for all multiple unit structures.

3. Different persons per household and occupancy base ratios in the single-family category for places over and under 2,500 persons, but except as noted below, no other size of place distinctions.

4. Modifications to single-family and apartment unit household sizes for places between 10-49,999, relative to the 50,000+ and 2,500-9,999 size categories.

Table 2 shows the factors that we used in the ratio-trend calculation of type and place-specific preliminary 1977 occupancy and household size ratios.

2. <u>Tests for nonlinearity in the rate of change in household size: Analysis of California and Washington data</u>

Analysis of the rates of change in household size requires many paired observations for 1970 and some subsequent year, which is not possible with data from the 1977 Minnesota survey. Both California and Washington have strong census programs, and upon request, both sets of state officials supplied us with census data on household size by structure type for 1970 and 1975-1977. These are shown in Table 3.

First, we tested for a significant difference in the rate of household size change by type of structure (Hypothesis 5). The rate of change was estimated separately for each structure type using an OLS regression of the logarithmically transformed California 1970 and 1975 household size data. The resulting beta-coefficients were all significantly different from each other at a .01 level or better (t-test).

The remainder of the tests concerned the last hypothesis, i.e. the possible nonlinear nature of rate changes. First, we examined the household size data to determine the existence of maxima or minima. If there are upper and lower limits to average household size for apartments (5+ units) and mobile homes, the average persons per household for these units will not be normally distributed, in that the tails will be cut off. Tests with the California data showed that both distributions were highly peaked, as well as positively skewed, suggesting the existence of minima, but not maxima. For the apartment category, out of 92 PPH values, only two were less than 1.20 and in the mobile homes category, out of 75 cases, only one value was less than 1.20. These findings indicate that for both apartments and mobile homes lower limits of 1.20 are reasonable.

Size and cost constraints of single-family homes also suggest the possibility of lower size limits for that category. We do not expect average size in the single-family category to drop much below 2.0. Out of 94 values for mean 1975 single-family household size in California cities, the lowest

Table 2

Mean Household Size and Occupancy by Type of Structure by Size of Place, Minnesota 1977

	Single Family	2-6 Units/Struc.	7+ Units/Struc.	Mobile Home	Average
Places under 2,500					
Household Size	3.065	2.148	1.435	2.530	3.031
Occupancy	92.9%	89.5%	89.5%	93.7%	92.2
Places over 2,500					
Household Size	2.931	2.148	1.435	2.530	2.704
Occupancy	97.3%	89.5%	89.5%	93.7%	97.2

Source: Minnesota Household Survey, State Planning Agency
Balance of State Sample (i.e., Twin Cities region is excluded).

Table 3

Mean Persons Per Household by Structure Type and Size of Place, California (1975) and Washington (1977)

<table>
<tr><th></th><th>Single Family</th><th>2-4 Units/Structure</th><th>5+ Units/Structure</th><th>Mobile Home</th></tr>
<tr><td>California</td><td></td><td></td><td></td><td></td></tr>
<tr><td>n=15 places ≤ 2,500*</td><td>3.41</td><td>3.01</td><td>2.08</td><td>2.20</td></tr>
<tr><td>n=72 places ≥ 2,500</td><td>3.13</td><td>2.35</td><td>1.93</td><td>1.92</td></tr>
<tr><td>Washington</td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>n=17 places ≤ 2,500</td><td>2.809</td><td colspan="2">2.061</td><td>2.431</td></tr>
<tr><td>n=14 places ≥ 2,500</td><td>3.082</td><td colspan="2">1.858</td><td>1.936</td></tr>
</table>

Sources:

Census Report Population Research Unit, Department of Finance, Sacramento, July 1975 and July 1976.

Population Trends, State of Washington, 1977, Population Studies Division, Office of Fiscal Management, Olympia, August 1977

Unpublished data in personal communication from Donald E. Pittenger, July 14, 1978.

*Includes data for 1976.

value was 2.27; therefore, it is reasonable, if not generous, to use a 2.0 minimum average size for single-family households.

Next, we considered the hypothesis of nonlinearity in the actual rates of change for single family units near the extreme values. We used the nonlinearity test recommended by Kmenta (1971). A set of dummy variables was used to test whether the slope and intercept for the regression of 1970 PPH on 1975 PPH were constant for all values of the independent variable. The 1970 California data were partitioned into groups (less than 3.01, 3.01 to 3.50, 3.51 and over) and dummy variables were assigned to the low and high groups. If the function were linear, the regression coefficients for the dummy variables would not be significantly different from zero. This was not the case. While the coefficient for the low group was essentially zero, the coefficient for the high group (1970 single family PPH of 3.51 or more) was significantly different from zero at the 5 percent significance level (See Table 4). In sum, these tests show that the relation between 1970 and 1975 single family household size is nonlinear, with the nonlinearity most evident for the places which had a relatively high (3.50 or more) mean single family household size in 1970.

We also tested the nonlinearity hypotheses with data from the state of Washington, which has a settlement pattern more similar to Minnesota's than the California case. We repeated the tests for curvilinearity in the rate of change for single-family household size using the Washington data for 31 cities. Curvilinearity was demonstrated by the regression equation using dummy variables for "high" (over 3.40 in 1970-1971) and "low" (under 2.85 in 1970-1971) categories. As shown in Table 4, the coefficient for the "high" category is

Table 4:

Regression Coefficients for the Nonlinearity Tests

1. Linear regression of 1970 single family household size on 1975 single family household size, for 81 California cities.

$$\text{SF PPH 75} = \underset{(.366)}{-0.981^{***}} + \underset{(.112)}{1.257}\ \text{SF PPH } 70^{***} - \underset{(.068)}{0.148}\ \text{HI}^{**} + \underset{(.071)}{0.067}\ \text{LOW} + e$$

$R^2 = .860$ $F = 158.1$

2. Linear regression of 1970 single family household size on 1977 single family household size, for 31 Washington cities.

$$\text{SF PPH 77} = \underset{(.958)}{3.015^{***}} - \underset{(.330)}{.0485}\ \text{PPH 70} + \underset{(.105)}{.167}\ \text{LOW} - \underset{(.082)}{.168}\ \text{HI}^{**} + e$$

$R^2 = .502$ $F = 9.064$

*** Significantly different from zero at 1% level
** Significantly different from zero at 5% level

different from zero at the 5 percent level of significance, and while the coefficient on the "low" category variable is not significantly different from zero, it is much larger than the almost zero coefficient found for the "low" California dummy variable.

These results indirectly support our hypothesis that the rate of change for Minnesota single-family household sizes can be expected to be nonlinear at the upper and, as the Washington example suggests, probably at the lower end of the size range. We expect more rapid declines in average single-family household size for places that had a 1970 average of 3.50 or more and a slower rate of decline for places with a small average single family household size in 1970.

3. Factors Altering the Rate of Decline in Household Size

Although the general form of the household decline function appears to be nonlinear, we cannot overlook the fact that there may be shifts up or down the curve, so that the actual rate of decline is not that which we might have predicted using the nonlinear model alone. This section first examines the factors underlying the general nonlinear form, and then considers the types of community or household changes that result in a slower or faster rate of decline than anticipated.

The hypothesis of nonlinearity in household size change derives from family lifecycle theory. If a family were to remain intact and in the same home throughout its lifecycle, the size of the household would increase after marriage and birth of children. When the children leave home upon reaching maturity, the household size would contract back down to its former size. This is the period of accelerated decline we observe for the "empty nesting" households which previously numbered four or more persons. But after the "empty nesting," which can occur fairly rapidly, household size may not change for many years. Large numbers of stable, one or two person elderly households contribute to a "bottoming out" or very slow rate of decline in household size.

The community-wide average household size for a given unit type will vary with the lifecycle stages of its residents and the extent to which shifts in household size are accompanied by movements to housing of a different structure type. If there are relatively few apartments or mobile homes suitable for one or two person households, smaller households are more likely to reside in the single family homes, despite apparent "excess capacity." Thus, where the housing unit mix is predominantly single family homes, as it is in virtually all small Minnesota cities and towns, the pattern of household size change in single family homes is <u>more</u> likely to follow the lifecycle stages and evidence nonlinearity. If we remove the assumption that families stay in one house or one unit type throughout their lifecycle, then the community's average single family household size will be influenced by changes in the composition of households with respect to lifecycle stage and its related size.

Lifecycle related household size changes can be demonstrated in the Minnesota case. In Minnesota between 1970 and 1977 average family size declined by 7.6%. Most of the 1970-77 difference in family size results from more two person households and substantially fewer households with six or more persons. This pattern of change in family size follows the shift toward more childless couples in the lifecycle stages before or after childrearing. As the children of the baby boom mature and enter the childbearing and childrearing stages, we expect fewer couples in the pre-childbearing stages but many more empty nesters.

This pattern of empty-nesting and subsequent bottoming-out is built into the single family persons per household calculations with the nonlinearity assumptions.

Suppose, however, that the pattern of household change does not follow the statewide norms described above. In this case, assuming rapid declines of household size resulting from empty nesting may not be realistic.

In what cases can we expect exceptions to the nonlinearity pattern? Where migrant households moving into a community differ markedly in household composition from persons already residing in the community, the community's average household composition will shift towards the migrants' type. For example, if families with three or four children move into a community which previously averaged no or one child per household, the community's average household size will not exhibit the expected rapid declines due to empty nesting. Alternatively, if one particular type of household (e.g. retired couples or individuals) moves out of the community, their departure will also affect the size distribution of households, hence the average household size.

In general, the following changes in the rate of size decline for single family households are expected for each migration pattern:

1. In-migrant families with children: Slows the rate of single family household decline; may increase average mobile home household size.

2. In-migrant retired couples: Accelerates the single family household decline or moves the community into the "bottoming out" stage of decline.

3. Out-migrant families with children: If not replaced by other families with children, will result in empty nesting or accelerated declines in household size.

4. Out-migrant retired couples or individuals: If replaced by families, results in deceleration in the decline of single family household size. If replaced by one or two person households, continued decline.

To a certain extent, changes in the mobile home household size will also reflect these migration related changes, because mobile homes are also a "family" housing option.

How are these community-specific, migration-related patterns to be assessed? Each community cannot undertake a survey of single family households. Instead, indirect measures of change in a community's age structure and mix of households by lifecycle stage will have to be used.

Aside from the housing unit information submitted by the jurisdiction, we have access to virtually no place-specific information about current household size or age composition of the communities. Data pertaining to migration patterns or changes in age composition are available only for school districts or counties.

In the absence of data that exactly fit our needs for place specific measures of lifecycle changes and housing turnover, we settled on the following substitutes.

(1) Student in-migration: Rates of student in-migration higher than the state average were assumed to indicate an influx of school children (or at least no net exodus), and places located in in-migration school districts were assumed to have a slower rate of household size decline than would otherwise be expected.

(2) County in-migration rates: Counties which experienced 1970-77 net in-migration substantially higher than the statewide county mean 1970-77 migration rate were assumed to have families moving in, thereby slowing the rate of household size decline.

(3) Proximity to a large city: If a town is located within 20 miles of a large city, (i.e. within commute distance to a large labor market), and if that town has experienced sizeable housing unit gains since 1970, we assumed that the place is a bedroom community. For such places the single family household size decline rate was slowed to reflect the likely presence of families moving into or staying in the community.

(4) Change in proportion over 65: In counties where the proportion of persons over age 65 has declined relative to the state average, we assumed that either older persons were moving out or young persons were moving in. In either instance, the rate of decline in size for single family households was assumed to be slower than would otherwise be expected.

Conversely, if the proportion of elderly in the county had increased relative to the state average, either older persons were moving in or not moving out, and/or young persons were moving out. In this case, we assumed that the household size decline would be faster than expected, with many households in the "empty nesting" phase.

(5) Proportion of mobile homes: If housing demand grows rapidly and exceeds the supply of affordable homes, the unhoused households are likely to turn to mobile homes to satisfy their housing needs. Thus, a substantially higher than average proportion of mobile homes indicates rapid expansion of housing demand. In this case, the mobile home average household size was increased to equal the single family household size.

Conversely, towns (not larger cities) that by 1979 have relatively few mobile homes probably have not experienced substantial family in-migration. Even if other parts of the school district evidence growth, we assumed that the in-migration had not taken place in this community, and, therefore, no adjustment to the household size was made to reflect in-migration.

(6) Little housing unit change: For places located in areas for which there are no strong in-migration symptoms, little growth or loss in the occupied housing stock is assumed to indicate either rapid declines in household size, or where household size was already low in 1970, slower declines as household size "bottoms out."

The percent decline rates for the various alternative estimates are shown in Table 5.

C. The Minnesota Method

The net result of the hypothesis testing and analysis was the decision to use the following housing unit methodology for the 1979 estimates:

$$P_{i,t} = (HU_{i,j,t} \times OCC_{i,j,t} \times PPH_{i,j,t}) + GQP_{i,t} \qquad (3)$$

where: P, HU, OCC, and NHP are as above, and
PPH = Persons per Household

with subscripts: i = the minor civil division
j = type of structure
t = year of estimate

Table 5: 1970-79 Estimated Percent Change in Single Family Household Size By City Size and Place Type

No student in-migration	1970 Pop. < 2500	1970 Pop. > 2500
1970 SF PPH 3.0 or less in 1970	- 6.1%	- 8.7%
1970 SF PPH 3.0 to 3.8 in 1970	-10.1	-17.4
1970 SF PPH 3.8 or more in 1970	-13.9	-20.2
Student In-Migration		
3.0-5.99%	- 7.7	-11.3
6.0% or more	- 5.0	- 7.4
Old county or little housing growth		
Bottoming out (1970 PPH less than 2.7 or housing unit loss since 1970)	- 3.0	- 4.3
Empty-nesting	-13.9	-20.2
Few mobile homes in small place		
Student In-migration 3% or more	-10.1	----
Young county, in-migration, or proximity		
Mobile homes less than 17% of all households and student migration less than 3%.	- 5.6	-12.9
Mobile homes over 17% of all housing and student migration greater than 8%.	- 0.3	- 2.8

The 1979 occupancy rates are to be estimated with:

$$OCC_{i,j,t} = \frac{OCC_{i,j,o}}{OCC_{k,j,o}} \times OCC_{k,j,t-2} \times \frac{\widehat{OCC}_{i,t}}{\left(\frac{OCC_{i,o}}{OCC_{k,o}} \times OCC_{k,t-2}\right)} \quad (4)$$

where: $\widehat{OCC}$ = Estimated overall occupancy from survey or meter data in estimate year t
k = Size of place category (over or under 2,500)
o = Base year (1970)
t-2 = Estimate year less two, i.e., 1977, the year of the survey

The 1979 persons per household is estimated as follows:

$$PPH_{i,j,t} = \left(\frac{PPH_{i,o}}{PPH_{k,o}} \times PPH_{j,k,t-2}\right)^{\left(1 + 2r_{j,k}\right)} \quad (5)$$

where: PPH = Persons per household
r = Average annual rate of change 1970-1977 in household size for unit type j in size class k
k = Size class

For the single family household size category, the estimate is subject to these constraints:

a. For 1970 SF PPH $\leq$ 3.0 ("bottoming out" households),

$$PPH_{i,1,1979} = PPH_{i,1,1970}^{(1 + 4.5r)} \quad (6)$$

b. For 1970 SF PPH $\geq$ 3.8 ("empty nesting" households),

$$PPH_{i,1,1979} = PPH_{i,1,1970}^{(1 + 11.3r)} \quad (7)$$

c. For places with student in-migration $> 6\%$,

$$PPH_{i,1,1979} = PPH_{i,1,1970}^{(1 + 3r)} \quad (8)$$

d. For places with $3\% \leq$ student in-migration $< 6\%$,

$$PPH_{i,1,1979} = PPH_{i,1,1970}^{(1 + 6r)} \quad (9)$$

e. For places in old counties or with little housing growth

(1) If 1970 SF PPH $\leq$ 2.70,

$$PPH_{i,1,1979} = PPH_{i,1,1970}(1 + 2.25r) \qquad (10)$$

(2) If 1970 SF PPH > 2.70,

$$PPH_{i,1,1979} = PPH_{i,1,1970}(1 + 11.3r)$$

f. For places in an in-migration or young county

(1) If student in-migration < 3% or > 8%,

$$PPH_{i,1,1979} = 1.05\ (PPH_{i,1,1979}) \qquad (11)$$

(2) If 1979 mobile homes > 11.2% of all housing units,

$$PPH_{i,1,1979} = 1.05\ (PPH_{i,1,1979})$$

g. For small places where mobile homes are less than 5.6% of 1979 housing and student migration greater than 3%,

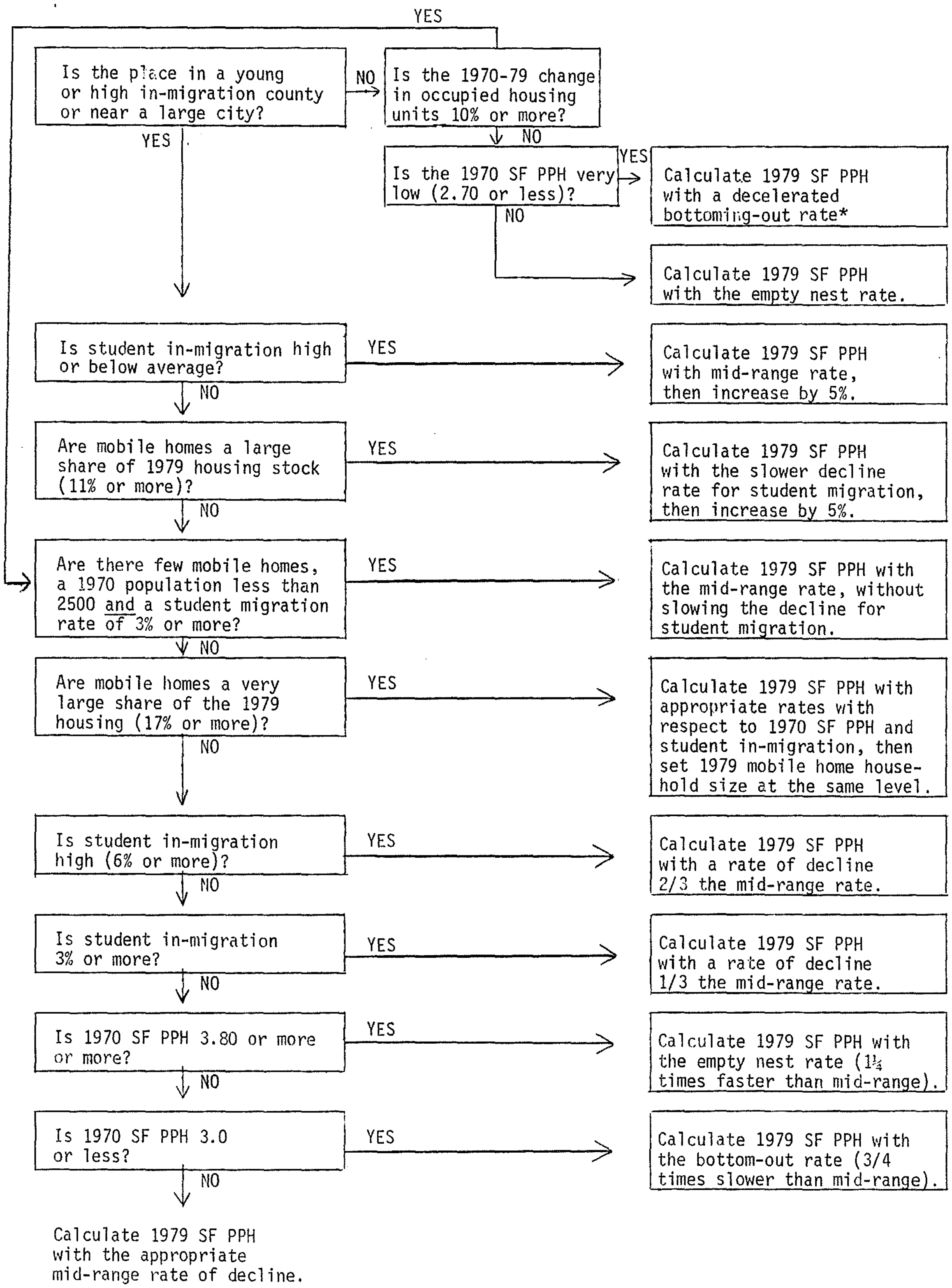
$$PPH_{i,1,1979} = PPH_{i,1,1970}(1 + 9r) \qquad (12)$$

where r = 1970-1977 average annual rate of change in single family household size (varies by size of place).

Note the equivalence of the estimating equations for constraints (b) and (e·2) and also for (f·1) and (f·2). Figure 1 shows that a place subject to more than one constraint will not receive a "double" adjustment. The constraints are ordered as shown in the flow chart, and the first constraint to which a place is subject determines the rate of decline used for single family households. Only under the (f) constraints can a place receive an adjustment for both student in-migration and county-level conditions.

Figure 1:

FLOWCHART FOR CALCULATION OF 1979 SINGLE FAMILY HOUSEHOLD SIZE



*All rates vary with 1970 city size.

If the calculation of the single family household size was subject to any constraint, the mobile home household size was recalculated as 80% of the new single family household size. But if the place contained a large proportion of mobile homes (more than 17% of all units in 1979), then the mobile home household size was set to equal the single family household size.

Without any constraints, the single family household size is calculated as:

$$PPH_{i,1,1979} = PPH_{i,1,1970}(1 + 9r) \tag{12}$$

For places under 2,500 in 1970, the basic average annual rate (r) of change in household size is -1.4% for single family units, -2.2% for multiples, and -1.6% for mobile homes. For places over 2,500, the average annual rates (r) are -1.9% for single family units, -2.2% for multiples, and -1.6% for mobile homes. The 1977 values for persons per household and occupancy rate by type of structure and size of place are given above in Table 2.

Note that the theory of nonlinearity is operationalized by two techniques. First, exponential rates of change in household size are used instead of percent change or other linear formulations. Secondly, the rates of change are discontinuous, with different rates of decline in single family household size being applied under each type of condition, as noted in constraints (a) to (g). Given our limited information about 1970-77 place specific changes in household size, it is impossible to calculate a specific nonlinear equation that fits the Minnesota situation.

D. Making the Method Work:

Before these calculations could be performed, certain assumptions were necessary to make the 1970 and 1977 data comparable. First, we assumed that redefinition of the 1977 2-6 unit and 7+ unit categories to the 2-4 and 5+ categories used in the census would not substantially alter household size or occupancy rate calculations.

Second, 1970 estimates of household size by type of structure were calculated using a ratio method for places under 2,500 while 1970 Census Fourth Count estimates were used for larger places. Separate methods were necessary because tests showed the Fourth Count estimates of household size to be unreliable for the smaller places. Third, the 1977 and 1970 categories of year-round units were made comparable by switching the 1970 "vacant-for-occasional-use" units to the seasonal category. All such changes involved deductions from the 1970 year-round count of single family dwelling units. Fourth, because the 1970 census did not count vacant mobile homes, the 1970 vacancy rate for mobile homes was assumed to equal the 1970 average vacancy rate.

Development of an accurate set of estimators is, however, only part of the calculation of population estimates. The other part consists in obtaining accurate housing unit and group quarters counts. If these counts are not accurate, parameter accuracy is of little value. Therefore, considerable attention was devoted to insuring the collection of reasonable and hopefully accurate housing counts.

Participation in the estimation program was optional, so we were not required to develop a housing count for the entire state. Those jurisdictions wanting an estimate collected the necessary housing unit and group quarters information. They chose from three different options. Depending on the jurisdiction's size, staff, and records, officials could choose to count all 1979 housing units, obtain a full count of all units from assessor's records, or provide building permit, demolition and conversion records to update the 1970 count. All places counted group quarters populations and provided some measures of vacancies, either from a field survey or utility records. The materials submitted by the jurisdictions were carefully reviewed to make sure that the counts were consistent with our records of permit activity, residential hook-up records, and the 1970 housing stock by unit type.

IV. How Well Did the Methodology Work

A true test would compare estimates with a census figure for that date. Unfortunately, we have no 1979 census data for the cities that participated in our program. However, 449 smaller places submitted acceptable "head counts" along with their housing information, and for these places we compared estimates with the actual count.*

Although the counts do not have the validity of census enumerations, they are reasonable alternative estimates with which to compare our estimates. Table 6 gives this comparison, which shows that the adopted methodology performed well in these small places, normally the ones that give demographers the most trouble. (84% of the places submitting counts had 500 or fewer persons.) The mean absolute percent difference was only 2.0 percent.

But the variance in the difference between the counts and the estimates is not insignificant. In Table 7, the differences are categorized by 1970 persons per household level. The differences are more likely to be large and negative for places with a low 1970 persons per household while they are more likely to be large and positive for places with a high 1970 persons per household. These results suggest that our rates of persons per household decline were not slow enough for the "bottoming out" places, while they were not fast enough for the "empty nesting" places.

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*Head counts were acceptable only if they met standard census criteria for enumerating group quarters, exclusion of non-resident students, and involved a door-to-door survey.

Table 6: Difference Between 1979 Estimates and Counts.

Percent Difference: (Est. - Count/Count)	Frequency	Percent
-10% or less	45	10.0
-9.9% to -5.0%	32	7.1
-4.9% to 0%	138	30.7
0.1% to 5%	110	24.5
5.1% to 10%	57	12.7
10.1% or more	67	14.9
TOTAL	449	99.9

Mean difference = 2.02
Median difference = 2.93
Standard deviation = 12.60

Table 7: Percent Difference Between 1979 Estimates and Counts by 1970 Persons Per Household

Percent Difference	1970 Persons per Household: 3.00 or less	3.01 to 3.79	3.80 or more	Total
-10% or less	26	18	1	45
-9.9% to -5%	17	9	6	32
-4.9% to 0%	65	47	26	138
0.1% to 5%	39	46	25	110
5.1% to 10%	17	25	15	57
10.1% or more	9	33	21	63
TOTAL	173	178	94	445

Closer examination of the differences between estimated and observed persons per household figures shows that the household size estimates for single family units are not too far off, but for the mobile home category the differences are large. About half of the estimated single family household sizes are within ±5% of the observed size, for the remaining estimates there is a slightly greater tendency to overestimate. For the mobile home estimates, however, only 14% are within ±5% of the observed size. One-half the mobile home estimates differ from the observed mobile home size by more than ±20%.

The dramatic differences in estimated vs. observed mobile home household size strongly suggest that our method for estimating mobile home household size is inappropriate. Of course, part of the difficulty in doing mobile home household size estimates derives from the limited number of mobile homes in each community, leaving the observed average household size subject to the influence of a few extreme values. Nonetheless, the observed size figures are distributed bimodally, either very large or very low. It's possible that mobile homes are used either as family housing or single person housing, with communities having occupants primarily of one type or the other, but confirmation of such a dichotomy will have to await the 1980 census.

The differences between the estimated and observed single family household sizes are more tractable. As noted above, about half the single family household size estimates are within ±5% of the observed figure for all levels of 1970 average single family household size. The distribution of the differences, however, does vary with respect to the 1970 single family household size. Although for all places our household size estimates had a one-in-two chance of being within 5% of the observed figure, if large discrepancies between the estimate and observed household size existed, they were over two times more likely to be positive for the places that had a high 1970 persons per household. We were also more likely to overestimate for places that had a mid-range 1970 PPH, but for places that had a low 1970 single family PPH we are equally likely to under or overestimate. These findings suggest that although the rate of decline for low PPH seems appropriate, the "empty nesting" rate of decline may not be fast enough - or apply to a broad enough spectrum of household sizes. We may need to extend the "empty nesting" category to 3.5 or 3.6 PPH in 1970.

Differences between the estimated and observed single family household size may also arise from an inability to accurately estimate household size when there is much new construction with its related population influx. The potentially complicating effects have been incorporated fully into the methodology, but not to the extent that any one variable can unduly shift the estimate away from the observed figure.

Another way to ascertain the relative accuracy of the nonlinear methodology is to contrast the estimates it produces against those resulting from a linear method. In Table 8, the differences between the nonlinear estimates and counts are contrasted with those resulting from a strictly linear methodology in which student in-migration is the only symptom altering the rate of household size decline. (There are no accelerated or decelerated rates for empty nesting or bottoming out, from whatever cause.) The nonlinear method, which assumes "empty nesting" and "bottoming out," as well as slower declines where families move in (or don't move out), produces estimates which are significantly more likely to be within 5% of the count. Whereas only 37% of the linear estimates fall within 5% of the count, 55% of the nonlinear estimates are that close.

Table 8: Percent Differences Between 1979 Estimates and Counts by Type of Methodology

Per Cent Difference: (Est. - Count/Count)	Nonlinear Method: Frequency of Difference	Nonlinear Method: Per Cent Distribution	Linear Method: Frequency of Difference	Linear Method: Per Cent Distribution
-10% or less	45	10.0	78	17.4
-9.9% to -5.0%	32	7.1	64	14.3
-4.9% to 0	138	30.8	76	16.9
0.1% to 5%	110	24.5	89	19.8
5.1% to 10%	57	12.7	46	10.2
10.1% or more	67	14.9	96	21.4
TOTAL	449	100.0	449	100.0

Chi-Square = 46.03
$p < .001$

While this is only a limited test of the efficacy of a nonlinear approach to estimating household size, the results reinforce the validity of the concept. If anything, our nonlinear assumptions are not strong enough, at least for the places under 500 which largely comprised the test group used here. A complete test of the method must await the 1980 census, as only then will we have a large enough sample of large <u>and</u> small cities for a test.

V. IMPLICATIONS FOR THE APPLICATION OF THE HOUSING UNIT METHOD

We believe that our experience contributes to the ongoing efforts to refine the housing unit method. In particular, we have demonstrated how statistical analysis of survey data can be used to determine appropriate unit-type categories for estimation of household population. Stratification by size of place also was introduced because the survey data showed significant differences in the levels and rates of change for occupancy and household size data for places with more and less than 2,500 persons.

Using household size data from California and Washington, we have shown that the recent declines in household size have been nonlinear. Size, cost, or other constraints operate to set minimum averages for household sizes in each category. Awareness of this prevented blind continuation of estimated declines below accepted minimum levels. The nonlinearity hypothesis was explicitly confirmed for the single family category, where the rate of decline is faster than average for places with relatively high average household sizes; it then slows, and decelerates again as the average size approaches the lower limit for single-family household sizes. This more precise knowledge of the functional form for recent changes in household size increased our confidence in our estimates and may prove of similar value to others working with the housing unit method.

Knowing more about the basic form of household size changes helps to predict short-term changes, but for dates far removed from the census or survey it may be necessary to re-survey in order to precisely define the changes in household size and housing unit mix. For state aid calculations, California requires a benchmark census every five years. With the 1980 census just around the corner, interested jurisdictions will soon have ample material from which to develop a detailed housing unit method, but unless the 1985 census provides tabulations of type-specific household data, agencies using the housing unit method may have to sponsor a mid-decade survey or census.

Despite its drawbacks, the housing unit method has clear-cut advantages over other methods. First and foremost is the information about the number of housing units and their distribution by type of unit. This information is invaluable to planners, developers, and officials providing municipal services. Second, because the housing unit method as developed here requires participation of local officials, they are more likely to understand how the numbers were prepared. If the number is lower than expected, this involvement and understanding may cut down the level of disbelief in an "alien" number. The extra understanding of the dynamics of population and household changes is most welcome.

Often the housing unit method is the only feasible method for calculating estimates of city or township populations. Perhaps for this reason, the housing unit method is used by over three-fourths of the state and local agencies preparing local estimates (Irwin, U.S. Bureau of the Census, 1978).

If nationwide survey designs were altered, the high survey or census cost of the housing unit method might be reduced. Currently, the U.S. Census Bureau makes available two sets of household size estimates: Average household size for the nation from the Current Population Survey (CPS) and owner and renter household sizes for the nation, major census regions, and some 60 SMSA's from the Annual Housing Survey. Although the Annual Housing Survey reports vacancy by type of structure, no data are made available for household size by type of structure.*

Since more reliable estimates may result from a type-specific methodology, tabulations from the Annual Housing Survey that include household size by type of structure, without regard to tenure, would be of great use.

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*Post-censal CPS reports are now planned to include household size by type of structure.

This information would be more applicable to the housing unit method than the current household size categories of owner and renter or persons per room. In addition, since household size by type of structure may vary substantially from place to place, the national and regional tabulations of household size and vacancy status would be more useful if disaggregated into the following categories:

Metropolitan

- Central city
- Balance

Non-Metropolitan

- County adjacent to metropolitan area
- County nonadjacent to metropolitan area
    - With a city of at least 25,000 persons
    - With no city as large as 25,000 persons

Alternatively, both metropolitan and non-metropolitan tabulations could be reported by city size if the sample were large enough to give reliable results for each cell. It also might be worth the additional cost to increase the sample to allow separate tabulations to be made available by division, instead of by region. Finally, the Census Bureau should encourage jurisdictions contracting for special censuses to enumerate population by dwelling unit type as is done in the California and Washington state censuses.

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